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A SPECTRAL LINE SURVEY FROM 138.3 TO 150.7 GHZ TOWARD ORION-KL

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ABSTRACT

We present the results of a spectral line survey from 138.3 to 150.7 GHz toward Orion-KL. The observations were made using the 14 m radio telescope of Taeduk Radio Astronomy Observatory. Typical system temperatures were between 500 and 700 K, with the sensitivity between 0.02 - 0.06 K in units of T_A^* .

A total of 149 line spectra are detected in this survey. Fifty lines have been previously reported, however we find 99 new detections. Among these new lines, 32 are 'unidentified', while 67 are from molecular transitions with known identifications. There is no detection of H or He recombination lines. The identified spectra are from a total of 16 molecular species and their isotopic variants. In the range from 138.3 to 150.7 GHz, the strongest spectral line is the J=3-2 transition of CS molecule, followed by transitions of the H₂CO, CH₃OH, CH₃CN, and SO₂. Spectral lines from the large organic molecules such as CH₃OH, CH₃OCH₃, HCOOCH₃, C₂H₅CN and CH₃CN are prominent; with 80 % of the identified lines arising from transitions of these molecules. The rotational temperatures and column densities are derived using the standard rotation diagram analysis for CH₃OH (¹³CH₃OH), HCOOCH₃, CH₃CN and SO₂ with $10 \sim 270$ K and $0.2 \sim 20 \times 10^{15}$ cm⁻². These estimates are fairly comparable to the values for the same molecule in other frequency regions by other studies.

Subject headings: ISM:individual (Orion-KL)-ISM:molecules-line:identification- radio line:molecular:interstellar

1. Introduction

Orion-KL is a unique source for study of numerous astro-chemical aspects associated with massive star formation. Spectral line surveys can provide an unbiased view on molecular constituents of such regions by fully probing various spectral lines in wide frequency bands, and also are necessary to understand physical and chemical processes in a massive star-forming region.

Toward Orion-KL there have been numerous molecular line surveys in the spectral ranges of 70-360 GHz and 607-900 GHz by other researchers (see Table 1). However, there are no spectral line surveys in the 2 mm band except for 150-160 GHz by Ziurys & McGonagle (1993, hereafter ZM93). ZM93 have detected over 180 spectral lines including about 45 unidentified features, and so concluded that Orion-KL is also very rich region for molecular lines in 2 mm band. We have been carrying out a spectral line survey toward Orion-KL to cover the entire 'unexplored' 2 mm spectral band. This paper presents our observational results of the survey from 138.3 to 150.7 GHz using the 14 m telescope of Taeduk Radio Astronomy Observatory (TRAO).

2. Observations

The survey used the TRAO 14 m telescope during 1999 April – May. The HPBW and beam efficiency of the telescope at 146 GHz are about 46" and 39%, respectively (Park et al. 1997). A 100/150 GHz dual channel SIS receiver which TRAO has developed (Park et al. 1999a,b) was used for the survey. A single sideband filter was employed to reject image spectra from an image sideband. The rejection ratio of the image side band is over 20 dB. Two filter banks of 256 channel of 1 MHz resolution were used in serial mode to get about 500 MHz band coverage during each observation. Observations were conducted with 25 different frequency settings to cover the entire frequency range between 138.3 and 150.7 GHz. Pointing of the telescope and focus of the secondary mirror were checked every two hours using Orion-KL itself in the SiO J=2-1, v = 1 maser line. The pointing accuracy is better than 10", with typical system temperature between 500 – 700 K and a sensitivity of 0.02 – 0.06 K in units of T^{*}_A. The data were taken in position switching mode using an emission free reference position of 30' azimuth off the source. Spectral line intensities were calibrated, corrected for atmospheric losses using the chopper wheel method, and expressed in T^{*}_A scale. The position of Orion-KL used for the observations is $(\alpha, \delta)_{1950.0} = (5^h 32^m 46^s.9, -5^\circ 24' 23'')$

3. Results and Discussion

A total of 149 spectral lines are detected with a complete spectrum shown in Fig. 1. Detailed identification of the molecular emission lines, LTE rotation diagram analysis of some molecular species, other interesting lines, and spatial origin of the molecular species are described in this section.

3.1. Identification of detected lines

The rest frequency scale for identification of the detected molecular emission lines is obtained by assuming $V_{LSR} = 8.4 \text{ km s}^{-1}$. This value is determined from a Gaussian fit to the CS J=2-1spectrum. This can be somewhat arbitrary as the reference value, because Orion-KL is known to consist of a number of kinematically different components with sizes of a few 10", such as extended ridge, hot core, compact ridge, and plateau (Sutton et al. 1995). The existence of these different velocity components may yield an uncertainty in the derived frequency of ~ 1 MHz or slightly larger.

We used two catalogs for line identification: the Lovas catalog (Lovas 1992) which is a collection of the molecular line frequencies determined from astronomical observations, and the JPL catalog (Pickett et al. 1998), a collection of theoretical calculations of molecular lines. In addition, catalogs by Anderson et al. (1992), Xu & Lovas (1997), and Tsunekawa et al. (2000, in private communication), and the Kawaguchi catalog (Kawaguchi 1999, in private communication) are complementarily used for the line identification.

If a detected line matches the frequency of any identified line in Lovas catalog to within $\sim \pm$ 1 MHz, it is regarded as previously 'observed'. However, if a detected line is not in the Lovas catalog, but in the list of one of the other five catalogs, it is considered as a 'new' detection. This case requires that any other transitions of the species responsible for the 'new' line should have been previously detected from other astronomical observations. We mark 'NDT' in the 6th column of Table 2 for the 'newly' detected transition.

If a detected line is not listed in any catalog, we designate it as an unidentified or "U" line. Occasionally a high excitation transition of a known species matches the frequency of a detected line, although no lower excitation transitions of the species have been detected. These matches are regarded as coincidences and marked as unidentified.

With a detection limit of ~ 3σ , a total of 149 molecular line spectra are detected. The detailed identifications of the spectra are given in Table 2. The frequency in the first column is the value given from the catalogs provided in the 5th column. For the 'U' lines, we give the frequencies determined from our observations. Molecular species, their transitions, intensity in T_A^* , and special comments for the spectra are given in the 2nd, 3rd, 4th, and 6th column of the Table 2.

Fifty of 149 spectral lines are found to have been previously identified from other studies, while there are 99 lines which represent the first detections towards an astronomical source. Sixty-seven of the new 99 lines are transitions predicted from theoretical calculations or detected from laboratory measurements. However, 32 detected lines remain "unidentified". We display all

scans with identifications of the spectra in Fig. 2.

The spectral region between 150000 MHz ~ 150760 MHz overlapped with the survey region by ZM93. ZM93 detect ~19 spectral lines in this region while we detect only 12 lines. The sensitivity between the two surveys is similar and the antenna temperatures for the strong lines (e.g., transitions of CH₃OH, SO₂, and H₂CO) for both observations are comparable. Moreover, the 2mm beam efficiency of the two telescopes is about the same (~ 0.4). The identifications for strong eight lines are the same between two studies, but for weak lines, different identifications are given. We especially note two transitions of CH₃OCH₃ at 150163.1 MHz and 150467.3 MHz. The former 150163.1 MHz line is considered to be 'unidentified' by ZM93 while the latter 150467.3 MHz line is not on their list. ZM93 assign the spectra at 150415.1 MHz and 150449.2 MHz as transitions of CH₃OH and HCOOCH₃, respectively. However, the line intensities in both observations are close to the noise level and so we leave these as undetected.

We also find two U lines in this overlapped spectral region for which ZM93 did not give any identification. In contrast ZM93 find 4 U lines for which we did not provide an identification. However, the antenna temperatures of the six U lines are ~ 0.1 K, which is close to noise level. Follow-up observations would be necessary for confirmation of the identification of the weak lines.

The identified 50 emission lines are found to originate from a total of 16 species and their isotopic variants. The strongest molecular transition between 138.3 to 150.7 GHz is the J=3-2 transition of the CS molecule, followed by the lines of the H₂CO, CH₃OH, CH₃CN, and SO₂.

An interesting point is that a considerable number of the detected lines are from large organic molecules such as CH₃OH (30), ¹³CH₃OH (4), CH₃OCH₃ (20), HCOOCH₃ (16), C₂H₅CN (15), and CH₃CN (7) (the numeric in parenthesis is the number of the detected transitions of the molecule). About 80 % of the identified lines are from the transitions of these organic molecules.

3.2. The LTE Rotation Diagram Analysis and Individual Molecules

We perform the standard LTE rotational diagram analysis to derive rotation temperatures (T_{rot}) and column densities (N) of several molecules for which more than four transitions are detected. The derived physical quantities are compared with results by other studies in different wavelength bands toward Orion-KL.

The equation for the LTE rotation diagram analysis (e.g., Turner 1991) is given as

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

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.

