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A SPECTRAL LINE SURVEY FROM 159.7 TO 164.7 GHZ TOWARD ORION-KL: THE DATA

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ABSTRACT

A spectral line survey is performed from 159.7 to 164.7 GHz toward Orion-KL, as an extension of our previous line survey from 138.3 to 150.7 GHz with the same 14 m radio telescope of Taeduk Radio Astronomy Observatory. Typical system temperatures were 260 − 1000 K to achieve a sensitivity of about 0.02 − 0.04 K in T_A^* unit. A total of 63 line spectra are detected in this survey. Among them, 54 lines lines are found to be the first detections towards an astronomical source and only 9 spectral lines have been previously identified from other observations. Forty-eight of 54 lines are believed to be from the known transitions of the known molecules, while 6 lines are 'unidentified'. All detected lines are found to be from a total of 10 molecular species and their isotopic variants. The molecular species with most numerous detected transitions are $HCOOCH_3$ (22), followed by CH_3OCH_3 (7), C_2H_5CN (7), and SO_2 (6). The LTE rotation diagram analysis using all homogeneous data with those from previous survey gives more reliable determination of physical quantities. The derived values of the rotation temperatures and column densities for $HCOOCH_3$, CH_3OCH_3, and SO_2 are are 75 ~ 197 K and 1.5 ~ 18 × 10^{15} cm^{-2}, respectively.

Key words : ISM:individual (Orion-KL)-ISM:molecules-line:identification- radio line:molecular:interstellar

I. INTRODUCTION

A spectral line survey is to observe a chemically rich object along wide frequency domain to make a systematic search of transitional lines of interstellar atoms and molecules. So this study should be a useful tool for better understanding of physical conditions of the observing target as well as findings of new transitions of molecules or 'unidentified' lines not listed in any catalog of transitions (e.g., Lee, Cho, & Lee 2001, hereafter LCL01).

Orion-KL, as a typical massive star forming region, is one of the best targets for the line survey because of not only its strongest intensity in most transitions of molecules, but also its chemical richness. Previous spectral line surveys in radio regime toward the Orion-KL cover nearly all regions, 70 − 360 GHz and 607 − 900 GHz (see LCL01 for summary). These surveys include our recent study by LCL01 which mainly surveyed the '*unexplored*' 2mm spectral band from 138.3 to 150.7 GHz. LCL01 have found as many as 149 line spectra detected from such a survey. Their finding is very surprising because majority of the detected lines, i.e., 99 lines of 149 detected lines, are actually new lines first detected in interstellar space. A significant fraction of the new lines (33) were found to be 'unidentified' due to non-existence of their identifications in any present line catalog while the rest of them are from known transitions of some species. So the spectral line survey toward Orion-KL should be very important not only to study physical or chemical processes in a massive star-forming region, but also to find new molecular lines from celestial objects.

This paper presents new results of the line survey from 159.7 to 164.7 GHz toward Orion-KL which remained still '*unexplored*', as an extension of our previous line survey from 138.3 to 150.7 GHz with the same 14 m radio telescope of Taeduk Radio Astronomy Observatory.

II. OBSERVATIONS

The survey was made using the TRAO 14 m telescope during 2000 February 22 − 25 with a 100/150 GHz dual channel SIS receiver which was developed by Park et al. (1999a, b). The HPBW and beam efficiency of the telescope at 146 GHz are about 46″ and 39%, respectively (Park et al. 1997). A single sideband filter was employed with a performance of rejection ratio of the image side band of over 20 dB. Each observation was designed to cover about 500 MHz band width using two filter banks of 256 channel of 1 MHz resolution in a serial mode. Observations were conducted with 9 different frequency settings to cover the frequency range between 159.7 and 164.7 GHz. Pointing of the telescope and focus of the secondary mirror were checked every two hours using Orion-KL itself with the SiO J= 2 − 1, v = 1 maser line. The pointing accuracy is better than 10″. Typical system temperature at ob-

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serving bands was between 260 − 1000 K to achieve a sensitivity of about 0.02 − 0.04 K in T_A^* unit. Position switching mode was used with 30′ azimuth offset for reference position. Spectral line intensities were calibrated, corrected for atmospheric losses using chopper wheel method, and expressed in T_A^* scale. The observational position of Orion-KL is the same as used in LCL01; $(\alpha, \delta)_{1950.0} = (5^h\ 32^m\ 46^s.9,\ -5^\circ\ 24'\ 23'')$.

III. RESULTS AND DISCUSSION

A total of 63 spectral lines are detected. All observed spectra are shown in Fig. 1. Detection statistics of the molecular emission lines, and LTE rotation diagram analysis of some molecular species together with the data from LCL01 are described in this section.

(a) Identification of detected lines

In line identification we considered only the spectral lines brighter than $\sim 3\sigma$. The methods for the line identification is basically the same as the ones used in LCL01. So we refer readers to LCL01 for more details of the methods. The same $V_{LSR} = 8.4$ km s^{-1} was assumed to obtain the rest frequency scale of the spectral lines, resulting in about 1 MHz uncertainty in the determined frequency due to a possibility of its multiple origins from Orion-KL.

