

# Isotopic ethyl cyanide $^{13}\text{CH}_3\text{CH}_2\text{CN}$ , $\text{CH}_3^{13}\text{CH}_2\text{CN}$ , and $\text{CH}_3\text{CH}_2^{13}\text{CN}$ : laboratory rotational spectrum and detection in Orion<sup>★,★★</sup>

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## ABSTRACT

**Context.** Astronomical spectra of hot molecular clouds in the wavelength range from centimeter to submillimeter show a huge number of rotational lines due to the emission of complex organic molecules, and a large fraction of these lines are unidentified. The assignment of these unidentified lines to new molecules, to known molecules in excited states, or to their isotopologues requires a good knowledge of the spectroscopic parameters of these molecules.

**Aims.** We present the experimental study of the spectroscopic properties of  $^{13}\text{C}$ -substituted ethyl cyanide  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ ,  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ , and  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ .

**Methods.** The rotational spectra of the three species in the ground state have been measured in the frequency ranges from 5 to 26 GHz using waveguide Fourier transform spectrometers and from 160 to 360 GHz using a source-modulated spectrometer employing backward-wave oscillators (BWOs).

**Results.** A new accurate set of spectroscopic constants has been determined for each isotopic species. This permits prediction of the position of rotational lines that are best suited for detection with an accuracy of a few hundreds of kHz. The three isotopologues have been detected in an Orion IRc2 IRAM survey via several hundred of lines, illustrating that many “unidentified” bands are definitely due to isotopologues of known molecules.

**Key words.** line: identification – methods: laboratory – molecular data – ISM: molecules – radio lines: ISM – submillimeter

## 1. Introduction

Radio spectra of hot molecular clouds (HMCs) exhibit thousands of rotational lines due to the emission of the molecules present in the clouds. Numerous spectral surveys of the chemically richest HMCs (e.g. in Orion, Sagittarius, etc.) have been performed in all the atmospheric spectral windows from 8 to 950 GHz (e.g. Nummelin et al. 1998; Schilke et al. 2001; White et al. 2003; Comito et al. 2005). These surveys show that the spectra are very dense. A large number of molecules have been identified in HMCs and are responsible for the observed emission lines. A non-exhaustive list of complex molecules detected in HMCs includes methyl formate ( $\text{CH}_3\text{OCHO}$ ), acetic acid ( $\text{CH}_3\text{COOH}$ ), glycolaldehyde ( $\text{CH}_2\text{OHCHO}$ ), dimethyl-ether ( $\text{CH}_3\text{OCH}_3$ ), methyl cyanide ( $\text{CH}_3\text{CN}$ ), and ethyl cyanide ( $\text{CH}_3\text{CH}_2\text{CN}$ ).

Most of these molecules have also been detected in warm gas around the low-mass protostar IRAS16293-2442

(Cazaux et al. 2003). Some molecules with a large spatial scale have been detected recently in emission and/or absorption: propenal ( $\text{CH}_2\text{CHCHO}$ ) and propanal ( $\text{CH}_3\text{CH}_2\text{CHO}$ ) (Hollis et al. 2004a), acetamide ( $\text{CH}_3\text{CONH}_2$ ) (Hollis et al. 2006), and glycolaldehyde (Hollis et al. 2004b). Because of the high temperature in HMCs, the low-lying vibrational or torsional state of large molecules can be significantly populated. Transitions from these vibrationally excited states have been detected in Sgr B2(N-LMH) for  $\text{C}_2\text{H}_3\text{CN}$ ,  $\text{CH}_3\text{CH}_2\text{OH}$  (Nummelin et al. 1998), or  $\text{CH}_3\text{CH}_2\text{CN}$  (Merhinger et al. 2004). Finally, isotopic species of the most abundant molecules such as CO, SO,  $\text{SO}_2$ ,  $\text{CH}_3\text{OH}$ ,  $\text{H}_2\text{CO}$ ,  $\text{NH}_3$ , HNC,  $\text{CH}_3\text{CN}$ ,  $\text{HC}_3\text{N}$ , are commonly observed in various astrophysical environments (e.g., Comito et al. 2005; Friedel et al. 2004 for HMCs).

However, a large number of lines in the interstellar spectra remain unidentified. In the Lovas catalogue (Lovas 2004), the unidentified lines (hereafter “U” lines) represent 16% of the observed lines. In most recent surveys of Orion KL and Sgr B2(N), the percentage of unidentified lines is about 8 to 20% (e.g. Nummelin et al. 1998; Schilke et al. 2001; Comito et al. 2005). However, the 3 mm survey of Sgr B2(N) performed by Friedel et al. (2004) with the BIMA array, in which 55% of the observed lines are unidentified, shows that the number of

\* Full Tables 6–8 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.125.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/466/255>

\*\* Tables 3–5, 9–11 and a sample page of Tables 6–8 are only available in electronic form at <http://www.aanda.org>

“U” lines tends to increase with higher sensitivity and smaller beam size, since spectral confusion is avoided and more (weak) lines are consequently observed. These “U” lines can be due (i) to new molecules, (ii) to vibrationally excited transitions from abundant molecules present in the ground state, (iii) to isotopologues of abundant molecules. However, at the moment, the lack of experimental data on excited states and isotopologues of large molecules prevents their identification in interstellar spectra. Since they contribute to the spectral congestion of the mm and submm spectra, it thus appears important to be able to identify these “U” lines confidently. This will “clean” the spectra and thus ease the search for new molecules. It will also give interesting information on the physical conditions and on the chemical processing going on in the HMCs. If the lines are due to excited state emission from known molecules, it allows us to trace the deepest regions of the clouds. The study of isotopologues gives information on the isotopic ratios and precise determination of abundances.

We present here an experimental study of the ground-state rotational spectrum of  $^{13}\text{C}$ -substituted ethyl cyanide ( $\text{CH}_3\text{CH}_2\text{CN}$ ). Ethyl cyanide is an abundant molecule observed in several hot molecular clouds via several hundreds of lines in the frequency range from 40 to 950 GHz. In hot molecular clouds, its column density is of the order of  $10^{15}$ – $10^{17}$   $\text{cm}^{-2}$  (Mehring & Snyder 1996; Miao & Snyder 1997). Mehringer et al. (2004) have detected transition from the first bending and torsional excited state of ethyl cyanide in Sgr B2(N-LMH). It has also been detected in the low-mass star-forming region IRAS 16293 with an abundance of about  $9 \times 10^{14}$   $\text{cm}^{-2}$  (Cazaux et al. 2003). The  $^{13}\text{C}$ -substituted ethyl cyanide dipole moment, which can be approximated to the value of the  $^{12}\text{C}$  species,  $\mu_a = 3.85$  Debye and  $\mu_b = 1.23$  Debye (Heise et al. 1973), is large. Consequently, lines from isotopologues of ethyl cyanide are intense and should be observable towards sources having a large amount of ethyl cyanide, such as Orion or Sgr B2.  $^{13}\text{C}$ -substituted ethyl cyanide has been studied by Heise et al. (1973). They measured a few small- $J$  transitions in the microwave range (8–40 GHz) of  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ ,  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ , and  $\text{CH}_3\text{CH}_2^{13}\text{CN}$  and deduced the rotational constants and the quadrupole coupling constant for each species. In order to be able to calculate reliable prediction of the line positions at high frequency, we performed new measurements of these species in the 8–26 GHz and in the 160–360 GHz frequency range. The experimental setup is presented in Sect. 2, the data analysis and the results, in Sect. 3, and both are discussed in Sect. 4. The detection of the three isotopologues in Orion IRC2 is presented in Sects. 5 and 6.