3 RESULTS AND DISCUSSION

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 3 – 10. The partition functions Q_{rot} are $\frac{1}{2} \left[\frac{\pi (kT_{rot})^3}{h^3 ABC}\right]^{1/2}$ for H₂CO and SO₂, $\frac{1}{3} \left[\frac{\pi (kT_{rot})^3}{h^3 AB^2}\right]^{1/2}$ for CH₃CN, $\left[\frac{\pi (kT_{rot})^3}{h^3 ABC}\right]^{1/2}$ for CH₃OCH₃ and C₂H₅CN, and $2 \left[\frac{\pi (kT_{rot})^3}{h^3 ABC}\right]^{1/2}$ for CH₃OH and HCOOCH₃, where A, B, and C are the rotational constants (Blake et al. 1986; Turner 1991).

The above equation is derived under the assumption that all lines are optically thin, all level populations are characterized by a single T_{rot} (LTE), $T_{rot} >> T_{bg}$ (background temperature), and that the Rayleigh-Jeans approximation is valid for all transitions (see Turner 1991). If these assumptions are valid and the line identifications are correct, the distribution of E_u/k versus log L of the data would exhibit a linear correlation, and the rotational temperature and the column density can be determined from the slope $[-(loge)/T_{rot}]$ and intercept $[log(N/Q_{rot})$ at $E_u = 0]$ through a linear least squares fit of the data.

On the other hand, if the distribution of E_u/k versus log L of the data in the rotation diagram deviates greatly from the linear correlation, the assumptions of low optical depth and LTE may not be valid and requires further consideration in deriving T_{ex} and N from the data. Moreover an incorrect line identification may also result in a large deviation of the data point from the correlation. Therefore, the LTE rotational diagram analysis itself can be useful for checking secure identification of spectral lines.

We applied this analysis for 7 molecules and one isotopic variant: CH₃OH (13 CH₃OH), HCOOCH₃, CH₃OCH₃, C₂H₅CN, SO₂, CH₃CN, and H₂CO. The transitions of 4 molecules [CH₃OH, HCOOCH₃, SO₂, and CH₃CN] and one isotopic variant (13 CH₃OH) are found to exhibit a linear distribution in the rotation diagram, allowing us to introduce the estimates of the physical quantities of the molecules and compare our results with those from other surveys. On the other hand, the rotational diagrams for three molecules: CH₃OCH₃, C₂H₅CN and H₂CO show scattered non-linear distributions. Therefore, the rotation temperatures and the column densities for these molecules are not derived.

Fig. 3 shows the diagrams for 6 molecules and one isotope variant used in the analysis. The diagram for H_2CO is not shown because of the large scatter seen in the data. In the following paragraphs we discuss the results of the rotational diagram analysis in sequence of increasing number of detected transitions of the molecule.

CH₃OH– Methanol is one of most widely observed species in molecular clouds and star-forming regions. The number of transitions detected (30) is the largest in our observations (Table 3). We find 19 new detections from a total of 30 methanol lines identified in our survey. The data distribution in the rotation diagram shows a fairly linear distribution with some scatter. In the rotation diagram analysis we use 26 transitions for which E_u/k and $S\mu^2$ are known. We removed a single data point from the [3(1) – 2(1) A-] transition in the analysis which shows a large deviation in the diagram (Fig. 3). The linear least squares fit to the data indicates a fairly good correlation (correlation coefficient; r = -0.86), yielding results of $T_{ex} = 160^{+21}_{-17}$ K and $N = 2.1^{+1.1}_{-0.7} \times 10^{16}$ cm⁻² which are close to 3 mm results ($T_{ex} = 192$ K and $N = 1.6 \times 10^{16}$ cm⁻²) obtained by Turner (1991).

Four transitions of the rare isotopic species, ¹³CH₃OH, are also detected with three new detections (Table 4). The linear least squares fit to the data, excluding a single deviated point [3(-1)-2(-1) E] results in a nearly perfect correlation (r = -0.998) (Fig. 3), producing T_{ex} = 40^{+3}_{-2} K and N = $1.2^{+0.2}_{-0.2} \times 10^{14}$ cm⁻². Using the terrestrial value of ¹²C/¹³C = 89 may provide an alternate (and more reliable) estimate (N = 1.1×10^{16} cm⁻²) of the column density of Methanol, which is close to the value determined using the LTE rotational method within the uncertainty.

 CH_3OCH_3 - Dimethyl ether is one of a few interstellar molecules with two internal rotors and we detect twenty transitions from this molecule in our survey (Table 5). In contrast to Methanol, there are no newly identified lines. The rotation diagram shows very scattered distribution of the data, indicating no linear correlation between E_u/k and log L (Fig. 3). This prevents us from inferring confident values of T_{rot} and N. Note that Johansson et al. (1984), Blake et al (1986), and Turner (1991) have deduced $T_{ex} = 63 - 91$ K and $N = 1.3 - 3.0 \times 10^{15}$ cm⁻² from their 3 mm data.

HCOOCH₃– Sixteen transitions of Methyl formate are detected (Table 6), with 8 lines believed to be 'first' detections. Turner (1991) has shown that this species has two components in the rotation diagram and our data in the rotational diagram also seem to exhibit two components (Fig. 3). The rotation analysis for one component yields $T_{ex} = 21.8^{+7.2}_{-4.4}$ K and $N = 2.3^{+4.9}_{-1.5} \times 10^{15}$ cm⁻². This rotational temperature is very close to that found by Turner (1991), but the column density is one order of magnitude higher than his result. The other, cooler component, shows $T_{ex} = 18.1^{+6.0}_{-3.6}$ K and $N = 2.6^{+5.5}_{-1.7} \times 10^{14}$ cm⁻² has not been seen by any other studies.

 C_2H_5CN – Fifteen transitions of Ethyl cyanide are detected (Table 7). Twelve lines are considered to be new detections. Interestingly, seven transitions seem to be K-type doubler lines whose frequencies are the same. The distribution of the data is not a simple linear appearance. So, the rotational diagram method does not seem to be applicable to derive T_{ex} and N of this molecule.

 ${
m SO}_2$ - Sulfur dioxide is detected in seven transitions (Table 8) of which four are newly detected lines. Five strong lines are found to consist of two clear velocity components, a relatively narrow and bright component of $V_{\rm LSR} \approx 6-8$ km s⁻¹ and $\Delta V_{\rm FWHM} \approx 14-31$ km s⁻¹, and a wide and weak component of $V_{\rm LSR} \approx 10-18$ km s⁻¹ and $\Delta V_{\rm FWHM} \approx 15-34$ km s⁻¹. The data of Log L and E_u/k for the former component show a good correlation (r = -0.92) with a slight scatter in the rotation diagram (Fig. 3). The analysis yields T_{ex} = 120^{+21}_{-20} K and N = $1.7^{+1.5}_{-0.1} \times 10^{16}$ cm⁻². Considering the uncertainty, our T_{ex} is fairly comparable to the value (138.5 K) found in the 3 mm observations by Turner (1991) and the value (~ 140 K) in 2 mm observations obtained by ZM93. The column density is also in close agreement with the results (N $\approx 1.5 \times 10^{16}$ cm⁻²) by Turner (1991) and (N $\approx 2.0 \times 10^{16}$ cm⁻²) by ZM93. The rotation diagram for the wide and weak component which we did not include in the Fig. 3 produces a very scattered distribution and we do not to derive T_{ex} and the N.

3 RESULTS AND DISCUSSION

CH₃CN- Methyl cyanide emissions are detected in the seven K-components from the J=8-7 transition over very narrow frequency range of about 700 MHz (Table 9). One transition [8(6)-7(6)] is a new detection. Previously different investigators have suggested several different values for the T_{ex} and N primarily due to the large scatter in the data. The overall distribution of our data points in the rotation diagram shows some scatter in the correlation (r = -0.61) (Fig. 3). The least squares fit results in T_{ex} = 273^{+381}_{-101} K and N = $1.3^{+5.1}_{-0.1} \times 10^{15}$ cm⁻². The T_{ex} is virtually the same as the value (274 K) for the hot core component by Blake et al. (1986) and the column density for the component is close to their estimate.

 H_2CO- Formaldehyde has three detected transitions (Table 10). All of the transitions have been previously observed by other studies. The line shapes of all spectra clearly exhibit two components, one a narrow bright emission component of $V_{LSR} \approx 8.6 - 8.9$ km s⁻¹ and $\Delta V_{FWHM} \approx 5 - 6$ km s⁻¹, and the other a broad faint emission component (presumably plateau emission) of $V_{LSR} \approx 7.0 - 8.3$ km s⁻¹ and $\Delta V_{FWHM} \approx 15 - 20$ km s⁻¹. Due to the high degree of scatter in the correlation we have not included the rotation diagram in Fig. 3 and also do not derive a rotational temperature and total column density for the two components.

In summary, the LTE rotational diagram analysis is fairly useful to derive important physical quantities (T_{ex} and N) from four molecules and one isotopic variant, each with more than 4 detected transitions. All the values are comparable to the estimates in different frequency regions by other researchers. The estimated values are compared with those from other studies in Table 11.