Catalogs used for line identification are the Lovas catalog (Lovas 1992), the JPL catalog (Pickett et al. 1998), Xu & Lovas (1997), Tsunekawa et al. (2000, in private communication), and Kawaguchi (2000, in private communication). Possible detection of recombination lines of H and He was also checked, but found not to be plausible in our survey frequency region.

In total 63 molecular line spectra were examined for the line identification. The detailed identifications of the spectra are given in Table 1. The frequency in the first column is the value derived from assumption of $V_{LSR} = 8.4$ km s^{-1}. Molecular species, their transitions, intensity in T_A^*, reference for catalog, and special comments for the spectra are given in the 2nd, 3rd, 4th, 5th and 6th column of the Table 1.

According to the same logics used in LCL01, only 9 spectral lines are found to have been previously identified from other observation of celestial objects, while most (54) of spectral lines are actually the first detections towards an astronomical source. Forty-eight of 54 lines are transitions which can be predicted from theoretical calculations or detected from laboratory measurements. However, other six lines remain "unidentified". All spectra with their identifications are displayed in Fig. 2.

The strongest emissions in the observed frequency range are from transitions of SO_2. The identified 57 lines are found to be emissions from a total of 10 molecular species and their isotopic variants. Most of the detected lines are from large organic molecules such as $HCOOCH_3$ (22), CH_3OCH_3 (7), C_2H_5CN (7), SO_2 (6), CH_3OH (3), and C_2H_5OH (3) (the numeric in parenthesis is the number of the detected transitions of the molecule). About 80 % of the identified lines have the origin of these organic molecules.

(b) The LTE Rotation Diagram Analysis and Individual Molecules

We perform the LTE rotation diagram analysis for $HCOOCH_3$, CH_3OCH_3, C_2H_5CN, and SO_2 which have a significant number of transitional lines detected. So this analysis together with data from LCL01 would give better determination of physical quantities of rotation temperatures (T_{rot}) and column densities (N) of the molecules.

We use the same equation for the LTE rotation diagram analysis as given in LCL01;

$$\log L = \log \frac{3k \int T_A^* dv}{8\eta_B \pi^3 \nu S \mu_i^2 g_I g_k} = \log \frac{N}{Q_{rot}} - \frac{E_u \ \log e}{k \ T_{rot}}, \qquad (1)$$

where k is the Boltzmann constant, $\int T_A^* dv$ the integrated intensity, η_B the beam efficiency of the telescope, ν the rest frequency of the spectrum, S the line strength, μ_i the relevant dipole moment, g_I the reduced nuclear spin weight, g_k the K-level degeneracy, E_u the upper state energy of the transition, Q_{rot} the rotational partition function, and N the column density.

The values for g_I, g_k, E_u/k, $S\mu_i^2$, $\int T_A^* dv$, and $logL$ for each molecule and their references are given in Table 2 − 5. The partition functions Q_{rot} that we use are $\frac{1}{2}[\frac{\pi(kT_{rot})^3}{h^3ABC}]^{1/2}$ for SO_2, $[\frac{\pi(kT_{rot})^3}{h^3ABC}]^{1/2}$ for CH_3OCH_3 and C_2H_5CN, and $2[\frac{\pi(kT_{rot})^3}{h^3ABC}]^{1/2}$ for $HCOOCH_3$ (Blake et al. 1986; Turner 1991), where the rotational constants (A, B, & C) are from Pickett et al. (1998).

This analysis would give a linear correlation in the E_u/k versus $\log L$ of the data if the conditions of LTE and low optical depth of the lines are valid. Thus the rotational temperature and the column density would be determined from the slope $[-(\log e)/T_{rot}]$ and intercept $[\log(N/Q_{rot})$ at $E_u = 0]$ through a linear least squares fit of the data. Large deviation of the data point from the correlation may mean that any of assumptions is not valid or line identification is not correct. Fig. 3 shows examples of the LTE rotational diagram analysis for transitions of four molecules. A line profile at 164619.5 MHz was considered to be a transition of $HCOOCH_3$ at that frequency. However, it turned out that this identification resulted in large deviation of the data point from the correlation. So we leave this profile unidentified rather than being identified as one of $HCOOCH_3$ transitions. Diagram for CH_3OCH_3 shows also one data which has large deviation from correlation. The identification corresponding to the data was assigned as 5(5,1)-6(4,2) AE transition of CH_3OCH_3 in LCL01. However, we believe this identification is unlikely. We discarded this data in the least squares fit in the rotational diagram analysis. In this