## 2. Experiments

The samples of the isotopic ethyl cyanides  $^{13}\text{CH}_3\text{CH}_2\text{CN}$  and  $\text{CH}_3^{13}\text{CH}_2\text{CN}$  were prepared from the corresponding  $^{13}\text{C}$ -substituted ethyl iodides,  $^{13}\text{CH}_3\text{CH}_2\text{I}$  and  $\text{CH}_3^{13}\text{CH}_2\text{I}$  (both 90% C-13, Sharp & Dohme, München), respectively, by a modified Kolbe-reaction (Autorenkollektiv, Organikum (8. Auflage), S.202, VEW Deutscher Verlag der Wissenschaften, Berlin 1968). For the species,  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ , normal ethyl iodide from Merck (Darmstadt) and  $\text{Na}^{13}\text{CN}$  was used. For all three syntheses, sodium cyanide was dispersed in a solution of the ethyl iodide in triethyleneglycol at room temperature. The mixture was then heated slowly to 110 °C and held at this temperature for 1 h. A magnetic stirrer was used to keep sodium cyanide well-dispersed throughout the mixture. The final

product was isolated by distillation in vacuum and dried over  $\text{P}_2\text{O}_5$ . The purity of the sample was controlled gas chromatographically and the impurities found were isonitrile and ethyliodide. The sample purity of the ethylcyanide was ca. 99.5%, so that additional purification was unnecessary.

In Kiel, the measurements in the centimeter-wave range were performed by means of microwave Fourier transform spectroscopy. Spectrometers in the ranges 8–18 GHz and 18–26.5 GHz were used, employing sample cells with a rectangular waveguide of length 12 m (Krüger et al. 1993; Sarka et al. 1997) and a circular waveguide cell of length 36 m (Meyer et al. 1991), respectively. The experiments were carried out at an ambient temperature and at gas pressures of ca. 0.1–0.2 Pa. Experimental transition frequencies were obtained from an analysis of the frequency-domain signals as obtained after Fourier transformation of the transient emission signal, using a peak-finder routine that yields line-center frequencies with an accuracy typically better than 20 kHz, depending on the strength of the line. In case of observed line splittings due to methyl internal rotation (AE-splittings), as well as the  $^{14}\text{N}$ -nuclear quadrupole coupling, the experimental peak frequencies were corrected to obtain hypothetical unsplit line frequencies (without nuclear quadrupole hyperfine structure) for the A-species of internal rotation.

The millimeter spectra were recorded in the spectral range 160–360 GHz using a source-modulated spectrometer employing phase-stabilized backwardwave oscillators (Russian Istok backwardwave oscillators). The signal was detected on an InSb He-cooled bolometer (see e.g. Willaert et al. 2006, for more details on the experimental setup). The accuracy of the measurements is better than 100 kHz. The measurements were performed at room temperature. The pressure in the absorption cell (stainless steel, 6 cm in diameter, 110 cm long) was about 20 mTorr (2.6 Pa) and typical line width was 700 kHz (*FWHM*).

## 3. Analysis

For each species, the rotational spectrum was fitted to a Watson’s Hamiltonian using A and S-reduction in  $I'$  representation (Watson 1977) and the spectroscopic parameters in both A and S reduction were determined (see Tables 1 and 2). The initial prediction of the millimeter spectrum was calculated from the rotational parameters (in A reduction) determined from previous spectroscopic measurements by Heise et al. (1973), and the quartic constants of the parent species were used. The prediction was then improved step by step as new identified lines were added to the fit. The same procedure was also used for the analysis of the microwave measurements, which was done separately first. Then the two sets of lines were fitted together using the calculated unsplit frequencies for lines with observed hyperfine structure and/or internal rotational splitting.

As in the case of  $^{12}\text{C}$ -ethyl cyanide,  $^{13}\text{C}$ -isotopologues of ethyl cyanide show a very dense and intense spectrum. Furthermore, the spectra are probably contaminated by lines from the main species and/or by lines from the low-frequency vibrationally excited states. Consequently, the measured spectra show a lot of lines, a large number of which appear to be blended or distorted. Such lines were not included in the fit. The experimental uncertainty of the measured lines was fixed to 20 kHz for the microwave data (below 40 GHz) and to 50 kHz for the millimeter data, except for few lines where it was fixed to 100 kHz (lines labelled with a star in the tables).

The spectroscopic parameters derived for each species and their uncertainty are presented in Tables 1 and 2 in S and

**Table 1.** Spectroscopic constants of the ground vibrational state of  $^{13}\text{C}$ - $\text{CH}_3\text{CH}_2\text{CN}$ , S-reduction.

	$^{13}\text{CH}_3\text{CH}_2\text{CN}^{(a)}$		$\text{CH}_3^{13}\text{CH}_2\text{CN}^{(b)}$		$\text{CH}_3\text{CH}_2^{13}\text{CN}^{(c)}$	
	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
$A/\text{MHz}$	27 342.6493	(18)	27 045.8625	(16)	27 635.4314	(17)
$B/\text{MHz}$	4598.04 294	(37)	4697.93 650	(36)	4689.88 817	(27)
$C/\text{MHz}$	4133.76 933	(33)	4207.12 530	(33)	4214.80 409	(25)
$D_J/\text{kHz}$	2.93 368	(28)	2.92 691	(40)	2.96 968	(22)
$D_{JK}/\text{kHz}$	-48.0110	(23)	-44.6051	(16)	-47.4475	(19)
$D_K/\text{kHz}$	546.013	(12)	525.451	(15)	553.632	(40)
$d_1/\text{Hz}$	-662.479	(54)	-684.022	(85)	-676.592	(35)
$d_2/\text{Hz}$	-30.335	(35)	-34.513	(36)	-31.932	(14)
$H_J/\text{Hz}$	0.00 9254	(76)	0.01 044	(15)	0.00 8702	(57)
$H_{JK}/\text{Hz}$	-0.12 574	(111)	-0.0370	(11)	-0.12 048	(59)
$H_{KJ}/\text{Hz}$	-1.5554	(25)	-1.5755	(36)	-1.5001	(16)
$H_K/\text{Hz}$	30.344	(40)	27.710	(59)	30.26	(27)
$h_1/\text{mHz}$	3.623	(20)	3.883	(48)	3.684	(15)
$h_2/\text{mHz}$	0.386	(19)	0.643	(26)	0.4937	(97)
$h_3/\text{mHz}$	0.0236	(49)	0.0483	(fixed)	0.0484	(27)

Standard deviation of the fits: <sup>(a)</sup> 24 kHz, <sup>(b)</sup> 32 kHz, <sup>(c)</sup> 23 kHz, see text for more details. Uncertainties given in parenthesis are in units of the last digit given, one standard deviation.

**Table 2.** Spectroscopic constants of the ground vibrational state of  $^{13}\text{C}$ - $\text{CH}_3\text{CH}_2\text{CN}$ , A-reduction.