3.3. Other Interesting Lines

CS Lines– Of the observed emission lines the CS molecule stands out in that the CS (3-2) emission is the strongest among the detected transitions and its three rare isotopes such as ¹³CS, C³⁴S, and C³³S are also strongly detected in our survey (Table 12). The main isotope CS (3-2) line appears to contain several components, among which a bright ridge component of $V_{\rm LSR} \approx 5.5 \text{ km s}^{-1}$ and $\Delta V_{\rm FWHM} \approx 8.2 \text{ km s}^{-1}$, and a broad plateau component of $V_{\rm LSR} \approx 6.5 \text{ km s}^{-1}$ and $\Delta V_{\rm FWHM} \approx 21.5 \text{ km s}^{-1}$ are included. The three rare-isotope species seem to trace a ridge component of $V_{\rm LSR} \approx 8 \sim 9 \text{ km s}^{-1}$ and $\Delta V_{\rm FWHM} \approx 5 \text{ km s}^{-1}$. Comparison of the CS emission with emissions from the isotope variants can give the CS optical depth. The ratios of integrated intensities between $C^{32}S$ and $C^{33}S$, and between $C^{32}S$ and $C^{34}S$ are about 36.6 and 5.5, respectively. These are significantly different from the terrestrial values of ${}^{32}S/{}^{33}S = 80$ and ${}^{32}S/{}^{34}S = 18$, meaning that the CS (3-2) emission is optically thick. This is also inferred from the fact that the ratio (about 11.9) of the integrated intensities between CS and ^{13}CS is small compared with the terrestrial value of $^{12}C/^{13}C = 89$. Assuming $T_{ex} = 65$ K and 32 S/ 34 S = 18 which are adopted from Sutton et al. (1995), we obtain N(C³⁴S) $\approx 1.1 \times 10^{13}$ cm⁻² and N(CS) $\approx 2.0 \times 10^{14}$ cm⁻² using the LTE method (e.g., Lee, Minh, & Irvine 1993). These estimates are one order of magnitude smaller than those of Sutton et al. (1995). This difference

3 RESULTS AND DISCUSSION

may be the result of the larger beam dilution in our survey.

Recombination Lines– The recombination lines in our survey frequency region are H35 α (147046.9 MHz), H44 β (144474.0 MHz), H50 γ (144678.9 MHz), He35 α (147106.8 MHz), He44 β (144532.9 MHz), and He50 γ (144737.9 MHz). The most plausible candidate of the radio recombination lines may be the U147112.9 line which has close frequency to He35 α , but the frequency difference between two is somewhat large (~ 6 MHz). So we leave the U147112.9 line unidentified. There is no clear evidence of detection for other recombination lines in our survey.

Unidentified (U) Lines– A total of 32 U lines toward Orion-KL are found in our survey. Several lines (e.g., U143006.7 and U143263.3) are tentative detections because of low S/N ratios of the spectra. We note that U139561.9, U146372.4, U146622.4, U146984.5, U147759.8, and U147943.7 are quite bright ($T_A^* \ge 0.3$ K). The frequency, ΔV_{FWHM} , antenna temperature, and integrated intensity of the U lines are given in Table 13 and marked with 'U' on the spectra in Fig. 2. All U lines have $\Delta V_{FWHM} \approx 2-18$ km s⁻¹ and seem to originate from various components such as ridge, hot core, and plateau. The U147943.7 line has two velocity components, presumably a hot core component ($\Delta V_{FWHM} \approx 5.1$ km s⁻¹) and a plateau component ($\Delta V_{FWHM} \approx 13.4$ km s⁻¹). The identities of numerous U lines may be either from unknown transitions of the known molecules with complex rotational structure or from any transitions of unknown molecules. We leave the identifications of these lines to be explored in a future study.

3.4. Regional Origin of the Molecular Species

The spectral lines of each molecular species can often trace physically different regions of molecular clouds, and so are useful for establishing the origin of the species and understanding the astro-chemical processes inside molecular clouds. Recently, Sutton et al (1995) have surveyed 5 distinct regions of the Orion molecular clouds with high spatial resolution (about 14'' beam) and characterized the kinematic properties and main tracers of the four distinguished spatial and kinematical components such as extended ridge, hot core, compact ridge, and plateau. Their data suggest that the extended ridge shows $V_{\rm LSR} \approx 9.8 \text{ km s}^{-1}$ and $\Delta V_{\rm FWHM} \approx 2.5 \text{ km s}^{-1}$, and the hot core $V_{\rm LSR} \approx 7.0 \ {\rm km \ s^{-1}}$ and $\Delta V_{\rm FWHM} \approx 8.0 \ {\rm km \ s^{-1}}$, the compact ridge $V_{\rm LSR} \approx 6.6 \ {\rm km \ s^{-1}}$ and $\Delta V_{\rm FWHM} \approx 8.0 \ {\rm km \ s^{-1}}$, and the plateau $V_{\rm LSR} \approx 5.5 \sim 9.8 \ {\rm km \ s^{-1}}$ and $\Delta V_{\rm FWHM} \approx 10 \sim 20 \text{ km s}^{-1}$. The beam of the TRAO telescope at 140 GHz is more than 3 times bigger than the JCMT beam at 330 GHz, and so encompasses nearly all components by Sutton et al. (1995). By comparing their kinematical values of these distinct components in the Orion clouds with our data, we are able to determine which component a given molecular species traces. For this purpose, we obtained the V_{LSR} and ΔV_{FWHM} of each detected transition from all species from Gaussian fits to the spectral lines (Table 11), which are also plotted in Fig. 4. The values for the molecules with multiple transitions are given in average. According to the kinematic values of the species, CH_2CHCN is thought to be mainly from the extended ridge and C_2H_5CN , CH_3CN , H₂CO, SO₂, NO, CS, HC₃N, and OCS from the plateau. The kinematic values of the remaining

species are similar to the values of the hot core or the compact ridge, and so it is difficult to discriminate where they are from, between the two regions.

4. Summary

We present the results from a spectral line survey toward Orion-KL in the frequency range from 138.3 to 150.7 GHz carried out using the 14 m radio telescope of TRAO.

A total of 149 molecular line spectra are detected from the survey. Line identification for the detected lines is performed using Lovas catalog (Lovas 1992) which is the collection of the observed molecular lines, and JPL (Pickett et al. 1998), Kawaguchi (1999), Anderson et al. (1992), Xu & Lovas (1997) and Tsunekawa et al. (2000) catalogs which are the collections of laboratory measurements or theoretical calculations of molecular transitions.

We identify fifty lines which have been previously reported by other studies, and 99 lines which are found to be new detections in the interstellar medium. Sixty-seven among the new lines are from molecular transitions with known identifications, however, 32 spectral lines remain "Unidentified". No clear evidence for detection of the recombination lines of H and He is found in our survey.

The detected emissions in the 2mm band arise from a total of 16 molecular species and their isotopic variants. It is important to note that about 80 % of the detected lines are from transitions of the large organic molecules such as CH₃OH, CH₃OCH₃, HCOOCH₃, C₃H₅CN, and CH₃CN. We found that the LTE rotation diagram analysis is useful as a check on the line identification and is used for deducing physical quantities of four molecular species and an isotopic variant, namely [CH₃OH (¹³CH₃OH), HCOOCH₃, CH₃CN, and SO₂]. Using this method we derive their rotation temperatures (10 ~ 270 K) and column densities ($0.2 ~ 20 \times 10^{15} \text{ cm}^{-2}$). These values are fairly comparable to the estimates by other studies in other frequency regions, indicating our line identifications are fairly secure. Relying on the kinematic values of the molecular species, it is found that emission of CH₂CHCN arises from the extended ridge and emissions of C₂H₅CN, CH₃CN, H₂CO, SO₂, NO, CS, HC₃N, and OCS originate in the plateau.

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Fig. 1. — All spectra obtained from 138.3 to 150.7 GHz toward Orion-KL. Strong lines are designated their identifications. 'U' is to mark 'Unidentified' line.

Fig. 2. — Line identifications of the spectra detected from 138.3 to 150.7 GHz toward Orion-KL. The spectral resolution is 1 MHz. The rest frequency scale for all spectra is determined by assuming $V_{\rm LSR} = 8.4 \rm \ km \ s^{-1}$.

Fig. 3. — Rotation Diagrams for the molecules with at least four detected transitions. The error bar is 1 σ . The data marked with open circles in the diagrams for CH₃OH and ¹³CH₃OH are excluded in the linear least squares fit of the data. The diagrams for CH₃OCH₃ and C₂H₅CN show little correlation between E_u/k and log L of the data, and so the linear least squares fit is not applied to the molecules.

Fig. 4. — Plot of V_{LSR} versus FWHM of the molecules detected from from 138.3 to 150.7 GHz toward Orion-KL. The values for the molecules with multiple transitions are given in average.