Table 1. Identifications of Spectral Lines Detected Toward Orion-KL

Frequency	Species^a	Transition	T_A^{*b}	Reference^c	Comments^d
159766.8	$HCOOCH_3$	13(9,4)-12(9,3) E	0.18	JPL	NDT
159777.1	$HCOOCH_3$	13(9,4)-12(9,3) A & 13(9,5)-12(9,4) A	0.26	JPL	NDT
159782.8	$HCOOCH_3$	13(9,5)-12(9,4) E	0.14	JPL	NDT
159833.5	U		0.08		
159888.9	C_2H_5CN	18(2,17)-17(2,16)	0.22	Lovas	
159930.7	$HCOOCH_3$	13(8,5)-12(8,4) E	0.20	JPL	NDT
159942.9	$HCOOCH_3$	13(8,6)-12(8,5) A & 13(8,5)-12(8,4) A	0.35	JPL	NDT
159946.0	$HCOOCH_3$	13(8,6)-12(8,5) E	0.19	JPL	NDT
159963.0	U		0.07		
160071.1	CH_3OH	unassigned	0.08		
160142.1	H_2CCO	8(1,8)-7(1,7)	0.35	JPL	NDT
160179.0	$HCOOCH_3$	13(7,6)-12(7,5) E	0.24	JPL	NDT
160193.5	$HCOOCH_3$	13(7,7)-12(7,6) E	0.55	JPL	NDT
160201.5	CH_3OCH_3	4(2,3)-3(1,2) 2 & 3	0.20	JPL	NDT
160204.1	CH_3OCH_3	4(2,3)-3(1,2) 1	0.27	JPL	NDT
160206.6	CH_3OCH_3	4(2,3)-3(1,2) 0	0.21	JPL	NDT
160211.5	C_2H_5OH	18(5,14)-19(1,18)	0.16	JPL	NDT
160219.0	CH_3OH	unassigned	0.21		
160283.6	U		0.09		
160343.0	SO_2	18(2,16)-18(1,17)	1.62	JPL	NDT
160518.3	CH_3OCH_3	15(2,14)-15(1,15) 2 & 3	0.08	JPL	NDT
160521.5	CH_3OCH_3	15(2,14)-15(1,15) 1	0.18	JPL	NDT
160543.0	SO_2	4(3,1)-5(2,4)	0.45	JPL	NDT
160578.4	$HCOOCH_3$	13(6,7)-12(6,6) E	0.26	JPL	NDT
160585.8	$HCOOCH_3$	13(6,8)-12(6,7) A	0.31	JPL	NDT
160591.1	$HCOOCH_3$	13(6,8)-12(6,7) E	0.27	JPL	NDT
160602.2	C_2H_5CN	5(3,3)-4(2,2)	0.36	JPL	NDT
160827.8	SO_2	10(0,10)-9(1,9)	2.46	Lovas	
161153.8	SO_2	15(5,11)-16(4,12)	0.39	JPL	NDT
161171.5	$HCOOCH_3$	13(5,9)-12(5,8) E & A	0.26	JPL	NDT
162020.1	$^{34}SO_2$	10(0,10)-9(1,9)	0.20	JPL	NDT
162136.9	C_2H_5CN	9(4,6)-9(3,7)	0.11	JPL	NDT
162328.0	CH_2CHCN	17(7,11)-16(7,10) & 17(7,10)-16(7,9)	0.12	Kawaguchi	NDT
162354.5	U		0.11		
162410.6	CH_3OCH_3	22(4,18)-22(3,19) 1	0.16	JPL	NDT
162475.0	C_2H_5CN	18(3,15)-17(3,14)	0.38	JPL	NDT
162529.9	CH_3OCH_3	8(1,8)-7(0,7) EE & AA	0.83	Lovas	
162768.8	$HCOOCH_3$	14(2,13)-13(2,12) E	0.63	JPL	NDT
162775.2	$HCOOCH_3$	14(2,13)-13(2,12) A	0.78	JPL	NDT
163016.8	C_2H_5CN	18(1,17)-17(1,16)	0.33	JPL	NDT
163119.4	SO_2	18(2,16)-17(3,15)	1.37	Lovas	
163161.5	CH_2CO	8(1,7)-7(1,6)	0.32	Lovas	
163605.5	SO_2	14(1,13)-14(0,14)	2.48	JPL	NDT
163753.4	HCCCN	18-17	2.09	JPL	NDT
163830.0	$HCOOCH_3$	14(1,13)-13(1,12) E	0.45	Lovas	
163835.9	$HCOOCH_3$	14(1,13)-13(1,12) A	0.41	Lovas	
163873.5	$^{13}CH_3OH$	7(0)-6(1) E	0.24	Lovas	

Table 1. *Continue*

Frequency	Species[a]	Transition	T_A^{*b}	Reference[c]	Comments[d]
163927.3	$HCOOCH_3$	15(0,15)-14(1,14) A	0.23	Lovas	
163948.7	C_2H_5CN	19(1,19)-18(1,18)	0.33	JPL	NDT
163961.8	$HCOOCH_3$	15(1,15)-14(1,14) A & E	0.55	JPL	NDT
163988.5	$HCOOCH_3$	15(0,15)-14(0,14) A & E	0.55	JPL	NDT
164023.3	$HCOOCH_3$	15(1,15)-14(0,14) A & E	0.22	JPL	NDT
164034.7	U		0.10		
164155.8	HCCCN	v7 - 18-17	0.23	Kawaguchi	NDT
164205.9	$HCOOCH_3$	13(4,9)-12(4,8) E	0.28	JPL	NDT
164223.8	$HCOOCH_3$	13(4,9)-12(4,8) A	0.38	JPL	NDT
164287.2	CH_2CHCN	17(1,16)-16(1,15)	0.14	JPL	NDT
164299.0	CH_3OH	15(2,14)-14(1,13)	0.17	XL	NDT
164393.6	C_2H_5OH	9(7,3)-10(6,4) & 9(7,2)-10(6,5)	0.29	JPL	NDT
164586.3	CH_2CHCN	19(0,19)-18(0,18)	0.30	JPL	NDT
164619.5	U		0.17		
164626.1	C_2H_5OH	5(4,1)-4(3,1)	0.17	JPL	NDT
164668.0	C_2H_5CN	18(2,16)-17(2,15)	0.25	JPL	NDT

[a] U line at 164619.5 MHz has frequency coincidence with a transition 10(3,3)-9(3,4) A of $HCOOCH_3$. But the rotational analysis finds the identification of the transition of $HCOOCH_3$ is unlikely.