	$^{13}\text{CH}_3\text{CH}_2\text{CN}^{(a)}$		$\text{CH}_3^{13}\text{CH}_2\text{CN}^{(b)}$		$\text{CH}_3\text{CH}_2^{13}\text{CN}^{(c)}$	
	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
$A/\text{MHz}$	27 342.6503	(20)	27 045.8630	(18)	27 635.4303	(19)
$B/\text{MHz}$	4598.06 735	(39)	4697.96 236	(40)	4689.91 341	(31)
$C/\text{MHz}$	4133.74 505	(37)	4207.10 003	(35)	4214.77 921	(29)
$\Delta_J/\text{kHz}$	2.99 463	(31)	2.99 599	(45)	3.03 369	(25)
$\Delta_{JK}/\text{kHz}$	-48.3778	(23)	-45.0189	(17)	-47.8322	(20)
$\Delta_K/\text{kHz}$	546.335	(13)	525.801	(17)	553.930	(45)
$\delta_J/\text{kHz}$	0.66 2503	(56)	0.68 4149	(84)	0.67 6665	(36)
$\delta_K/\text{kHz}$	12.097	(14)	12.749	(14)	12.5104	(59)
$\Phi_J/\text{Hz}$	0.010157	(90)	0.01169	(18)	0.009812	(68)
$\Phi_{JK}/\text{Hz}$	-0.06061	(89)	0.03828	(13)	-0.0852	(35)
$\Phi_{KJ}/\text{Hz}$	-1.7894	(28)	-1.827	(39)	-1.637	(12)
$\Phi_K/\text{Hz}$	30.558	(44)	27.880	(64)	29.95	(30)
$\phi_J/\text{Hz}$	0.003662	(18)	0.003886	(52)	0.003647	(17)
$\phi_{JK}/\text{Hz}$	0.0798	(83)	0.143	(10)	0.1329	(36)
$\phi_K/\text{Hz}$	4.7551	(fixed)	4.7551	(fixed)	2.77	(23)

Standard deviation of the fits: <sup>(a)</sup> 27 kHz, <sup>(b)</sup> 37 kHz, <sup>(c)</sup> 23 kHz, see text for more details. Uncertainties given in parenthesis are in units of the last digit given, one standard deviation.

A-reduction, respectively. They are slightly better-determined in S-reduction than in A-reduction (see below for a detailed discussion for each species). To check this, we used GAUSSIAN 03 (Frisch et al. 2003) to calculate the reduction parameters  $s_{111}$  (Watson 1977) using ab initio (B3LYP/cc-pVTZ) harmonic force field. This parameter is indeed slightly smaller in the S-reduction ( $s_{111}(\text{S}) = 0.11 \times 10^{-6}$ ) than in the A-reduction ( $s_{111}(\text{A}) = 0.34 \times 10^{-6}$ ). Consequently, we present the list of the measured transitions and the results of the fit using S-reduction for the three species. The tables are available as online material (Tables 3–5). In both A and S-reduction, the standard deviation of the fits is within the experimental uncertainty (see below).

For  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ , 193 lines were included in the fit (Table 3), including  $\mu_a$  and  $\mu_b$  transitions (136 and 57, respectively). Twenty-three lines are fitted below 40 GHz with  $0 \leq J \leq 33$  and with a  $K_a$  value up to 8. In the 160–360 GHz frequency range, 170 lines are assigned with  $10 \leq J \leq 51$  and with a  $K_a$  value up to 24. The standard deviation of the fit in S-reduction is 24 kHz. All the S-parameters are well-determined. In A-reduction, using the same list of measured

lines, all the parameters are also well-determined except for  $h_K$ , which we fixed to the value of the  $^{12}\text{C}$ -species given by Pearson et al. (1994). The standard deviation of the fit in A-reduction is 27 kHz.

A total of 161 transitions were assigned and included in the fit for  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ , 84  $\mu_a$  transitions, and 77  $\mu_b$  transitions (Table 4). The fit includes 62 lines in the low-frequency range (below 40 GHz) with  $0 \leq J \leq 41$  and a  $K_a$  value up to 8 and 99 lines in the 173–360 GHz frequency range with  $8 \leq J \leq 69$  and a  $K_a$  value up to 32. In S-reduction all the parameters are well-determined except for  $h_3$ . Its value has been fixed to the value of the main isotopic species that was calculated from the parameters in the A-reduction given by Pearson et al. (1994). The resulting fit has a standard deviation of 32 kHz. In A-reduction, all parameters except for  $h_K$  are well-determined. As for  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ , the  $h_K$  value was fixed to the value of the  $^{12}\text{C}$ -species given by Pearson et al. (1994). The standard deviation of the fit in A-reduction is 37 kHz.

For  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ , the fit includes 208 lines, 81  $\mu_a$  transitions, and 127  $\mu_b$  transitions (Table 5). Below 40 GHz, 113 transitions



that for the lines that are the most suitable for detection, i.e. the strongest lines having  $J$  value up to  $\sim 50$  and a low  $K_a$  value, the error on the predicted frequencies is a few hundred kHz, suitable for line identification in the interstellar spectra. The error is larger for the weakest lines and increases as  $J$  and  $K_a$  become larger, i.e., as the frequency increases. Using the SPCAT program from Pickett (1998), we calculated the lines frequency in S-reduction for the three species. The frequencies predicted using A or S-reduction agree within 100 kHz for most of the lines. Only the weakest transitions and transitions with a high  $J$  value show higher discrepancy. However, the frequency difference is smaller than 500 kHz for transitions with  $J \geq 40$  and as high as 1 MHz for  $J \geq 55$ .

## 5. Astronomical observations

The observations were carried out using the IRAM 30 m radio telescope during 2004 September (3 mm and 1.3 mm), 2005 March (2 mm), and 2005 April (3 mm and 1.3 mm). Four SiS receivers operating at 3, 2, and 1.3 mm were used simultaneously. Each receiver was tuned to a single sideband with image rejections within 20–27 dB (3 mm receivers), 12–16 dB (2 mm receivers), and 13 dB (1.3 mm receivers).

System temperatures were 100–350 K for the 3 mm receivers, 200–500 K for the 2 mm receivers and 200–800 K for the 1.3 mm receivers, depending on the observed frequency, the weather, and the source elevation. The intensity scale was calibrated using two absorbers at different temperatures and using the Atmosphere Transmission Model ATM (Cernicharo 1985; Pardo et al. 2001).

Pointing and focus were regularly checked on the nearby quasar 0420-014. The observations were made in the balanced wobbler-switching mode, with a wobbling period of 0.5 Hz and a beam throw of  $\pm 240''$ . The backends were two filter banks with 512 MHz bandwidth and 1 MHz resolution and a correlator divided into two bands of 512 MHz bandwidth and 1.25 MHz resolution. We pointed toward the position  $\alpha = 5^{\text{h}}35^{\text{m}}14.4^{\text{s}}$ ,  $\delta = -5^{\circ}22'30.0\text{s}''$  (2000) corresponding to Orion IRC2. The detailed procedure used for the analysis of the line survey is described in Tercero et al. (in preparation). Figure 1 shows selected lines of the three  $^{13}\text{C}$  isotopologues of  $\text{CH}_3\text{CH}_2\text{CN}$ . Observed parameters for all observed lines of these three isotopologues in the line survey of Tercero et al. (in preparation) are given in Tables 9–11.

## 6. Astronomical modelling

In agreement with previous observations of Orion, four well defined kinematic regions are implied by the observed velocities and line widths: (i) the narrow ambient cloud feature at  $v_{\text{LSR}} \approx 9 \text{ km s}^{-1}$  and characterized by line widths of  $\lesssim 5 \text{ km s}^{-1}$  forming a N-S *extended ridge*; (ii) a quiescent, compact region, *compact ridge*, ( $v_{\text{LSR}} \approx 8 \text{ km s}^{-1}$ ,  $\Delta v \approx 3 \text{ km s}^{-1}$ ) identified for the first time by Johansson et al. (1984); (iii) the more turbulent and compact *plateau* ( $v_{\text{LSR}} \approx 6\text{--}10 \text{ km s}^{-1}$ ,  $\Delta v \gtrsim 25 \text{ km s}^{-1}$ ); (iv) the *hot core* component ( $v_{\text{LSR}} \approx 3\text{--}5 \text{ km s}^{-1}$ ,  $\Delta v \lesssim 10\text{--}15 \text{ km s}^{-1}$ ) first observed in ammonia emission (Morris et al. 1980). These components correspond to regions with differing physical and chemical conditions (Blake et al. 1987, 1996).