TABLE 1 Previous spectral line surveys toward the Orion-KL region

observed Frequency	Telescope	Reference	Comments
observed Frequency 72 - 91 GHz 70 - 115 GHz 150 - 160 GHz 215 - 247 GHz 216 - 242 GHz 247 - 263 GHz 257 - 273 GHz 330 - 360 GHz 330 - 360 GHz	Telescope Onsala 20 m NRAO 12 m FCRAO 14 m OVRO 10.4 m OVRO Array OVRO 10.4 m JCMT 15 m NRAO 12 m	Reference Johansson et al. 1984 Turner 1989 Ziurys & McGonagle 1993 Sutton et al. 1985 Blake et al. 1986 Blake et al. 1986 Greaves & White 1991 Jewell et al. 1989	Comments
325 - 360 GHz 334 - 343 GHz 607 - 725 GHz 780 - 900 GHz 190 - 900 GHz	CSO 10.4 m JCMT 15 m CSO 10.4 m CSO 10.4 m CSO 10.4 m	Schilke et al. 1997 Sutton et al. 1995 Schilke et al. 1999 Schilke et al. 1999 Serabyn & Weisstein 1995	in progress Low resolution (200 MHz)

Frequency (MHz)	Species	Transition	${{ m T}_{ m A}^{* a}}_{ m (K)}$	Reference ^b	Comments
138259.9	U		0.10		
138343.2	U		0.09		
138351.1	C_2H_5CN	16(1,16)-15(1,15)	0.29	$_{\rm JPL}$	NDT
138396.4	U		0.13		
138739.3	^{13}CS	J=3-2	0.56	Lovas	
139256.7	U		0.09		
139335.9	C_2H_5CN	16(0.16) - 15(0.15)	0.17	$_{\rm JPL}$	NDT
139355.1	$\overline{SO_2}$	5(3.3)-6(2.4)	0.26	$_{\rm JPL}$	NDT
139416.9	Ū		0.10		
139432.5	U		0.14		
139436.0	Ū		0.14		
139474.5	SO_2	26(7.19)-27(6.22)	0.12	JPL	NDT
139483.5	H_2CS	4(1.3)-3(1.2)	0.41	Lovas	
139500.4	CH ₃ OCH ₃	9(3.6)-9(2.7) AE	0.10	JPL	NDT
139503.7	CH ₃ OCH ₃	9(3.6)-9(2.7) EE	0.15	JPL	NDT
139506.9	CH ₃ OCH ₃	9(3.6)-9(2.7) AA	0.16	JPL	NDT
139561 9	U	0(0,0) 0(2,1) 1111	0.32	01 L	
139582 1	Ŭ		0.13		
139862.3	U		0.08		
139878.4	U		0.00		
139903 0	CH [°] OH	unassigned	0.10	$\mathbf{T}\mathbf{I}\mathbf{T}\mathbf{T}$	NDT
140033 1	CH ₂ OH	23(-2)-23(1) E	0.03 0.17	Lovas	ND I
140035.1 140197.5	Hacco	7(17) 6(16)	0.17	Lovas	
140127.5 140151.1	CHOOH	$v_{1} = 0.18(0) - 18(-1) E$	0.10	Lovas	
140101.1	CH ₂ OH	$v_t = 0, 10(0) - 10(-1) L$	0.29		NDT
140100.0 140174.6	U	unassigned	0.10	1011	ND1
140174.0	SO	$6(2 \ 4) \ 6(1 \ 5)$	1.21	Loves	
140300.2	$H_{\rm LCO}$	0(2,4) - 0(1,3) 2(1,2), 1(1,1)	2.14	Lovas	
140859.5		$2(1,2)^{-1}(1,1)$ 11(2.8) 10(2.7) A	0.41	Lovas	
141200.4	$\Pi COOCII_3$	11(3,6)-10(3,7) A $7(2,4)$ $6(2,2)$ 8_{7} $7(2,5)$ $6(2,4)$	0.41 0.11	LOVAS	NDT
141402.0 141441.2	$\Pi_2 \cup \cup \cup$	$((3,4)-0(3,3) \otimes ((3,3)-0(3,4))$	0.11	JFL VI	ND1 NDT
141441.0 141507.1	13CU OU	$v_t = 0, 0(0) \cdot 1(1) E$ $v_t = 0, 2(1) 2(1) F$	0.28	AL VI	ND1 NDT
141097.1	13CU OU	$v_t = 0, 3(-1)-2(-1)$ E	0.29		ND1
141002.0	^{13}CU OU	$v_t = 0, 3(0) - 2(0) \text{ A}$ $v_t = 0, 2(2) 2(2) \text{ E} \left\{ t_2 2(2) 2(2) \text{ E} \right\}$	0.20	LOVAS	NDT
141023.3	13 CH ₃ OH	$v_t = 0, \ 3(2) - 2(2) \to 3(-2) - 2(-2) \to 0$	0.32	AL VI	ND1 NDT
141029.2	СП ₃ ОН	$v_t = 0, \ 3(1) - 2(1) \ \mathrm{E}$	0.28	ΛL	ND1
141040.5	U	11(9,0) $10(9,9)$ E	0.13	ותו	NDT
141653.0	HCOOCH ₃	$11(2,9)-10(2,8) \to 11(2,9)-10(2,8)$	0.56	JPL	ND1 NDT
141667.0	HCOOCH ₃	11(2,9)-10(2,8) A	0.38	JPL	NDT
141829.1	CH_3OCH_3	8(3,5)-8(2,6) EA	0.17	JPL	NDT
141832.3	CH_3OCH_3	8(3,5)-8(2,6) EE	0.37	JPL	NDT
141835.5	CH_3OCH_3	8(3,5)-8(2,0) AA	0.18	JPL	NDT
141983.7	U		0.36	mimm	NDT
142054.4	CH_3OH	unassigned	0.14	TUTT IDI	NDT NDT
142346.3	C_2H_5CN	16(2,15)-15(2,14)	0.21	JPL	$ND'\Gamma$
142735.1	HCOOCH ₃	13(1,13)-12(1,12) A	0.33	Lovas	
142815.5	HCOOCH ₃	$13(0,13)-12(0,12) \to 0$	0.20	$_{\rm JPL}$	NDT
142924.5	$HCOOCH_3$	$13(1,13)$ - $12(0,12) \to 13(1,13)$	0.23	$_{\rm JPL}$	NDT

 TABLE 2

 Identifications of Spectral Lines Detected Toward Orion-KL

Frequency (MHz)	Species	Transition	${ m T}^{* a}_{ m A}$ (K)	Reference ^b	Comments
143006.7	U		0.20		
143057.1	SO_2	16(2,14)-16(1,15)	0.97	Lovas	
143108.3	CH_3OH	$v_t = 0, 17(0)-17(-1) E$	0.18	XL	NDT
143169.5	CH ₃ OH	$v_t = 0, 7(3)-8(2) E$	0.97	XL	NDT
143240.5	HCOOCH ₃	12(1,11)-11(1,10) A	0.34	$_{\rm JPL}$	NDT
143263.3	U		0.07		
143337.7	C_2H_5CN	16(7.9)-15(7.8) & 16(7.10)-15(7.9)	0.33	$_{\rm JPL}$	NDT
143343.9	C_2H_5CN	16(9.8)-15(9.7) & 16(9.7)-15(9.6)	0.19	$_{\rm JPL}$	NDT
143357.2	C ₂ H ₅ CN	16(6.10) - 15(6.9) & 16(6.11) - 15(6.10)	0.28	$_{ m JPL}$	NDT
143360.4	C ₂ H ₅ CN	16(10.7) - 15(10.6) & 16(10.6) - 15(10.5)	0.25	JPL	NDT
143383.0	C ₂ H ₅ CN	16(11.6) - 15(11.5) & 16(11.5) - 15(11.4)	0.09	JPL	NDT
143407.2	C ₂ H ₅ CN	16(512) - 15(511) & 16(511) - 15(510)	0.32	JPL	NDT
143410.8	C ₂ H ₅ CN	16(0,12) $16(0,11)$ $(0,11)$ $16(0,11)$ $16(0,10)16(12.5)$ $15(12.4)$ & $16(12.4)$ $15(12.3)$	0.02	JPL	NDT
143507.0	C ₂ H ₅ CN	16(12,0) $16(12,1)$ $(12,1)$ $16(12,0)16(4,13)$ - $15(4,12)$	0.22	Lovas	1121
143529.2	C ₂ H ₂ CN	16(3,14) - 15(3,13)	0.22	Lovas	
143525.2 1/3535.3	C ₂ H ₅ CN	16(4, 12) - 15(4, 11)	0.20 0.22	Lovas	
143500.0 1/3500.4	CH ₂ OCH ₂	7(3,4),7(2,5), AF	0.22	Lovas	
1435399.4	CH ₂ OCH ₂	7(3,4) $7(2,5)$ FE	0.10	Lovas	
143003.0	$C^{\Pi_3}OC^{\Pi_3}$	7(3,4)-7(2,5) LL 7(2,4) $7(2,5)$ AA	0.10 0.17	Lovas	
143000.2		P(5,4) - P(2,3) AA P(6,22) = 20(2,27) gauge	0.17 0.14	IDI	NDT
140010.1	$U_2 \Pi_5 O \Pi$	28(0,23)-29(2,27) gaucine	0.14 0.20	ĴΓĽ	ND1
143021.0 143065 9		$a_{1} = 0.2(1).2(1)$	0.20	Larra	
143003.0	$U_{13}U_{1}$	$v_t = 0, \ S(1) - 2(1) \ A$	0.00	Lovas	
144207.0	U		0.11		
144351.4	U		0.14		
144570.2		2 2(0) 2(0) 1	0.13	A T TT	NDT
144572.0	CH_3OH	$v_t = 2, 3(0) - 2(0) \text{ A}$	0.09	ALH	NDT
144583.9	CH_3OH	$v_t = 2, 3(-1)-2(-1) E$	0.09	ALH	NDT
144589.8	CH_3OH	$v_t = 1, 3(1)-2(1)$ A	0.14	XL T	NDT
144617.1	Co-S	J=3-2	1.31	Lovas	NDT
144728.7	CH_3OH	$v_t = 1, 3(-2)-2(-2) \to \& 3(2)-2(2) \to 1$	0.31	XL WI	NDT
144734.5	CH ₃ OH	$v_t = 1, 3(1)-2(1) E$	0.41	XL WI	NDT
144750.2	CH ₃ OH	$v_t = 1, 3(-1)-2(-1) E$	0.23	XL	NDT
144762.2	$CH_2CHCN - v2$	15(2,13)-14(2,12)	0.21	Kawaguchi	NDT
144768.2	CH ₃ OH	$v_t = 1, 3(0)-2(1)$ A	0.18	XL -	NDT
144828.0	DCN	J=2-1 F'=2-1	0.96	Lovas	
144859.0	CH_3OCH_3	6(3,3)- $6(2,4)$ EE	0.17	JPL	NDT
144878.6	CH_3OH	$v_t = 1, 3(1)-2(1) $ A	0.19	XL	NDT
145093.6	CH_3OH	$v_t = 0, 3(0) - 2(0) $ E	1.82	Lovas	
145097.5	CH_3OH	$v_t = 0, 3(-1)-2(-1) $ E	2.06	Lovas	
145103.2	CH ₃ OH	$v_t = 0, 3(0) - 2(0) $ A	1.82	Lovas	
145124.4	CH_3OH	$v_t = 0, \ 3(2)-2(2) \ A$	1.50	Lovas	
145126.4	CH_3OH	$v_t = 0, 3(2)-2(2) \to \& 3(-2)-3(-2) \to$	2.00	Lovas	
145131.9	CH_3OH	$v_t = 0, 3(1)-2(1) $ E	1.70	Lovas	
145133.5	CH_3OH	$v_t = 0, \ 3(2)-2(2) \ A$	1.74	Lovas	
145560.9	HC_3N	J=16-15	1.01	Lovas	
145602.9	H_2CO	2(0,2)-1(0,1)	2.45	Lovas	
145680.4	CH ₃ OCH ₃	5(3.2)-5(2.3) EE	0.14	Lovas	