[b] peak antenna temperatures

[c] JPL- Pickett et al. 1998; Lovas - Lovas 1992; Kawaguchi - Kawaguchi 1999; XL - Xu & Lovas 1997; S. Tsunekawa et al. 2000, private communication.

[d] NDT - Newly Detected Transition from the known molecule

Table 2. Transitions of CH_3OCH_3

Frequency (MHz)	Transition $J(K_{-1},K_{+1})$	V_{LSR} km s^{-1})	ΔV_{FWHM} (km s^{-1})	g_I	g_k	E_u/k^a (K)	$S\mu^{2(a)}$ (Debye^2)	$\int T_A^* dv \pm \sigma$ (K km s^{-1})	$\log L$
160201.5	4(2,3)-3(1,2) EA	7.2	6.4	1	0.40	14.7		1.2 ± 0.2	
160204.1	4(2,3)-3(1,2) EE	7.7	3.5	1	1.60	14.7	1.40	1.0 ± 0.2	12.08
160206.6	4(2,3)-3(1,2) AA	8.2	5.4	1	1.00	14.7	0.87	1.2 ± 0.1	12.58
160518.3	15(2,14)-15(1,15)AE/EA	7.6	4.5	1		114.2	0.88	0.4 ± 0.1	
160521.5	22(2,21)-21(3,18) EE	7.9	2.7	1	1.60	114.2	3.53	0.6 ± 0.1	11.48
162410.6	22(2,21)-21(3,18) EE	7.2	3.4	1	1.60	254.2	11.11	0.6 ± 0.1	10.92
162529.9	22(2,21)-21(3,18) AA	8.4	4.1	1	1.60	33.1	3.98	4.0 ± 0.1	12.42

[a] From Groner et al. 1998

Table 3. Transitions of $HCOOCH_3$

Frequency (MHz)	Transition $J(K_{-1},K_{+1})$	V_{LSR} (km s^{-1})	ΔV_{FWHM} (km s^{-1})	g_I	g_k	E_u/k^aa (K)	$S\mu^{2a}$ (Debye^2)	$\int T_A^* dv \pm \sigma$ K km s^{-1}	$\log L$
159766.8	13(9,4)-12(9,3) E	7.6	3.5	1	2	109.5	18.2	0.6 ± 0.1	10.70
159777.1	13(9,4)-12(9,3) A &13(9,5)-12(9,4) A	8.0	3.8	2	1	107.5	18.2	0.9 ± 0.0	10.81
159782.8	13(9,5)-12(9,4) E	8.0	1.9	1	2	107.5	18.2	0.3 ± 0.1	10.38
159930.7	13(8,5)-12(8,4) E	8.1	3.5	1	2	96.2	21.7	0.8 ± 0.1	10.68
159942.9	13(8,6)-12(8,5) A &13(8,5)-12(8,4) A	7.5	3.7	2	1	96.2	21.7	1.4 ± 0.1	10.94
159946.0	13(8,6)-12(8,5) E	9.7	4.8	1	2	96.2	21.7	1.0 ± 0.1	10.77
160179.0	13(7,6)-12(7,5) E	7.9	3.5	1	2	86.3	24.7	0.9 ± 0.1	10.67
160193.5	13(7,7)-12(7,6) E	8.3	4.1	1	2	86.3	24.7	2.0 ± 0.2	11.04
160578.4	13(6,7)-12(6,6) E	7.9	4.0	1	2	77.7	27.4	1.0 ± 0.1	10.70
160585.8	13(6,8)-12(6,7) E	8.6	3.4	2	1	77.7	27.4	1.1 ± 0.1	10.73
160591.1	13(6,8)-12(6,7) E	7.8	3.3	1	2	77.7	27.4	1.1 ± 0.1	10.71
161171.5	13(5,9)-12(5,8) E & A	7.6	3.8	1	2	70.5	28.6	1.3 ± 0.2	10.76
162768.8	14(2,13)-13(2,12) E	8.1	4.7	1	2	62.7	36.1	3.3 ± 0.2	11.08
162775.2	14(2,13)-13(2,12) A	7.3	5.5	2	1	62.7	36.1	6.8 ± 0.4	11.40
163830.0	14(1,13)-13(1,12) E	8.7	4.2	1	2	62.6	36.2	2.1 ± 0.2	10.84
163835.9	14(1,13)-13(1,12) A	8.7	3.8	2	1	62.6	36.1	1.6 ± 0.2	10.77
163927.3	15(0,15)-14(1,14) A	8.6	3.4	2	1	64.6	6.4	1.2 ± 0.1	11.34
163961.8	15(1,15)-14(1,14) A & E	8.5	3.7	1	2	64.6	39.3	3.6 ± 0.2	11.07
163988.5	15(0,15)-14(0,14) A & E	8.4	6.0	1	2	64.6	39.3	3.8 ± 0.2	11.10
164205.9	13(4,9)-12(4,8) E	9.0	5.9	1	2	64.9	31.5	1.1 ± 0.2	10.67
164223.8	13(4,9)-12(4,8) A	7.8	3.9	2	1	64.9	31.5	1.7 ± 0.2	10.83