In modelling the emission from the isotopologues of  $\text{CH}_3\text{CH}_2\text{CN}$ , we find that a two-component model is enough to reproduce all line intensities and profiles reasonably well: the hot core component and the plateau. For the core a column density of  $1.6 \times 10^{15} \text{ cm}^{-2}$ , a linewidth of  $5 \text{ km s}^{-1}$  and a rotational temperature of 300 K are the best parameters for reproducing the bulk of the ethyl cyanide emission. A broad velocity component is

needed to fully reproduce the observations. It corresponds to the plateau for which we obtain a column density of  $6 \times 10^{13} \text{ cm}^{-2}$ , a rotational temperature of 150 K, and a linewidth of  $20 \text{ km s}^{-1}$ . For the core component we assumed a source with uniform brightness temperature and a diameter of  $7''$  placed  $3''$  from the pointed position (the observations were pointed towards IRC2, while the CN bearing species seems to come from a small region  $3''$  North.) For the plateau component we assumed a size for the source of  $30''$ . A first look at the main isotope's observed lines indicate that the column density to explain them will imply that some lines will not be optically thin and the derived isotopic  $^{12}\text{C}/^{13}\text{C}$  abundance ratio could be  $>30$ . The detailed modelling of ethyl cyanide including the main isotope, the vibrationally excited states, and all spectroscopically known isotopologues, will be published elsewhere (Tercero et al. in preparation).

Figure 1 shows selected observed lines of the three  $^{13}\text{C}$  isotopologues, together with the model results. It can be seen that the agreement between observations and the model is very good. Tables 9–11 gives the model predictions, observed intensities and frequencies, and predicted frequencies from the rotational constants obtained in this paper, for all lines of the three isotopes that are not strongly blended with other lines. It is worth noting that the three isotopologues of ethyl cyanide contribute with more than 700 lines in the 80–280 GHz domain covered by the Orion line survey of Tercero et al. (in preparation).

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## Online Material

**Table 3.** Measured transitions of the ground vibrational state of  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ .

$J'$	Transition					Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
	$K'_a$	$K'_c$	$J''$	$K''_a$	$K''_c$					
1	0	1	0	0	0	8731.787	-0.014	1.0000	a	0.291
13	2	11	13	2	12	8820.637	-0.001	0.5509	a	29.814
6	1	5	6	1	6	9741.825	0.002	0.3102	a	7.042
22	3	19	22	3	20	10142.777	-0.036	0.7152	a	81.064
14	2	12	14	2	13	11484.067	0.010	0.5035	a	33.963
23	3	20	23	3	21	12811.652	0.004	0.6706	a	87.863
30	5	26	29	6	23	12888.797	-0.035	4.7812	b	154.899
7	1	6	7	1	7	12981.545	-0.010	2.6900	a	9.131
4	0	4	3	1	3	13241.366	-0.045	1.6139	b	2.909
30	5	25	29	6	24	13523.629	0.015	4.7844	b	154.919
15	2	13	15	2	14	14614.108	0.018	0.4619	a	38.414
33	4	29	33	4	30	15275.167	0.002	0.8033	a	176.688
8	1	7	8	1	8	16676.336	0.006	0.2378	a	11.518
2	1	2	1	1	1	16999.464	-0.007	1.5000	a	1.617
2	0	2	1	0	1	17456.478	-0.017	1.9998	a	0.874
2	1	1	1	1	0	17927.960	-0.015	1.5000	a	1.663
1	1	0	1	0	1	23208.440	0.013	1.5000	b	1.065
2	1	1	2	0	2	23679.910	0.003	2.4746	b	1.663
3	0	3	2	0	2	26167.010	0.018	2.9994	a	1.746
3	2	2	2	2	1	26196.320	0.045	1.6667	a	4.813
3	2	1	2	2	0	26224.320*	-0.077	1.6667	a	4.814
1	1	1	0	0	0	31475.950	-0.010	1.0000	b	1.050
2	1	2	1	0	1	39743.600	-0.029	1.5000	b	1.617
19	1	19	18	1	18	160026.237	0.003	18.9300	a	54.353
19	0	19	18	0	18	160670.979	-0.076	18.9406	a	54.251
19	1	19	18	0	18	163749.602	0.001	14.9503	b	54.353
19	2	18	18	2	17	164569.131	0.031	18.7719	a	58.174
19	8	12	18	8	11	166089.133	0.031	15.6320	a	104.369
19	9	11	18	9	10	166093.022	0.011	14.7372	a	117.359
19	7	13	18	7	12	166101.509	-0.012	16.4214	a	92.902
19	10	9	18	10	8	166108.275	-0.031	13.7372	a	131.866
19	11	9	18	11	8	166132.304	0.077	12.6319	a	147.887
19	6	14	18	6	13	166139.856	-0.021	17.1056	a	82.962
19	12	7	18	12	6	166163.093	-0.034	11.4213	a	165.416
19	13	6	18	13	5	166199.966	-0.001	10.1055	a	184.449
19	5	15	18	5	14	166223.974	0.022	17.6844	a	74.555
19	5	14	18	5	13	166226.873	-0.025	17.6844	a	74.55
19	14	6	18	14	5	166242.075	0.009	8.6844	a	204.980
19	15	4	18	15	3	166288.950	-0.004	7.1581	a	227.003
19	3	17	18	3	16	166292.896	0.021	18.5229	a	62.338
19	16	3	18	16	2	166340.300	0.001	5.5265	a	250.513
19	17	2	18	17	1	166395.875	0.018	3.7896	a	275.503
19	18	2	18	18	1	166455.400	-0.042	1.9474	a	301.966
19	4	15	18	4	14	166456.762	-0.036	18.1576	a	67.699
19	3	16	18	3	15	167484.066	-0.007	18.5249	a	62.490
19	1	18	18	1	17	167617.028	-0.016	18.8983	a	57.137
19	2	17	18	2	16	169635.261	-0.010	18.7983	a	59.240
51	6	45	51	5	46	200312.750	0.018	33.3052	b	415.494
25	1	24	24	2	23	200333.644	0.005	12.6546	b	96.551
24	0	24	23	1	23	200393.875	0.007	20.0546	b	85.159
10	3	8	9	2	7	200679.951	0.022	3.6961	b	22.931
31	11	21	32	10	22	200714.382	-0.015	3.6058	b	237.128
38	3	36	38	2	37	200763.718	-0.012	14.0305	b	222.469
27	5	22	27	4	23	200800.625	-0.013	14.7565	b	129.471
26	5	21	26	4	22	201821.081	0.030	14.0988	b	121.578
47	3	44	47	2	45	202443.284	0.054	21.9164	b	340.449
36	12	25	37	11	26	202489.130	0.029	4.3788	b	304.243
29	2	27	28	3	26	202590.950	0.012	8.6623	b	132.075
41	13	29	42	12	30	204255.377	-0.021	5.1537	b	380.156
46	14	32	47	13	35	206025.390	0.023	5.9295	b	464.859
25	10	16	26	9	17	207666.029	-0.071	2.6210	b	171.235
51	15	36	52	14	39	207810.182	0.048	6.7058	b	558.346
35	12	23	36	11	26	211217.493	-0.008	4.1583	b	293.745
40	13	27	41	12	30	212966.680	-0.029	4.9322	b	368.202
45	14	31	46	13	34	214714.901	0.030	5.7075	b	451.450
50	15	35	51	14	38	216473.279	-0.005	6.4834	b	543.483

Table 3. continued.