TABLE 2—Continued

Frequency (MHz)	Species	Transition	${{ m T}^{*}_{ m A}}^{ m a}_{ m (K)}$	Reference ^b	Comments
145755.6	$C^{33}S$	J=3-2 F=9/2-7/2 & F=7/2-5/2	0.19	Lovas	
145766.1	CH_3OH	$v_t = 0, 16(0) - 16(-1) E$	0.29	XL	NDT
145876.2	Ŭ		0.15		
145946.8	OCS	J=12-11	0.80	Lovas	
146120.0	C_2H_5CN	16(2,14)-15(2,13)	0.28	$_{\rm JPL}$	NDT
146129.6	U		0.17		
146368.3	CH_3OH	$v_t = 0, 3(1)-2(1)$ A	0.96	XL	NDT
146372.4	U		0.42		
146550.1	SO_2	10(4,6)-11(3,9)	0.32	$_{\rm JPL}$	NDT
146605.5	$\overline{SO_2}$	4(2,2)-4(1,3)	0.99	$_{\rm JPL}$	NDT
146618.8	CH ₃ OH	$v_t = 0, 9(0)-8(1)$ A	1.23	XL	NDT
146622.4	Ŭ		0.74		
146894.5	C_2H_5CN	17(1,17)-16(1,16)	0.28	$_{\rm JPL}$	NDT
146969.0	CS	J=3-2	6.17	Lovas	
146977.7	HCOOCH ₃	$12(3,10)-11(3.9) \to 100$	0.63	Lovas	
146984.5	U		0.38		
146988.0	HCOOCH ₃	12(3,10)-11(3.9) A	0.44	Lovas	
147024.9	CH ₃ OCH ₃	7(1.7)-6(0.6) EE	0.51	Lovas	
147072.7	CH ₃ CN	8(6)-7(6)	0.26	JPL	NDT
147103.9	CH ₃ CN	8(5)-7(5)	0.54	Lovas	
147112.9	U		0.16		
147129.2	CH ₃ CN	8(4)-7(4)	0.56	Lovas	
147149.1	CH ₃ CN	8(3)-7(3)	1.28	Lovas	
147163.3	CH ₃ CN	8(2)-7(2)	1.16	Lovas	
147171.8	CH ₃ CN	8(1)-7(1)	1.53	Lovas	
147174.6	CH ₃ CN	8(0)-7(0)	1.68	Lovas	
147206.8	CH ₃ OCH ₃	6(3.4)- $6(2.5)$ EE	0.25	JPL	NDT
147759.8	U		0.34	-	
147943.7	Ŭ		0.30		
147979.7	U		0.14		
148028.1	HCOOCH ₃	12(6.6)-11(6.5) E	0.24	$_{\rm JPL}$	NDT
148040.6	HCOOCH ₃	12(6.7) - 11(6.6) E	0.33	JPL	NDT
148045.8	HCOOCH ₃	12(6.6)-11(6.5) A	0.24	JPL	NDT
148111.9	CH ₃ OH	$v_t = 0, 15(0) - 15(-1) E$	0.67	XL	NDT
148249.2	U		0.16		
148500.4	CH ₃ OCH ₃	8(3.6)-8(2.7) EE	0.18	$_{\rm JPL}$	NDT
148503.8	CH ₃ OCH ₃	8(3.6)-8(2.7) AA	0.19	JPL	NDT
148797.8	HCOOCH ₃	$12(4.9) \cdot 11(4.8) E$	0.16	JPL	NDT
148806.3	HCOOCH ₃	12(4.9)-11(4.8) A	0.19	JPL	NDT
149439.9	CH ₃ OCH ₃	19(3.17)-18(4.14) EE	0.15	JPL	NDT
149532.5	CH ₃ OH	$v_t = 0, 14(2)-13(3) E$	0.68	XL	NDT
149569.8	CH ₃ OCH ₃	9(3.7)-9(2.8) EE	0.21	$_{\rm JPL}$	NDT
149878.8	CH ₃ OCH ₃	5(5.1)-6(4.2) AE	0.14	JPL	NDT
150141.6	CH ₃ OH	$v_t = 0.14(0)-14(-1)$ E	0.67	Lovas	
150155.3	U		0.08	20.00	
150163 1	CH ₃ OCH ₂	25(4.21)-25(1.24) A A	0.00	JPL	NDT
	011000110		···-	v	1, 1, 1

TABLE 2—Continued

TABLE 2—Continued

Frequency (MHz)	Species	Transition	${{ m T}_{ m A}^{sta}}\ ({ m K})$	Reference ^b	Comments ^c
$\begin{array}{c} 150186.7\\ 150381.1\\ 150439.1\\ 150467.3\\ 150498.3\\ 150546.5\\ 150600.8\\ 150618.3\end{array}$	U SO ₂ NO CH ₃ OCH ₃ H ₂ CO NO HCOOCH ₃ HCOOCH ₃	15(5,11)-16(4,12) $2\Pi_{1/2} J=3/2-1/2 F=3/2-3/2(+-)$ 22(2,21)-21(3,18) EE 2(1,1)-1(1,0) $2\Pi_{1/2} J=3/2-1/2 F=5/2-3/2(+-)$ 12(4,8)-11(4,7) E 12(4,8)-11(4,7) A	$\begin{array}{c} 0.10\\ 0.57\\ 0.10\\ 0.13\\ 5.47\\ 0.17\\ 0.28\\ 0.25 \end{array}$	Lovas Lovas JPL Lovas Lovas Lovas Lovas	NDT

 $^{\mathrm{a}}\mathrm{peak}$ antenna temperatures

^bJPL- Pickett et al. (1998); Lovas - Lovas (1992); Kawaguchi - Kawaguchi (1999); XL - Xu & Lovas (1997); ALH -Anderson et al. (1992); TUTT - Tsunekawa, Ukai, Toyama, & Takagi 2000 ^cNDT - Newly Detected Transition from the known molecule