[a] From Kawaguchi (2000) in private communication

Table 4. Transitions of C_2H_5CN

Frequency (MHz)	Transition $J(K_{-1},K_{+1})$	V_{LSR} (km s^{-1})	ΔV_{FWHM} (km s^{-1})	g_I	g_k	E_u/k^a (K)	$S\mu^{2(a)}$ (Debye^2)	$\int T_A^* dv \pm \sigma$ (K km s^{-1})	$\log L$
159888.9	18(2,17)-17(2,16)	4.5	14.6	1	1	77.7	263.0	3.3 ± 0.2	10.52
160602.2	5(3,3)-4(2,2)	8.1	3.4	1	1	16.5	4.2	1.3 ± 0.1	11.92
162136.9	9(4,6)-9(3,7)	7.8	7.5	1	1	37.2	6.4	0.8 ± 0.1	11.52
162475.0	18(3,15)-17(3,14)	4.0	12.5	1	1	83.8	259.0	4.4 ± 0.2	10.65
163016.8	18(1,17)-17(1,16)	4.8	15.3	1	1	76.0	265.0	5.2 ± 0.3	10.71
163948.7	19(1,19)-18(1,18)	4.2	12.7	1	1	80.2	280.2	4.3 ± 0.2	10.60
164668.0	18(2,16)-17(2,15)	4.1	14.2	1	1	79.0	263.3	3.7 ± 0.3	10.57

[a] From JPL catalog

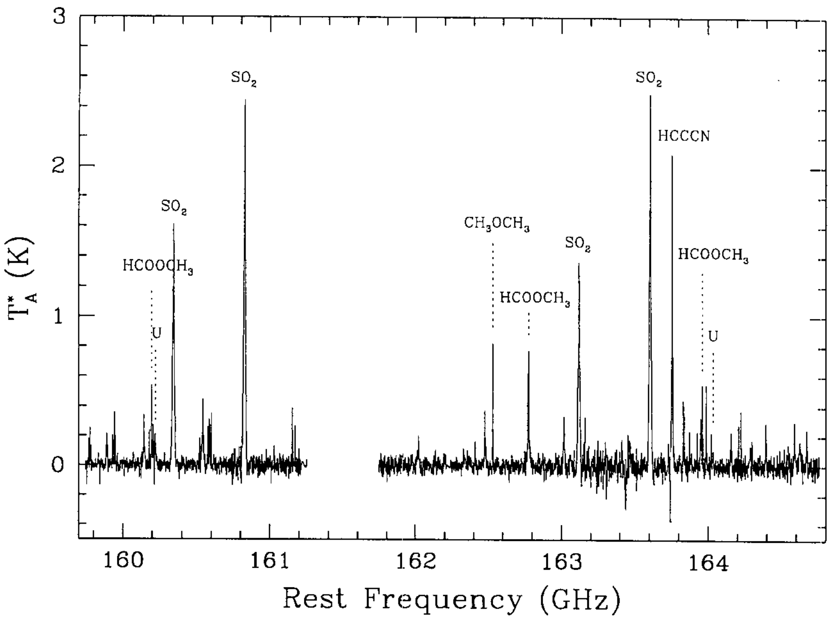

Fig. 1.— All spectra obtained from 159.7 to 164.7 GHz toward Orion-KL. Strong lines are designated their identifications. 'U' is to mark 'Unidentified' line. Note that there is no data in about 500 MHz band in 161.5 GHz because of no observation there.

way the LTE rotational diagram analysis itself can be a useful tool for checking secure identification of spectral lines.

The case of C_2H_5CN with 7 additional transitions from this study does not show any linear correlation between the data of E_u/k and $\log L$, indicating no validity of this analysis. The other cases for molecules, however, show a fairly good correlation among all of the data, allowing us to better estimate the physical quantities of the molecules.

We present the results of the rotational diagram analysis to compare with those from previous studies.

CH_3OCH_3– Together with the data from LCL01, Dimethyl ether has now detections of 26 transitions by adding data of 7 more transitions from this study (Table 2). In the rotational analysis we used 23 transitional data by excluding three data (one from LCL01 and two from this study) of which spin weight and line strength are not known. The previous data only from LCL01 seemed not suitable for the rotational analysis because of no linear correlation between E_u/k and $\log L$ (see Fig. 3 of LCL01). However, all data including the new ones from this study give a likely linear correlation with rather large scatter in the distribution of the data. We discarded one previous data at the frequency of 149878.8 GHz in the least squares fit. This rotation analysis by using all the data up to 165 GHz now can give some estimation of $T_{ex} = 197.4^{+164.5}_{-61.7}$ K and $N = 1.1^{+2.5}_{-0.6} \times 10^{16}$ cm^{-2}, although the error is somewhat high. It should be necessary to collect more data for better estimation.