$J'$	$K'_a$	Transition				Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
		$K'_c$	$J''$	$K''_a$	$K''_c$					
47	6	41	47	5	42	217173.407	-0.017	28.7146	b	357.302
29	11	18	30	10	21	218192.084	-0.001	3.1696	b	219.339
34	12	22	35	11	25	219942.900	0.044	3.9387	b	283.539
46	6	40	46	5	41	220951.757	0.012	27.7406	b	343.509
39	13	26	40	12	29	221675.619	0.008	4.7113	b	356.539
44	14	30	45	13	33	223402.661	-0.002	5.4858	b	438.332
45	6	39	45	5	40	224476.868	0.008	26.8213	b	330.016
49	15	34	50	14	37	225135.488	0.038	6.2613	b	528.911
54	16	38	55	15	41	226884.609	0.007	7.0372	b	628.266
28	11	17	29	10	20	226925.942	0.035	2.9537	b	210.882
50	3	47	50	2	48	228283.377	0.014	21.6854	b	383.454
33	12	21	34	11	24	228665.396	-0.064	3.7200	b	273.624
38	13	25	39	12	28	230382.355	0.005	4.4910	b	345.167
43	14	29	44	13	32	232088.953	0.007	5.2645	b	425.504
48	15	33	49	14	36	233796.798	-0.006	6.0394	b	514.628
28	1	28	27	1	27	234578.709	0.052	27.9332	a	114.840
28	0	28	27	0	27	234693.820	0.039	27.9342	a	114.825
53	16	37	54	15	40	235516.628	-0.073	6.8150	b	612.531
51	3	48	51	2	49	236657.801	-0.033	21.6461	b	398.325
28	2	27	27	2	26	240526.912	-0.011	27.8099	a	120.284
28	1	27	27	1	26	242178.053	0.020	27.8373	a	119.968
28	3	26	27	3	25	244390.469	0.044	27.6593	a	125.318
28	10	19	27	10	18	244788.651	0.029	24.4292	a	194.856
28	9	19	27	9	18	244799.020	0.072	25.1078	a	180.347
28	11	18	27	11	17	244799.620	-0.049	23.6792	a	210.882
28	12	16	27	12	15	244826.863	0.030	22.8577	a	228.420
28	8	21	27	8	20	244839.562	0.040	25.7149	a	167.363
28	13	16	27	13	15	244866.876	0.047	21.9649	a	247.465
28	14	15	27	14	14	244917.512	0.001	21.0005	a	268.010
28	7	21	27	7	20	244926.445	-0.062	26.2505	a	155.910
28	15	13	27	15	12	244977.411	-0.008	19.9648	a	290.050
28	16	12	27	16	11	245045.511	-0.021	18.8576	a	313.578
28	6	23	27	6	22	245089.645	0.043	26.7147	a	146.000
28	6	22	27	6	21	245094.088	0.040	26.7147	a	146.000
28	17	11	27	17	10	245121.106	-0.004	17.6790	a	338.588
28	18	11	27	18	10	245203.596	-0.009	16.4290	a	365.073
28	19	9	27	19	8	245292.588	-0.009	15.1075	a	393.026
28	5	24	27	5	23	245363.475	-0.051	27.1070	a	137.648
28	20	9	27	20	8	245387.747	-0.013	13.7146	a	422.440
28	5	23	27	5	22	245457.481	-0.067	27.1070	a	137.658
28	21	8	27	21	7	245488.826	-0.005	12.2503	a	453.306
28	4	25	27	4	24	245535.703	0.032	27.4254	a	130.841
28	22	7	27	22	6	245595.604	0.007	10.7145	a	485.618
28	23	6	27	23	5	245707.909	0.032	9.1074	a	519.365
28	24	4	27	24	3	245825.528	0.011	7.4288	a	554.541
28	4	24	27	4	23	246658.154	0.028	27.4273	a	131.000
28	2	26	27	2	25	248935.085	-0.012	27.8281	a	123.487
30	6	24	30	5	25	249174.110	-0.080	16.0047	b	163.231
31	6	26	31	5	27	249416.860	0.010	16.6299	b	172.285
28	3	25	27	3	24	249580.945	-0.017	27.6940	a	126.437
29	6	23	29	5	24	249657.780	0.002	15.3741	b	154.469
30	6	25	30	5	26	249761.030	-0.005	15.9963	b	163.230
30	3	28	29	3	27	261540.610	-0.025	29.6744	a	142.480
30	13	18	29	13	17	262339.703	-0.011	24.3673	a	264.675
30	6	24	29	6	23	262678.575	0.028	28.8004	a	163.231
30	5	26	29	5	25	262991.196	0.069	15.3004	a	154.899
30	4	27	29	4	26	263084.417	0.009	29.4619	a	148.100
30	5	25	29	5	24	263162.025*	-0.109	29.1664	a	146.14
31	2	30	30	2	29	265544.775	-0.021	30.8126	a	146.023
30	2	28	29	2	27	265968.621	-0.023	29.8165	a	140.947
31	1	30	30	1	29	266639.175*	0.119	30.8263	a	136.94
32	0	32	31	1	31	267416.117	-0.006	28.1913	b	139.97
32	1	32	31	1	31	267600.895	-0.014	31.9332	a	139.97
32	0	32	31	0	31	267648.854	-0.010	31.9335	a	139.96
32	1	32	31	0	31	267833.634	-0.016	28.1937	b	139.96
31	3	29	30	3	28	270083.054	0.007	30.6805	a	142.48



Table 3. continued.