Frequency (MHz)	$\begin{array}{c} {\rm Transition} \\ v_t \ J(K_{-1},K_{+1}) \end{array}$	$\begin{array}{c} V_{\rm LSR} \\ ({\rm km~s^{-1}}) \end{array}$	$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km \ s^{-1}) \end{array}$	\mathbf{g}_{I}	g_k	${{ m E_u/k^a} \over { m (K)}}$	${}^{\mathrm{S}\mu^{\mathrm{2a}}}_{\mathrm{(Debye^2)}}$	$ \int T_A^* dv \pm \sigma $ (K km s ⁻¹)	Log L
139903.0	unassigned	10.3	7.3	1	2			0.7 ± 0.2	
140033.1	0 23(-2)-23(1) E	7.2	4.4	1	2	668.7	19.21	0.8 ± 0.2	10.80
140151.1	0 18(0)-18(-1) E	7.2	5.7	1	2	407.4	6.22	1.7 ± 0.7	11.62
140166.6	unassigned	7.8	4.1	1	2			0.4 ± 0.1	
141441.3	$1 \ 0(0) - 1(1) \ E$	7.4	4.7	1	2	300.8	0.89	1.4 ± 0.1	12.38
142054.4	unassigned	9.1	4.7	1	2			0.8 ± 0.2	
143108.3	0 17(0)-17(-1) E	7.2	7.4	1	2	367.1	6.61	1.7 ± 0.3	11.59
143169.5	$0\ 7(3)-8(2)$ E	7.8	3.9	1	2	112.8	1.81	2.4 ± 0.4	12.28
143865.8	0 3(1)-2(1) A	8.0	4.5	1	2	28.4	2.09	3.6 ± 0.2	12.41
144572.0	2 3(0)-2(0) A	6.9	6.2	1	2	522.1	2.35	0.6 ± 0.1	11.59
144583.9	2 3(-1)-2(-1) E	8.1	7.3	1	2	545.6	2.09	0.7 ± 0.1	11.67
144589.8	1 3(1)-2(1) A	7.7	8.4	1	2	339.4	2.16	1.2 ± 0.2	11.92
144728.7	1 3(-2)-2(-2) E &	6.8	7.7	1	2	378.8	1.34	2.5 ± 0.2	12.44
	3(2)-2(2) A								
144734.5	$1 \ 3(1)-2(1) \ E$	6.4	10.4	1	2	304.4	2.15	4.5 ± 0.3	12.50
144750.2	1 3(-1)-2(-1) E	6.2	7.7	1	2	426.2	2.15	1.5 ± 0.2	12.03
144768.2	1 3(0)-2(1) A	7.7	5.6	1	2	437.9	2.42	1.1 ± 0.1	11.83
144878.6	1 3(1)-2(1) A	7.4	4.0	1	2	26.1	2.16	0.9 ± 0.1	11.76
145093.6	$0 \ 3(0)-2(0) \ E$	8.0	5.0	1	2	27.1	2.42	9.8 ± 0.2	12.79
145097.5	0 3(-1)-2(-1) E	8.7	6.7	1	2	19.5	2.16	13.1 ± 0.3	12.97
145103.2	0 3(0)-2(0) A	8.5	5.8	1	2	13.9	2.42	11.0 ± 0.8	12.84
145124.4	0 3(2)-2(2) A	5.6	8.0	1	2	51.7	1.36	16.1 ± 0.2	13.24
145126.4	$0 \ 3(2)-2(2) \to \&$	9.7	8.0	1	2	39.9	1.34	16.1 ± 0.2	13.26
	3(-2)-3(-2)E								
145131.9	$0 \ 3(1)-2(1) \ E$	7.2	7.7	1	2	35.0	2.21	14.4 ± 0.3	13.01
145133.5	$0 \ 3(2)-2(2) \ A$	10.5	7.8	1	2	38.0	1.35	14.6 ± 0.2	13.20
145766.1	0 16(0)-16(-1) E	7.2	6.5	1	2	327.9	6.96	1.9 ± 0.3	11.60
146368.3	$0 \ 3(1)-2(1)A$	8.2	4.2	1	2	28.6	2.16	4.3 ± 0.2	12.47
146618.8	0 9(0)-8(1) A	9.1	8.4	1	2	104.5	8.33	9.9 ± 1.2	12.26
148111.9	0 15(0)-15(-1) E	7.5	7.0	1	2	289.8	7.26	4.9 ± 0.2	12.05
149532.5	$0 \ 14(2)-13(3) \to 0$	7.4	6.2	1	2	265.2	4.20	4.0 ± 0.3	12.14
150141.6	0 14(0)-14(-1) E	8.0	6.9	1	2	255.2	7.49	4.5 ± 0.3	11.93

TABLE 3 Transitions of CH_3OH

^aFrom Xu & Lovas (1997) except for 3(0)-2(0) A transition (144572.0 MHz) from Anderson et al. (1990) and 3(-1)-2(-1) E transition (144583.9 MHz) from Anderson et al. (1992)

 ${\rm S}\mu^{2{\rm a}}$ ${\rm V_{LSR} \atop (km \ s^{-1})}$ $\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km \ s^{-1}) \end{array}$ $\int T_A^* dv \pm \sigma$ (K km s⁻¹) Frequency Transition $\mathrm{E}_{\mathrm{u}}/\mathrm{k}^{\mathrm{a}}$ $\log L$ \mathbf{g}_{I} $\mathbf{g}_{\mathbf{k}}$ $(Debye^2)$ (MHz) $v_t \ J(K_{-1},K_{+1})$ (\mathbf{K}) 0 3(-1)-2(-1) E 141597.17.01 $\mathbf{2}$ 26.78.62 2.0 ± 0.2 11.559.3 $\mathbf{2}$ 141602.50 3(0)-2(0) A 8.23.11 13.64.72 0.8 ± 0.1 11.411 2 2.0 ± 0.2 11.12141623.50 3(2)-2(2) E & 6.439.622.807.80 3(-2)-2(-2) E 141629.2 $0 \ 3(1)-2(1) \ E$ 6.76.91 219.36 2.0 ± 0.2 11.1934.7

TABLE 4 Transitions of $^{13}\mathrm{CH}_3\mathrm{OH}$

^aFrom Xu & Lovas (1997)

Frequency (MHz)	$\begin{array}{c} Transition \\ J(K_{-1},K_{+1}) \end{array}$	${\rm V_{LSR} \atop (km \ s^{-1})}$	$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	gı	gk	$\begin{array}{c} E_u/k^a \\ (K) \end{array}$	$\begin{array}{c} {\rm S}\mu^{2{\rm a}}\\ ({\rm Debye}^2) \end{array}$	$ \int T_A^* dv \pm \sigma $ (K km s ⁻¹)	Log L
139500.4	9(3,6)-9(2,7) AE	7.1	5.9	1	0.40	53.7	1.37	0.7 ± 0.1	12.56
139503.7	9(3,6)-9(2,7) EE	7.5	5.4	1	1.60	53.7	3.65	0.9 ± 0.2	11.68
139506.9	9(3,6)-9(2,7) AA	9.0	5.3	1	1.00	53.7	2.28	0.9 ± 0.1	12.07
141829.1	8(3,5)-8(2,6) EA	7.9	3.8	1	0.67	45.5	0.78	0.7 ± 0.2	12.57
141832.3	$8(3,5)-8(2,6) \to 10^{-10}$	8.4	3.7	1	2.67	45.5	3.14	1.4 ± 0.2	11.70
141835.5	8(3,5)-8(2,6) AA	8.1	4.4	1	1.00	45.5	1.18	0.8 ± 0.5	12.32
143599.4	7(3,4)- $7(2,5)$ AE	7.8	4.5	1	0.40	38.2	0.99	0.7 ± 0.1	12.74
143603.0	$7(3,4)-7(2,5) \to 100$	8.1	2.1	1	1.60	38.2	2.65	0.6 ± 0.1	11.61
143606.2	7(3,4)- $7(2,5)$ AA	7.7	2.9	1	1.00	38.2	1.66	0.5 ± 0.1	11.98
144859.0	6(3,3)- $6(2,4)$ EE	7.6	4.1	1	2.67	31.8	2.16	0.7 ± 0.1	11.58
145680.4	$5(3,2)-5(2,3) \to 5(3,2)-5(2,3)$	8.4	4.7	1	1.60	26.3	1.60	0.7 ± 0.2	11.89
147024.9	$7(1,7)-6(0,6) \to 100$	7.9	6.0	1	2.67	26.1	3.38	3.0 ± 0.5	11.98
147206.8	6(3,4)- $6(2,5)$ EE	8.5	5.0	1	1.60	31.8	2.14	1.2 ± 0.3	12.01
148500.4	$8(3,6)-8(2,7) \to 100$	7.5	4.9	1	1.60	45.5	3.04	1.0 ± 0.1	11.75
148503.8	8(3,6)-8(2,7) AA	7.0	3.8	1	1.00	45.5	1.90	0.7 ± 0.1	12.04
149439.9	$19(3,17)-18(4,14) \to 100$	9.8	6.2	1	2.67	185.9	1.95	1.0 ± 0.2	11.72
149569.8	$9(3,7)-9(2,8) \to 100$	7.9	3.9	1	2.67	53.7	3.47	0.9 ± 0.2	11.45
149878.8	5(5,1)- $6(4,2)$ AE	9.6	5.9	1	0.33	48.8	0.01	0.9 ± 0.2	14.88
150163.1	25(4,21)-25(1,24) AA	7.3	8.0	1	1.00	321.0	8.81	1.0 ± 0.2	11.50
150467.3	22(2,21)-21(3,18) EE	6.9	6.6	1	1.60	233.1	0.67	0.9 ± 0.2	12.40