$HCOOCH_3$– Methyl formate consists of the largest number (22) of the detected transitions (Table 3) which is larger than the one (16) detected in the wider frequency range between 138.3 and 150.7 GHz in the previous study. We perform the rotational analysis with a total number of 38 transitions to derive the physical quantities. What is different from results in the previous study is that there does not seem to be a clear two components in the distribution of data which are seen with less data. Rather, the diagram shows more likely one component with some scatter (Fig. 3). This least squares fit yields $T_{ex} = 75.2^{+46.0}_{-20.7}$ K and $N = 1.5^{+2.9}_{-0.9} \times 10^{15}$ cm^{-2}. This gives higher T_{ex}, but similar column density to those ($T_{ex} = 21.8^{+7.2}_{-4.4}$ K and $N = 2.3^{+4.9}_{-1.5} \times 10^{15}$ cm^{-2}) of the warmer component of LCL01.

C_2H_5CN– Ethyl cyanide has seven detected transitions in this study. Our new diagram consists of 19 data. However, the distribution of the data is still not a simple linear one. So, the rotational diagram method seems not applicable to derive T_{ex} and N of this molecule.

SO_2– Sulfur dioxide is detected in six transitions. The analysis using a total of 17 points yields $T_{ex} = 136.0^{+29.6}_{-52.3}$ K and $N = 1.8^{+2.3}_{-0.9} \times 10^{16}$ cm^{-2}. These results are fairly comparable to the values from previous study with less data ($T_{ex} = 120^{+21}_{-20}$ K and

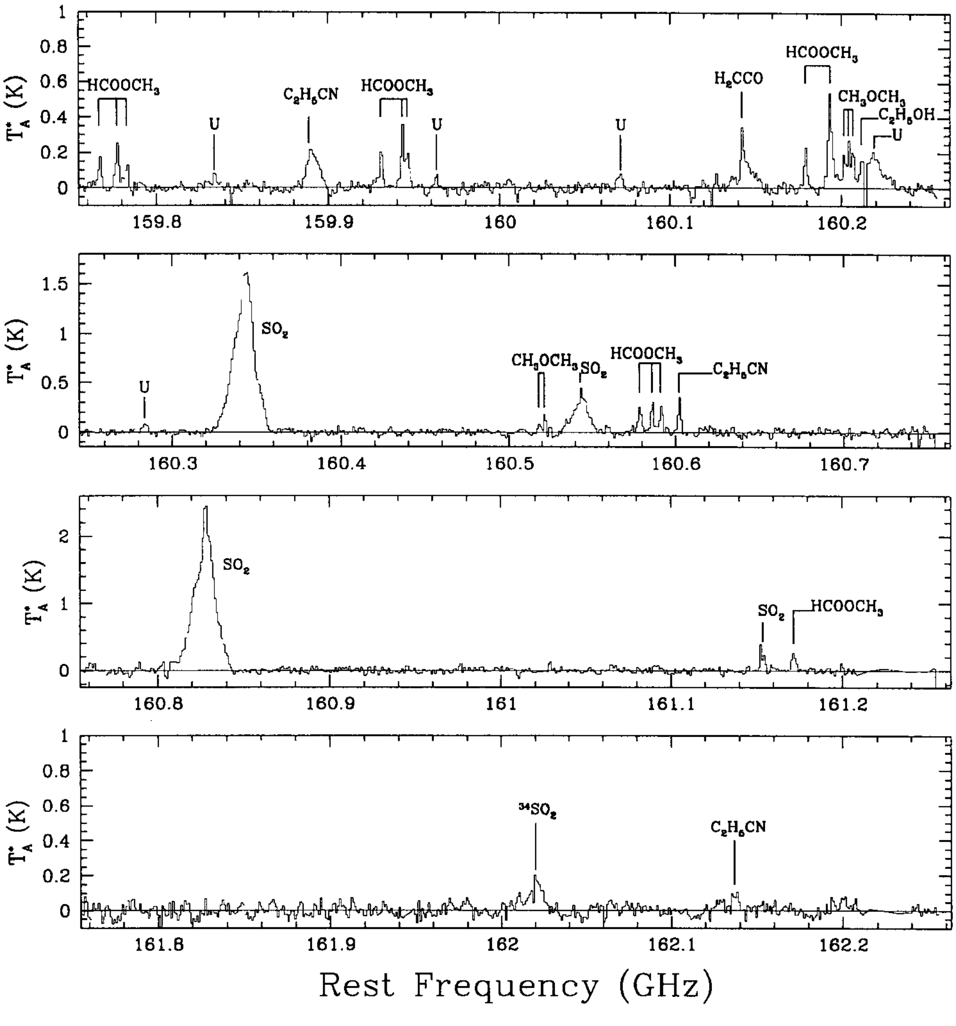

Fig. 2.— Line identifications of the spectra detected from 159.7 to 164.7 GHz toward Orion-KL. The spectral resolution is 1 MHz. The rest frequency scale for all spectra is determined by assuming V_{LSR} = 8.4 km s^{-1}.