$J'$	Transition						Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
	$K'_a$	$K'_c$	$J''$	$K''_a$	$K''_c$						
31	10	22	30	10	21	271014.330	0.003	27.7749	a	212.06	
31	11	21	30	11	20	271015.430	0.008	27.0975	a	228.09	
31	4	28	30	4	27	271843.387	-0.006	30.4780	a	148.10	
31	5	26	30	5	25	272034.865	-0.018	30.1932	a	154.92	
32	2	31	31	2	30	273858.241	0.012	31.8130	a	146.02	
31	4	27	30	4	26	273902.663	-0.034	30.4840	a	148.36	
31	2	29	30	2	28	274393.857	-0.002	30.8089	a	140.95	
32	1	31	31	1	30	274796.266	-0.004	31.8238	a	145.83	
33	0	33	32	1	32	275703.647	-0.018	29.2011	b	148.89	
33	1	33	32	0	32	276034.933	-0.011	29.2029	b	148.89	
32	3	30	31	3	29	278603.322	-0.029	31.6858	a	151.49	
32	12	21	31	12	20	279772.356	0.006	27.5007	a	254.67	
32	14	19	31	14	18	279859.510	-0.018	25.8757	a	294.27	
32	16	16	31	16	15	279995.091	-0.020	24.0006	a	339.85	
32	6	27	31	6	26	280262.780	0.001	30.8754	a	172.28	
32	19	13	31	19	12	280267.080	-0.046	20.7193	a	419.32	
32	6	26	31	6	25	280281.703	-0.002	30.8754	a	172.29	
32	4	29	31	4	28	280589.844	-0.010	31.4929	a	157.17	
32	5	28	31	5	27	280626.915	-0.006	31.2181	a	163.97	
32	5	27	31	5	26	280923.629	-0.001	31.2183	a	163.99	
33	2	32	32	2	31	282160.483	0.016	32.8132	a	155.16	
32	2	30	31	2	29	282759.346	-0.006	31.8004	a	150.10	
33	1	32	32	1	31	282958.925	0.008	32.8217	a	155.00	
32	4	28	31	4	27	283048.455	-0.007	31.5014	a	157.50	
34	1	34	33	1	33	284097.236	-0.014	33.9331	a	158.09	
34	0	34	33	0	33	284127.747	-0.021	33.9333	a	158.09	
33	9	25	32	9	24	288537.625	-0.043	30.5462	a	225.552	
33	13	20	32	13	19	288542.025	0.023	27.8795	a	292.675	
33	8	26	32	8	25	288624.850*	-0.076	31.0614	a	202.95	
33	2	31	32	2	30	291067.998	-0.005	32.7913	a	169.241	
34	3	32	33	3	31	295577.772	-0.010	33.6941	a	180.218	
34	4	31	33	4	30	298038.650	-0.017	33.5192	a	186.119	
34	5	30	33	5	29	298264.398	-0.001	33.2636	a	192.930	
35	2	34	34	2	33	298735.381	0.031	34.8133	a	184.223	
35	1	34	34	1	33	299303.327	0.005	34.8185	a	184.134	
35	2	33	34	2	32	307534.084	0.001	34.7726	a	189.483	
37	2	36	36	2	35	315276.922	0.004	36.8129	a	204.920	
36	6	31	35	6	30	315491.883	0.054	35.0003	a	221.965	
36	6	30	35	6	29	315558.436*	0.110	35.0004	a	211.45	
37	1	36	36	1	35	315672.795	0.017	36.8162	a	204.920	
36	5	32	35	5	31	315894.994	0.005	35.3038	a	213.710	
38	1	38	37	1	37	317066.100	0.025	37.9329	a	208.226	
38	0	38	37	0	37	317078.208	0.027	37.9330	a	208.225	
38	1	38	37	0	37	317123.217	0.011	34.2383	a	208.226	
15	5	10	14	4	11	337515.735*	0.087	6.0893	b	42.87	
44	3	41	43	4	40	338832.968	-0.028	14.1851	b	299.871	
38	8	31	38	7	32	341597.080	-0.071	19.8804	b	265.100	
37	8	29	37	7	30	341845.924	0.010	19.2632	b	254.001	
37	8	30	37	7	31	341861.311*	-0.104	19.2631	b	242.61	
41	2	40	40	2	39	348284.689	0.025	40.8117	a	249.800	
41	1	40	40	1	39	348468.256	0.021	40.8130	a	249.773	
40	4	37	39	4	36	349933.000	-0.017	39.5739	a	251.839	
42	1	42	41	1	41	350005.923	-0.013	41.9328	a	253.278	
42	0	42	41	0	41	350010.627	-0.012	41.9328	a	253.278	
40	6	35	39	6	34	350767.487	0.033	39.1002	a	267.001	
40	6	34	39	6	33	350967.063	0.047	39.1004	a	267.027	
40	5	36	39	5	35	351092.104	-0.002	39.3709	a	258.795	
41	3	39	40	3	38	354343.168	0.004	40.7060	a	257.093	
40	3	37	39	3	36	355723.668	0.024	39.7462	a	249.611	
43	1	43	42	1	42	358236.456	-0.014	42.9327	a	265.228	
43	0	43	42	0	42	358240.157	-0.016	42.9328	a	265.227	

**Table 4.** Measured transitions of the ground vibrational state of  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ .

$J'$	Transition					Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
	$K'_a$	$K'_c$	$J''$	$K''_a$	$K''_c$					
1	0	1	0	0	0	8905.044	-0.006	1.0000	a	0.297
11	1	11	10	2	8	9481.367	-0.008	1.1558	b	19.775
39	5	34	39	5	35	9656.697	-0.019	1.0887	a	251.698
13	2	11	13	2	12	9913.694	0.007	0.5460	a	30.318
30	4	26	30	4	27	10040.036	-0.023	0.9171	a	150.964
6	1	5	6	1	6	10297.775	-0.022	0.3103	a	7.159
10	3	8	11	2	9	10934.004	0.013	1.6211	b	23.135
19	3	17	18	4	14	11641.784	-0.007	2.9697	b	63.330
8	1	7	7	2	6	12005.052	-0.036	1.5239	b	11.728
22	3	19	22	3	20	12116.649	0.002	0.7030	a	82.487
15	4	12	16	3	13	12748.766	0.021	2.3772	b	47.745
14	2	12	14	2	13	12872.438	0.002	0.4983	a	34.556
6	2	4	7	1	7	13027.601	0.011	0.8766	b	9.269
24	4	21	23	5	18	13135.700	0.027	3.7734	b	101.395
34	6	29	33	7	26	13375.237	-0.018	5.3335	b	204.243
12	1	12	11	2	9	13621.397	-0.006	1.1409	b	23.225
20	5	16	21	4	17	13663.533	-0.038	3.1486	b	81.296
7	1	6	7	1	7	13721.366	-0.014	0.2692	a	9.292
25	6	20	26	5	21	14111.813	0.024	3.9224	b	123.786
4	0	4	3	1	3	14383.683	0.011	3.1450	b	2.966
30	7	24	31	6	25	14408.589	0.017	4.6963	b	175.211
35	8	28	36	7	29	14685.542	-0.027	5.4698	b	235.563
35	8	27	36	7	30	14703.948	0.020	5.4697	b	235.563
41	5	36	41	5	37	14828.858	0.006	0.9956	a	276.067
24	4	20	23	5	19	15152.112	0.050	3.7862	b	101.460
15	2	14	14	3	11	15161.704	-0.014	2.2440	b	38.557
23	3	20	23	3	21	15240.446	-0.017	0.6576	a	89.433
32	4	28	32	4	29	15661.815	-0.008	0.8240	a	169.949
2	1	2	1	1	1	17319.429*	0.010	1.5000	a	1.620
2	0	2	1	0	1	17801.970*	-0.064	1.9998	a	0.891
2	1	1	1	1	0	18301.029	0.031	1.5000	a	1.669
24	3	21	24	3	22	18882.863	0.007	0.6153	a	96.692
4	2	3	5	1	4	19620.967	0.032	0.6473	b	5.985
14	1	14	13	2	11	19786.625	-0.014	1.0370	b	30.978
5	2	3	6	1	6	19871.579	0.018	0.7241	b	7.478
16	2	14	16	2	15	20308.852	-0.004	0.4200	a	43.957
20	3	18	19	4	15	20314.677	-0.015	3.1547	b	69.285
9	3	7	10	2	8	21018.173	0.006	1.3911	b	20.160
14	2	12	13	3	11	21138.489	-0.044	2.3321	b	34.556
15	1	15	14	2	12	21749.882	0.018	0.9612	b	35.281
19	1	19	18	2	16	21915.027	-0.007	0.6331	b	55.323
9	1	8	9	1	9	22000.678	-0.017	0.2140	a	14.466
25	4	22	24	5	19	22299.882	-0.002	3.9737	b	108.854
16	2	15	15	3	12	22363.699	-0.026	2.3607	b	43.280
14	4	11	15	3	12	22367.840	0.008	2.1573	b	43.280
30	5	26	29	6	23	22807.601	-0.005	4.7622	b	157.312
1	1	0	1	0	1	22838.291*	-0.007	1.5000	b	1.059
16	1	16	15	2	13	22943.481	-0.002	0.8781	b	39.867
9	1	8	8	2	7	22960.085	0.022	1.8613	b	14.466
18	1	18	17	2	15	23015.849	0.015	0.7106	b	49.888
25	3	22	25	3	23	23066.250	0.016	0.5760	a	104.263
2	1	1	2	0	2	23337.236	-0.026	2.4727	b	1.669
17	1	17	16	2	14	23363.507	-0.003	0.7932	b	44.737
14	4	10	15	3	13	23850.332	0.008	2.1485	b	43.281
3	1	2	3	0	3	24100.582	-0.018	3.4044	b	2.585
5	0	5	4	1	4	24125.648	0.005	2.2277	b	4.446
17	2	15	17	2	16	24800.110	0.002	0.3880	a	49.121
25	4	21	24	5	20	25052.940	0.039	3.9927	b	108.942
4	1	3	4	0	4	25145.986	0.005	4.2789	b	3.805
3	1	3	2	1	2	25974.033	-0.003	2.6666	a	2.487
1	1	1	0	0	0	31252.510*	-0.033	1.0000	b	1.042
2	1	2	1	0	1	39666.830*	-0.082	1.5000	b	1.620
20	1	20	19	0	19	173995.349	0.022	16.1379	b	61.039
20	2	19	19	2	18	176356.794	0.027	19.7769	a	65.074
21	0	21	20	1	20	178081.995	0.020	17.1280	b	66.979
20	9	12	19	9	11	178310.299	-0.005	15.9505	a	123.373