TABLE 5 Transitions of CH_3OCH_3

^aFrom JPL catalog

Frequency (MHz)	$\begin{array}{c} Transition \\ J(K_{-1},K_{+1}) \end{array}$	$\begin{array}{c} V_{\rm LSR} \\ (\rm km~s^{-1}) \end{array}$	$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	gı	gk	${{ m E}_{ m u}/k^{ m a}} m (K)$	${}^{\mathrm{S}\mu^{\mathrm{2a}}}_{\mathrm{(Debye^2)}}$	$ \int T_A^* dv \pm \sigma \\ {\rm K \ km \ s^{-1}} $	Log L
141260.4	11(3,8)-10(3,7) A	8.4	4.9	2	1	45.8	27.13	2.0 ± 0.2	11.05
141653.0	$11(2,9)-10(2,8) \to 10(2,8)$	7.3	8.5	1	2	43.3	28.18	4.4 ± 0.2	11.37
141667.0	11(2,9)-10(2,8) A	7.6	3.9	2	1	43.3	28.18	1.7 ± 0.1	10.96
142735.1	13(1,13)-12(1,12) A	9.4	5.9	2	1	49.0	34.04	2.1 ± 0.2	10.96
142815.5	13(0,13)-12(0,12) A	6.6	7.9	2	1	49.0	34.04	1.5 ± 0.3	10.82
142924.5	$13(1,13)-12(0,12) \to$	7.0	9.0	1	2	49.0	30.31	1.5 ± 0.4	10.87
143240.5	12(1,11)-11(1,10) A	9.0	4.9	2	1	44.4	30.85	1.4 ± 0.4	10.83
146977.7	$12(3,10)-11(3,9) \to$	9.1	6.0	1	2	52.1	29.78	3.9 ± 0.4	11.28
146988.0	12(3,10)-11(3,9) A	8.0	2.9	2	1	52.1	29.78	1.4 ± 0.2	10.83
148028.1	$12(6,6)-11(6,5) \to 12(6,6)-11(6,5)$	8.1	3.9	1	2	70.0	23.93	1.1 ± 0.1	10.82
148040.6	$12(6,7)-11(6,6) \to 12(6,7)-11(6,6) \to 12(6,7)-11(6,6) \to 12(6,7)-11(6,6)$	9.3	5.4	1	2	70.0	23.93	1.8 ± 0.2	11.03
148045.8	12(6,6)-11(6,5) A	8.5	4.1	2	1	70.0	23.93	0.9 ± 0.1	10.75
148797.8	$12(4,9)-11(4,8) \to 12(4,9)-11(4,8)$	8.0	3.2	1	2	56.9	28.32	0.7 ± 0.2	10.52
148806.3	12(4,9)-11(4,8) A	8.4	3.5	2	1	56.9	28.34	0.8 ± 0.2	10.60
150600.8	$12(4,8)-11(4,7) \to 12(4,8)-11(4,7) \to 12(4,8)-11(4,7) \to 12(4,8)-11(4,7)$	8.1	3.3	1	2	57.1	28.33	1.0 ± 0.2	10.70
150618.3	12(4,8)-11(4,7) A	8.6	3.4	2	1	57.1	28.35	1.1 ± 0.1	10.74

TABLE 6 TRANSITIONS OF HCOOCH_3

^aFrom Bauder (1979) for all E_u/k and $S\mu^2$ except for those for J=13-12 transitions which are from Plummer et al (1984).

Frequency (MHz)	$\begin{array}{c} Transition \\ J(K_{-1},K_{+1}) \end{array}$	$\begin{array}{c} V_{\rm LSR} \\ ({\rm km~s^{-1}}) \end{array}$	$\begin{array}{c} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	gı	gk	$\begin{array}{c} E_{\rm u}/k^{\rm a} \\ ({\rm K}) \end{array}$	${ m S}\mu^{2{ m a}}$ (Debye ²)	$ \int T_A^* dv \pm \sigma $ (K km s ⁻¹)	Log L
138351.1	16(1,16)-15(1,15)	4.4	12.7	1	1	57.8	235.7	3.7 ± 0.3	10.68
139335.9	16(0,16)-15(0,15)	3.0	18.8	1	1	57.5	236.1	2.5 ± 0.2	10.51
142346.3	16(2,15)-15(2,14)	3.9	15.1	1	1	62.7	233.0	3.3 ± 0.4	10.63
143337.7	16(7,9)-15(7,8) &	6.0	12.3	1	1	113.0	191.5	4.1 ± 0.3	10.79
	16(7,10) - 15(7,9)								
143343.9	16(9,8)-15(9,7) &	7.5	11.5	1	1	148.6	161.9	2.3 ± 0.8	10.83
	16(9,7)-15(9,6)								
143357.2	16(6,10)- $15(6,9)$ &	4.8	9.7	1	1	98.6	203.6	2.8 ± 0.3	10.61
	16(6,11)-15(6,10)								
143360.4	16(10,7)-15(10,6) &	6.1	11.0	1	1	169.6	144.3	2.5 ± 0.8	10.72
	16(10,6)-15(10,5)								
143383.0	16(11,6)-15(11,5) &	4.2	11.0	1	1	192.9	124.9	1.2 ± 0.2	10.47
	16(11,5)-15(11,4)								
143407.2	16(5,12)-15(5,11) &	5.8	8.2	1	1	86.3	213.8	2.9 ± 0.4	10.60
	16(5,11)-15(5,10)								
143410.8	16(12,5)-15(12,4) &	8.6	11.7	1	1	218.4	103.6	2.8 ± 1.0	10.91
	16(12,4)-15(12,3)								
143507.0	16(4,13)-15(4,12)	5.5	16.6	1	1	76.4	222.0	3.4 ± 0.3	10.66
143529.2	16(3,14)-15(3,13)	5.9	12.1	1	1	68.6	228.5	3.4 ± 0.4	10.65
143535.3	16(4,12)-15(4,11)	8.2	16.0	1	1	76.4	222.1	3.5 ± 1.1	10.86
146120.0	16(2,14)-15(2,13)	1.9	13.9	1	1	63.7	233.2	3.7 ± 0.5	10.67
146894.5	17(1,17)-16(1,16)	3.7	12.2	1	1	64.8	250.6	4.1 ± 0.5	10.68

TABLE 7 Transitions of C_2H_5CN

^a From JPL catalog

Frequency (MHz)	$\begin{array}{c} Transition \\ J(K_{-1},K_{+1}) \end{array}$		$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	$\mathbf{g}_{\mathbf{I}}$	g_k	${{ m E}_{ m u}/k^{ m a}} m (K)$	${}^{\mathrm{S}\mu^{2\mathrm{a}}}$ (Debye ²)	$\begin{array}{l} \int T_A^* dv \pm \sigma \\ ({\rm K \ km \ s^{-1}}) \end{array}$	Log L
139355.1	5(3,3)-6(2,4)	8.3	13.9	1	1	35.9	1.3	3.8 ± 0.3	12.93
		18.0	14.5	1	1	35.9	1.3	2.2 ± 0.7	12.70
139474.5	26(7,19)-27(6,22)	6.7	9.6	1	1	443.4	10.2	0.9 ± 0.2	11.43
140306.2	6(2,4)-6(1,5)	7.4	15.3	1	1	29.2	10.2	19.3 ± 0.5	12.76
		14.8	22.0	1	1	29.2	10.2	17.1 ± 3.0	12.71
143057.1	16(2,14)-16(1,15)	6.9	17.8	1	1	137.6	34.6	18.0 ± 1.4	12.19
		17.0	19.2	1	1	137.6	34.6	11.6 ± 1.6	12.00
146550.1	10(4,6)-11(3,9)	5.5	30.5	1	1	89.9	3.4	10.2 ± 0.5	12.95
146605.5	4(2,2)-4(1,3)	5.9	24.3	1	1	19.0	6.1	25.2 ± 1.5	13.08
150381.1	15(5,11)-16(4,12)	6.8	21.4	1	1	171.8	5.4	10.6 ± 0.8	12.75
		10.1	34.2	1	1	171.8	5.4	10.4 ± 1.2	12.73

TABLE 8 Transitions of SO_2

^aFrom Helminger & DeLucia (1985)

Frequency (MHz)	$\begin{array}{l} Transition \\ J(K_{-1},K_{+1}) \end{array}$	$\begin{array}{c} V_{\rm LSR} \\ (\rm km~s^{-1}) \end{array}$	$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	gı	g_k	${{ m E}_{ m u}/k^{ m a}} m (K)$	${ m S}\mu^{2a}$ (Debye ²)	$ \int T_A^* dv \pm \sigma $ (K km s ⁻¹)	Log L
147072.7	8(6)-7(6)	3.7	13.0	0.50	2.0	275.3	53.6	3.4 ± 0.5	11.27
147103.9	8(5)-7(5)	7.9	13.4	0.25	2.0	209.6	74.6	5.9 ± 0.6	11.66
147129.2	8(4)-7(4)	7.5	8.7	0.25	2.0	145.6	91.9	4.5 ± 0.6	11.46
147149.1	8(3)-7(3)	7.8	5.1	0.50	2.0	95.8	105.3	6.8 ± 0.4	11.27
147163.3	8(2)-7(2)	6.9	8.0	0.25	2.0	60.3	114.8	7.6 ± 0.9	11.59
147171.8	8(1)-7(1)	6.9	8.9	0.25	2.0	38.9	120.6	13.5 ± 1.6	11.81
147174.6	8(0)-7(0)	8.4	9.7	0.50	1.0	31.8	122.5	15.6 ± 1.8	11.87