Table 5. Transitions of SO_2

Frequency (MHz)	Transition $J(K_{-1},K_{+1})$	V_{LSR} (km s^{-1})	ΔV_{FWHM} (km s^{-1})	g_I	g_k	E_u/k^a (K)	$S\mu^{2(a)}$ (Debye^2)	$\int T_A^* dv \pm \sigma$ (K km s^{-1})	$\log L$
160343.0	18(2,16)-18(1,17)	8.8	25.8	1	1	31.3	36.2	41.0 ± 0.3	12.48
160543.0	4(3,1)-5(2,4)	7.6	19.3	1	1	49.7	0.8	7.2 ± 0.3	13.37
160827.8	10(0,10)-9(1,9)	8.9	25.6	1	1	173.2	17.1	55.8 ± 0.5	12.94
161153.8	15(5,11)-16(4,12)	9.6	5.6	1	1	171.8	5.4	1.7 ± 0.2	11.92
163119.4	18(2,16)-17(3,15)	8.1	23.6	1	1	170.9	9.9	29.7 ± 0.5	12.90
163605.5	14(1,13)-14(0,14)	8.6	24.4	1	1	101.8	17.1	54.7 ± 0.4	12.92

[a] From Helminger & De Lucia (1985) and Kawguchi (2000) in private comunication

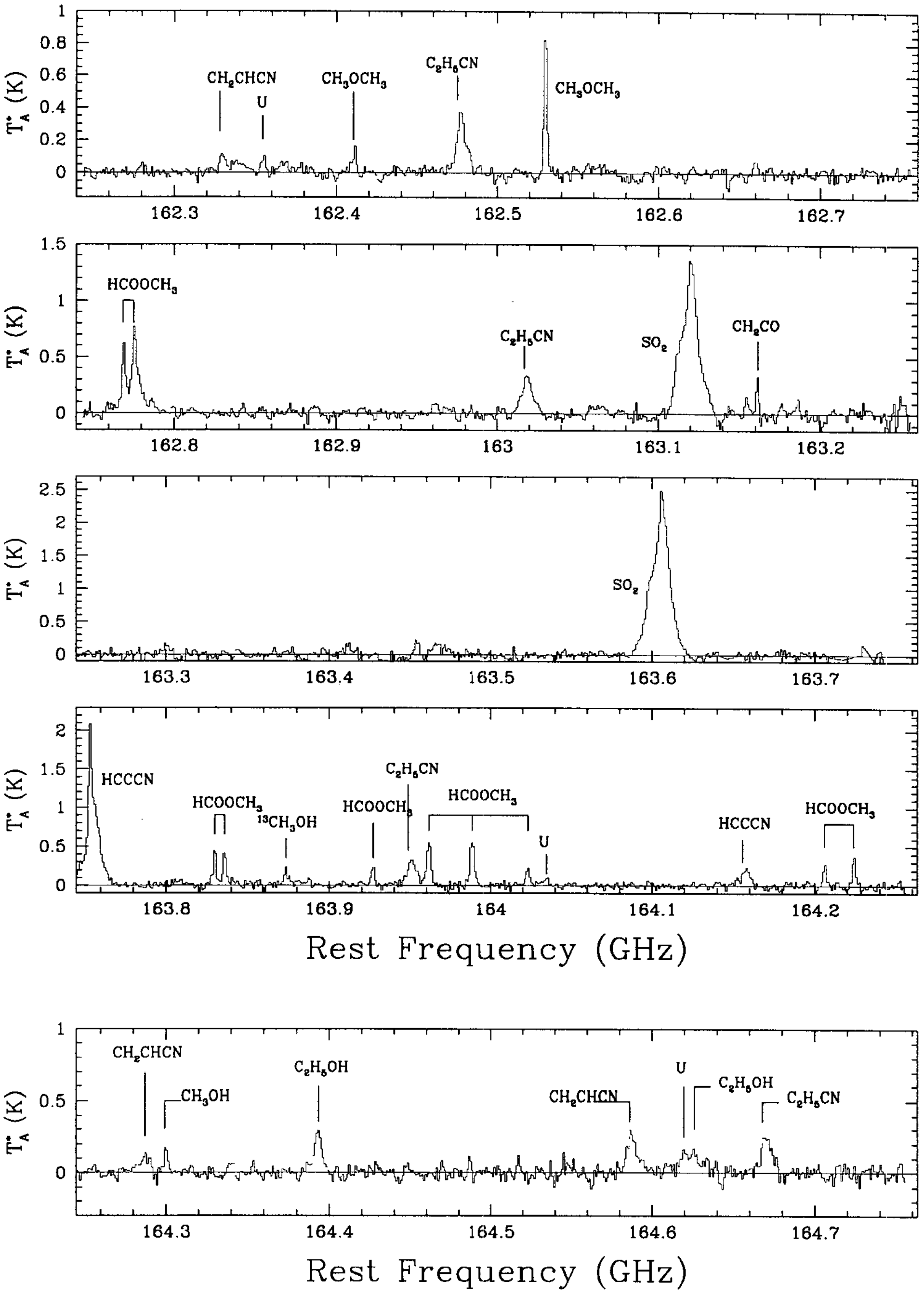

Fig. 2. - *continue*

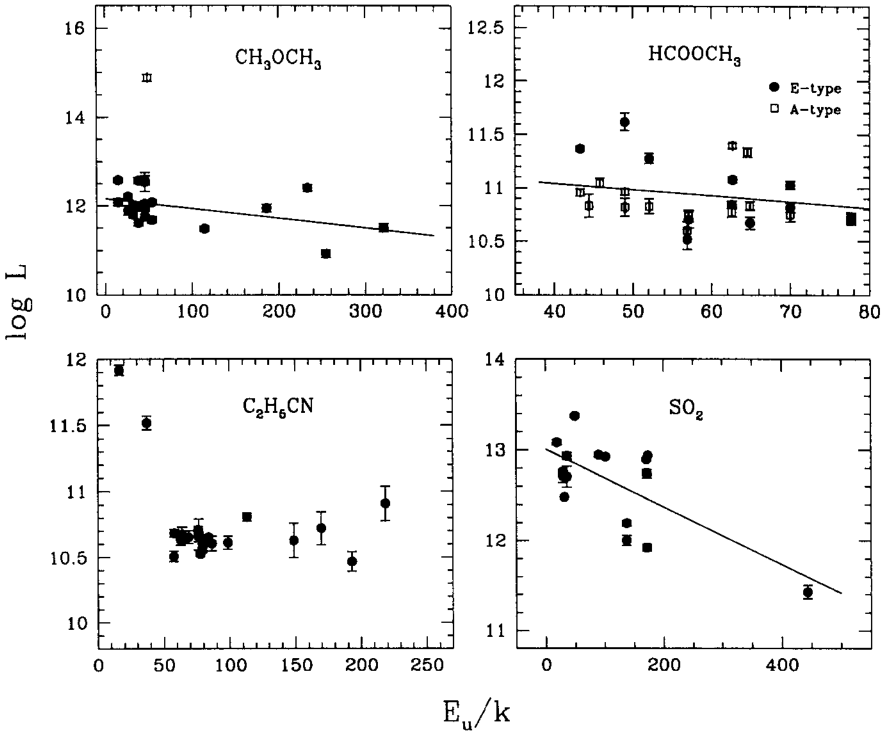

Fig. 3.— Rotation Diagrams for four molecules together with data from LCL01. The error bar is 1 σ. The data marked with open square in the diagram for CH$_3$OCH$_3$ is excluded in the linear least squares fit of the data. The diagram for C$_2$H$_5$CN shows still little correlation between E$_u$/k and $\log L$ of the data, and so the rotational diagram analysis is not applied for this molecule.

N = $1.7^{+1.5}_{-0.1} \times 10^{16}$ cm^{-2}) as well as the values from other studies in other frequency regimes – ~ 138.5 K and N $\approx 1.5 \times 10^{16}$ cm^{-2} in the 3 mm observations by Turner (1991), and ~ 140 K and N $\approx 2.0 \times 10^{16}$ cm^{-2} in 2 mm observations by Ziurys & McGonagle (1993).

Unidentified (U) Lines– A total of 6 U lines are found toward Orion-KL. The U lines are marked with 'U' on the spectra in Fig. 2. The frequency, ΔV_{FWHM}, antenna temperature, and integrated intensity of the U lines are given in Table 6. All U lines except for U164619.5 have $\Delta V_{FWHM} \approx 4 - 5$ km s^{-1}, indicating that the lines may originate from a hot core region. The U164619.5 has $\Delta V_{FWHM} \approx 10.6$ km s^{-1} and so is thought to be from plateau component of Orion-KL. Whether the U lines are from unknown transitions of the known complex molecules or from any transitions of unknown molecules is to be explored in further study.