**Table 4.** continued.

$J'$	$K'_a$	Transition					Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
		$K'_c$	$J''$	$K''_a$	$K''_c$						
20	8	13	19	8	12	178315.818	0.001	16.8005	a	110.600	
20	10	11	19	10	10	178318.655	0.013	15.0004	a	137.638	
20	11	10	19	11	9	178337.208	0.038	13.9504	a	153.393	
20	7	14	19	7	13	178341.762	0.019	17.5505	a	99.326	
20	12	8	19	12	7	178363.807*	0.100	12.8004	a	170.631	
20	13	8	19	13	7	178396.995*	0.112	11.5503	a	189.349	
20	6	15	19	6	14	178400.958*	0.118	18.2004	a	89.556	
20	14	7	19	14	6	178435.877	0.081	10.2003	a	209.541	
20	3	18	19	3	17	178510.736	0.040	19.5448	a	69.285	
20	5	16	19	5	15	178518.421	0.009	18.7502	a	81.296	
20	4	17	19	4	16	178701.651	0.042	19.1995	a	74.557	
20	1	19	19	1	18	179348.625	0.016	19.8827	a	64.225	
21	1	21	20	1	20	179811.950	-0.012	20.9295	a	67.037	
21	0	21	20	0	20	180219.881	0.027	20.9348	a	66.979	
20	3	17	19	3	16	180294.217	-0.026	19.5492	a	69.528	
21	1	21	20	0	20	181949.853	0.012	17.1636	b	67.037	
20	2	18	19	2	17	182346.464	-0.001	19.8086	a	66.451	
34	3	32	34	2	33	182384.257	-0.029	13.3793	b	183.493	
16	2	15	15	1	14	182426.658	0.020	6.2256	b	43.280	
23	1	22	22	2	21	184902.128	0.025	11.0620	b	83.871	
21	2	20	20	2	19	184998.569	-0.004	20.7831	a	71.245	
21	9	13	22	8	14	186728.043	0.022	2.0760	b	129.618	
21	9	13	20	9	12	187229.852	0.033	17.1433	a	129.618	
21	10	11	20	10	10	187235.861	0.007	16.2386	a	143.884	
21	8	14	20	8	13	187239.436	-0.003	17.9529	a	116.846	
21	11	10	20	11	9	187253.313	0.006	15.2385	a	159.639	
21	7	15	20	7	14	187272.318	-0.001	18.6671	a	105.573	
21	12	9	20	12	8	187279.700	0.047	14.1433	a	176.878	
21	13	9	20	13	8	187313.411*	0.102	12.9528	a	195.598	
21	14	7	20	14	6	187353.281	0.048	11.6670	a	215.791	
21	15	7	20	15	6	187398.821*	0.104	10.2860	a	237.453	
21	3	19	20	3	18	187400.405*	0.080	20.5649	a	75.536	
21	16	5	20	16	4	187449.377*	0.120	8.8098	a	260.578	
21	5	17	20	5	16	187480.600	0.044	19.8097	a	87.550	
21	5	16	20	5	15	187490.829	0.008	19.8097	a	87.551	
21	4	18	20	4	17	187679.400	-0.012	20.2374	a	80.817	
21	1	20	20	1	19	187870.493	0.024	20.8747	a	70.492	
21	4	17	20	4	16	187900.112	-0.020	20.2375	a	80.841	
21	3	18	20	3	17	189588.113	0.016	20.5716	a	75.852	
21	2	19	20	2	18	191453.322	-0.007	20.8164	a	72.837	
24	1	23	23	2	22	195818.289	0.093	12.0843	b	90.980	
25	5	21	25	4	22	200978.255	-0.078	13.4867	b	115.558	
21	5	16	21	4	17	201170.954	-0.069	11.0038	b	87.551	
25	0	25	24	1	24	212814.767	-0.001	21.2390	b	93.817	
25	1	25	24	1	24	213528.288	-0.015	24.9307	a	93.841	
25	2	24	24	2	23	219359.808	0.006	24.7989	a	98.797	
25	1	24	24	1	23	221481.444	0.016	24.8432	a	98.368	
17	9	9	18	8	10	222436.415	0.018	1.2591	b	106.422	
26	1	26	25	0	25	222657.909	-0.025	22.2678	b	101.244	
27	11	17	28	10	18	222729.986	-0.036	2.7400	b	203.361	
25	3	23	24	3	22	222791.608	-0.006	24.6257	a	103.494	
47	15	33	48	14	34	222874.167	-0.024	5.8161	b	504.293	
25	8	18	24	8	17	222945.684	-0.037	22.4406	a	144.806	
25	6	20	24	6	19	223146.875	0.045	23.5604	a	123.786	
25	5	21	24	5	20	223377.774	-0.034	24.0000	a	115.558	
25	20	5	24	20	4	223408.176*	-0.101	9.0003	a	395.599	
25	5	20	24	5	19	223426.457	-0.029	24.0000	a	115.563	
25	21	4	24	21	3	223492.281	-0.031	7.3602	a	425.950	
25	22	3	24	22	2	223581.060	0.022	5.6402	a	457.722	
25	4	22	24	4	21	223594.357	-0.021	24.3580	a	108.854	
13	3	11	12	2	10	223653.826	-0.054	4.2335	b	33.851	
25	23	3	24	23	2	223674.332	0.028	3.8401	a	490.908	
25	4	21	24	4	20	224297.077	-0.029	24.3588	a	108.942	
30	2	28	29	3	27	226172.501	-0.049	9.9797	b	143.692	
41	4	37	40	5	36	226833.862	0.052	7.5143	b	270.892	
25	3	22	24	3	21	226974.967	-0.026	24.6495	a	104.263	