TABLE 9 Transitions of CH_3CN

^aFrom Pearson & Müller (1996)

Frequency (MHz)	$\begin{array}{c} Transition \\ J(K_{-1},K_{+1}) \end{array}$	$\begin{array}{c} V_{\rm LSR} \\ (\rm km~s^{-1}) \end{array}$	$\begin{array}{l} \Delta V_{\rm FWHM} \\ (\rm km~s^{-1}) \end{array}$	gı	g_k	$\begin{array}{c} E_{\rm u}/k^{\rm a} \\ ({\rm K}) \end{array}$	$S\mu^{2a}$ (Debye ²)	$ \int T_A^* dv \pm \sigma $ (K km s ⁻¹)	Log L
140839.5	2(1,2)-1(1,1)	8.6	5.5	0.75	1.0	21.9	8.2	17.7 ± 0.3	13.24
		8.3	19.9	0.75	1.0	21.9	8.2	7.4 ± 0.6	12.86
145602.9	2(0,2)-1(0,1)	8.9	4.7	0.25	1.0	10.5	10.9	12.4 ± 0.2	13.43
		7.0	15.1	0.25	1.0	10.5	10.9	4.2 ± 0.7	12.95
150498.3	2(1,1)-1(1,0)	8.8	5.7	0.75	1.0	22.6	8.2	33.3 ± 0.3	13.49
		7.8	17.3	0.75	1.0	22.6	8.2	20.4 ± 0.7	13.28

TABLE 10 Transitions of H_2CO

^aWinnewisser et al. (1979)

Molecule	$\frac{V_{\rm LSR}{}^{\rm a}}{\rm (km~s^{-1})}$	$\begin{array}{c} \Delta V_{\rm FWHM}{}^{\rm a} \\ (\rm km~s^{-1}) \end{array}$	${{ m T_{rot}}^{ m b}}$ (K)	$\frac{\rm N^b}{\rm (cm^{-2})}$	${{ m T_{rot}}^{\sf c}}$ (K)	${ m N^c} \ ({ m cm}^{-2})$	References ^d
C_2H_5CN	5.3 ± 1.8	12.9 ± 2.7					
CH ₃ CN	7.0 ± 1.4	9.5 ± 2.7	273	$1.3 imes 10^{15}$	77-274	$0.6 - 6.5 imes 10^{16}$	$2,\!4,\!5,\!6$
CH ₃ OCH ₃	8.0 ± 0.8	4.9 ± 1.4					
H_2CO	8.8 ± 0.1	5.3 ± 0.5	10	$1.6 imes 10^{14}$	40	2.4×10^{14}	5
	7.7 ± 0.7	17.4 ± 2.4					
HCOOCH_3	8.2 ± 0.8	5.1 ± 1.9	22	2.3×10^{15}	22-90	$0.3 - 3.0 imes 10^{15}$	$4,\!5,\!6$
			18	$2.6 imes 10^{14}$			
SO_2	6.8 ± 0.9	19.0 ± 7.0	120	$1.7 imes 10^{16}$	106 - 150	$1.5 - 3.0 imes 10^{16}$	$1,\!4,\!5,\!6$
	15.0 ± 3.5	22.5 ± 8.4					
NO	8.2 ± 0.4	9.9 ± 0.7					
CH_3OH	7.8 ± 1.1	6.4 ± 1.6	158	$1-2\times 10^{16}$	114 - 192	$0.8 - 30 imes 10^{16}$	$3,\!5,\!6,\!7$
$^{13}\mathrm{CH}_{3}\mathrm{OH}$	8.0 ± 0.9	5.9 ± 1.6	40	$1.2 imes 10^{14}$	130 - 180	$4.2 - 50 imes 10^{14}$	7
\mathbf{CS}	8.3 ± 0.0	5.7 ± 0.1	65	$2.0 imes 10^{14}$			
	6.3 ± 0.5	24.1 ± 1.6					
^{13}CS	9.0 ± 0.2	5.3 ± 0.4					
$C^{34}S$	9.1 ± 0.1	5.2 ± 0.2	65	$1.1 imes 10^{13}$			
$C^{33}S$	8.1 ± 0.4	5.3 ± 0.9					
H_2CCO	7.8 ± 0.5	4.1 ± 0.0					
H_2CS	8.7 ± 0.1	5.7 ± 0.4					
C_2H_5OH	9.8 ± 0.8	7.3 ± 2.4					
CH_2CHCN	9.3 ± 0.3	2.1 ± 0.2					
DCN	8.3 ± 0.1	7.5 ± 0.2					
HC_3N	8.7 ± 0.1	5.8 ± 0.3				•••	
	5.6 ± 0.8	17.2 ± 1.8				•••	
OCS	7.8 ± 0.3	6.5 ± 0.8				•••	
	5.5 ± 0.6	15.8 ± 1.2					

TABLE 11 Physical Quantities

^aThese were obtained from the Gaussian fit of the spectra. In case of molecules with multi line detections the average values are given.

 $^{\rm b}{\rm This}$ study. ${\rm T}_{\rm ex}$ for CS was adopted from Shutton et al. (1995)

^cOther studies ^d1-Schloerb et al (1983), 2-Johanson et al. (1984), 3-Sutton et al. (1985), 4-Blake et al. (1986), 5-Turner (1991), 6-Ziurys & McGonagle (1993), 7-Sutton et al. (1995)

Frequency (MHz)	Molecule	$\frac{V_{\rm LSR}}{\rm (km~s^{-1})}$	$\frac{\Delta V_{FWHM}}{(\rm km~s^{-1})}$		${f T}^*_{ m A}\ ({ m K})$
138739.3	^{13}CS	9.0	5.3	3.2 ± 0.2	0.56
144617.1	$C^{34}S$	9.1	5.2	6.9 ± 0.3	1.23
145755.6	$\rm C^{33}S$	8.1	5.0	1.0 ± 0.2	0.19
146969.0	\mathbf{CS}	8.2	5.5	37.7 ± 0.5	6.46
		6.5	21.5	28.4 ± 1.2	1.24

TABLE 12TRANSITIONS OF CS

Frequency (MHz)	$\Delta \mathrm{V_{FWHM}}\ \mathrm{(km\ s^{-1})}$	${f T}^*_{ m A}$ (K)	$\int T_A^* dv$ (K km s ⁻¹)
129950.0	0.1	0.10 ± 0.02	0.80
138239.9	8.1 8.4	0.10 ± 0.03	0.89
138343.2	8.4 0.2	0.09 ± 0.03	0.81
130390.4	9.5	0.13 ± 0.03 0.00 ± 0.02	1.29
139230.7	10.2	0.09 ± 0.02 0.10 ± 0.02	0.93
139410.9	7.0 11.1	0.10 ± 0.02 0.14 ± 0.01	1.80
139432.3	77	0.14 ± 0.01 0.14 ± 0.02	1.00
139450.0	1.1	0.14 ± 0.02 0.32 ± 0.02	1.10
139501.9	4.0	0.32 ± 0.02 0.13 ± 0.02	1.00
139362.1	4.9	0.13 ± 0.02 0.08 ± 0.02	1.47
139802.3	17.5	0.08 ± 0.02 0.10 ± 0.02	1.47
140174.6	5.4	0.10 ± 0.02 0.08 ± 0.02	0.47
141646 5	5.4 6.3	0.03 ± 0.02 0.13 ± 0.04	0.47
141040.5 141083.7	2.8	0.15 ± 0.04 0.36 ± 0.04	1.07
143006 7	2.0	0.30 ± 0.04 0.20 ± 0.06	0.73
143263 3	9.5	0.20 ± 0.00 0.07 ± 0.03	0.75
143821.6	3.8	0.01 ± 0.03 0.20 ± 0.04	0.10
144267.0	21.3	0.11 ± 0.03	2 40
144351 4	9.0	0.11 ± 0.03 0.14 ± 0.03	1 34
1443702	14.6	0.11 ± 0.00 0.13 ± 0.04	2.04
145876.2	11.8	0.15 ± 0.05	1.89
146129.6	9.0	0.17 ± 0.05	1.62
146372.4	5.4	0.42 ± 0.06	2.40
146622.4	7.3	0.74 ± 0.09	5.73
146984.5	2.0	0.38 ± 0.06	0.82
147112.9	13.1	0.16 ± 0.07	2.20
147759.8	17.6	0.34 ± 0.03	6.38
147943.7	5.1	0.30 ± 0.03	1.65
	13.4	0.09 ± 0.03	1.35
147979.7	5.6	0.14 ± 0.02	0.85
148249.2	5.8	0.16 ± 0.04	0.97
150155.3	13.1	0.08 ± 0.03	1.08
150186.7	9.3	0.10 ± 0.04	0.97

TABLE 13 UNIDENTIFIED LINES^a

^a All parameters were obtained from Gaussian fit. Note U147943.7 has two velocity components.