IV. SUMMARY

We present the results of the spectral line survey from 159.7 to 164.7 GHz toward Orion-KL performed with the 14 m radio telescope of TRAO. This is an extension of the previous line survey (LCL01) from 138.3 to 150.7 GHz made with the same telescope and receiver.

Table 6.– Unidentified lines[a]

Frequency (MHz)	ΔV_{FWHM} (km s^{-1})	T^*_A (K)	$\int T^*_A dv$ (K km s^{-1})
159833.5	4.3	0.09 ± 0.02	0.40
159963.0	3.8	0.08 ± 0.02	0.33
160283.6	6.6	0.09 ± 0.02	0.60
162354.5	5.4	0.09 ± 0.02	0.54
164034.7	5.2	0.10 ± 0.03	0.54
164619.5	10.6	0.13 ± 0.03	1.46

[a] All parameters were obtained from Gaussian fit.

All the procedures we used to reduce the data, to identify the detected lines, and to perform rotational analysis of each molecules are the same as given in LCL01.

In total sixty-three lines were detected. We found only 9 spectral lines to have been previously identified from other observation toward celestial objects, and the rest 54 detected lines to be the first detections towards an astronomical source. Forty-eight of 54 lines are transitions predictable with theoretical calculations or detectable with laboratory measurements. However, other six detected spectral lines found to be unknown, i.e., "unidentified". No possible detection of the recombination lines of H and He is found in the surveyed frequency area.

All detected emissions are found to be from a total of 10 molecular species and their isotopic variants. $HCOOCH_3$ has most numerous (22) transitions detected in this frequency region, followed by CH_3OCH_3 (7), C_2H_5CN (7), and SO_2 (6). We found that the LTE rotation diagram analysis of above three species except for C_2H_5CN using all homogeneous data with those from LCL01 gives more reliable determination of physical quantities. The derived values of the rotation temperatures and column densities are are 75 $\sim$ 197 K and $1.5 \sim 18 \times 10^{15}$ cm^{-2}, respectively. The 6 lines are found to be "Unidentified" because there is no identification found in the present catalogs. Identification of the U lines is to be explored in further study.

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