**Table 4.** continued.

$J'$	$K'_a$	Transition				Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
		$K'_c$	$J''$	$K''_a$	$K''_c$					
25	2	23	24	2	22	227385.495	-0.013	24.8276	a	101.387
8	4	5	7	3	4	229304.243	-0.035	4.0457	b	22.753
8	4	4	7	3	5	229321.787*	0.125	4.0455	b	22.753
11	8	4	12	7	5	231101.016	0.076	0.4208	b	67.780
16	9	8	17	8	9	231353.174	-0.046	1.0673	b	101.366
49	3	46	49	2	47	231542.472*	-0.154	20.8620	b	375.864
13	3	10	12	2	11	231728.449	0.046	4.0071	b	33.872
46	15	32	47	14	33	231731.580	0.025	5.5954	b	490.320
25	2	24	24	1	23	234341.014	0.033	13.4227	b	98.797
27	3	25	26	3	24	240366.920	-0.012	26.6467	a	119.237
27	7	21	26	7	20	240900.160	-0.019	25.1858	a	149.313
27	6	22	26	6	21	241070.960	-0.057	25.6671	a	139.570
27	6	21	26	6	20	241075.450*	-0.084	25.6671	a	139.570
27	5	23	26	5	22	241354.180	-0.053	26.0739	a	131.359
27	5	22	26	5	21	241449.960	-0.036	26.0740	a	131.370
27	4	23	26	4	22	242677.730	-0.063	26.4061	a	124.825
28	5	23	27	5	22	250479.760	-0.071	27.1070	a	139.725
17	3	15	16	2	14	250482.920	0.005	5.0273	b	52.312
30	1	30	29	0	29	255854.360*	-0.084	26.3207	b	133.662
18	3	16	17	2	15	256380.340	0.012	5.2588	b	57.673
15	10	5	16	9	8	284979.200	0.019	0.6624	b	110.872
25	3	23	24	2	22	290534.920	0.000	7.7052	b	103.494
68	7	62	68	6	63	298152.660*	0.064	39.7600	b	736.517
69	7	63	69	6	64	301242.380*	-0.054	40.1274	b	757.101
28	3	26	27	2	25	302996.360	-0.019	9.4131	b	127.546
29	3	27	28	2	26	307130.700	-0.040	10.0946	b	136.147
38	31	7	37	31	6	341021.260	-0.064	12.7109	a	930.840
39	16	23	38	16	22	347838.580*	0.059	32.4369	a	423.970
40	32	8	39	32	7	359108.350	0.046	14.4004	a	1000.083

**Table 5.** Measured transitions of the ground vibrational state of  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ .

$J'$	Transition					Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
	$K'_a$	$K'_c$	$J''$	$K''_a$	$K''_c$					
59	7	52	59	7	53	8039.170	-0.030	1.3896	a	565.494
49	6	43	49	6	44	8092.547	0.007	1.2477	a	393.175
21	3	18	21	3	19	8292.111	-0.039	0.7606	a	75.979
30	4	26	30	4	27	8345.508	-0.052	0.9325	a	151.184
47	10	38	48	9	39	8755.744	0.032	7.4591	b	412.596
1	0	1	0	0	0	8904.683	0.003	1.0000	a	0.297
13	2	11	13	2	12	9134.949	-0.030	0.5500	a	30.375
24	4	20	23	5	19	9292.286	0.016	3.7964	b	101.741
40	5	35	40	5	36	9523.942	-0.012	1.0653	a	264.043
50	9	42	49	10	39	9595.237	-0.009	7.8849	b	441.762
50	9	41	49	10	40	9598.753	-0.006	7.8850	b	441.762
60	7	53	60	7	54	9831.807	-0.034	1.3465	a	583.464
21	5	17	22	4	18	9847.631	-0.010	3.3706	b	88.030
6	1	5	6	1	6	9968.495	-0.005	0.3103	a	7.173
50	6	44	50	6	45	9985.912	0.013	1.2038	a	408.170
16	4	12	17	3	15	10125.809	-0.001	2.5800	b	52.820
31	4	27	31	4	28	10523.974	-0.005	0.8865	a	160.504
22	3	19	22	3	20	10631.182	0.000	0.7129	a	82.604
21	5	16	22	4	19	10689.657	0.012	3.3662	b	88.031
11	3	8	12	2	11	11000.105	-0.002	1.7678	b	26.590
45	8	38	44	9	35	11342.344	-0.002	7.1100	b	357.341
45	8	37	44	9	36	11356.180	-0.016	7.1101	b	357.341
26	6	21	27	5	22	11602.414	0.006	4.1457	b	132.218
41	5	36	41	5	37	11799.156	0.004	1.0209	a	276.372
26	6	20	27	5	23	11849.255	-0.009	4.1447	b	132.218
14	2	12	14	2	13	11887.289	0.011	0.5025	a	34.607
51	6	45	51	6	46	12234.502	0.016	1.1601	a	423.475
19	3	16	18	4	15	12539.047	-0.014	3.0304	b	63.658
15	2	14	14	3	11	12699.180	0.004	2.2745	b	38.643
12	1	12	11	2	9	12971.981	-0.004	1.1927	b	23.269
40	7	34	39	8	31	13011.395	-0.001	6.3344	b	281.864
40	7	33	39	8	32	13064.292	-0.066	6.3345	b	281.865
32	4	28	32	4	29	13120.933	-0.005	0.8420	a	170.135
31	7	25	32	6	26	13167.294	0.018	4.9209	b	185.377
7	1	6	7	1	7	13283.439	0.011	0.2690	a	9.305
23	3	20	23	3	21	13418.017	0.005	0.6682	a	89.540
4	0	4	3	1	3	13755.208	0.001	1.6155	b	2.967
23	1	23	22	2	20	14207.170	-0.003	0.4415	b	80.005
10	3	8	11	2	9	14217.930	-0.002	1.6205	b	23.311
42	5	37	42	5	38	14490.223	-0.007	0.9773	a	288.992
35	6	30	34	7	27	14580.891	-0.011	5.5574	b	215.336
36	8	28	37	7	31	14724.127	-0.031	5.6958	b	247.542
35	6	29	34	7	28	14776.125	0.002	5.5582	b	215.343
15	2	13	15	2	14	15118.989	0.015	0.4609	a	39.147
30	5	26	29	6	23	15953.290	0.012	4.7777	b	157.764
33	4	29	33	4	30	16178.439	-0.026	0.7989	a	180.079
24	3	21	24	3	22	16686.715	-0.018	0.6263	a	96.787
8	1	7	8	1	8	17063.758	0.004	0.2379	a	11.739
15	4	12	16	3	13	17193.716	0.008	2.3803	b	48.055
2	1	2	1	1	1	17334.420	0.003	1.5000	a	1.641
2	0	2	1	0	1	17802.003	0.015	1.9998	a	0.891
51	9	43	50	10	40	18802.099	0.000	8.0958	b	456.938
51	9	42	50	10	41	18807.078	0.017	8.0958	b	456.938
2	1	1	1	1	0	18284.549	0.007	1.5000	a	1.688
16	2	14	16	2	15	18843.906	0.026	0.4242	a	43.996
43	3	40	44	2	43	18960.355	0.003	0.4660	b	292.510
15	4	11	16	3	14	19053.454	-0.005	2.3683	b	48.056
25	4	21	24	5	20	19062.862	0.006	4.0049	b	109.215
20	5	16	21	4	17	19256.527	-0.005	3.1539	b	81.778
10	3	7	11	2	10	19308.140	-0.009	1.5691	b	23.314
14	1	14	13	2	11	19715.201	0.001	1.1027	b	31.032
39	2	38	38	3	35	19731.494	0.076	0.6349	b	231.255
34	4	30	34	4	31	19734.187	-0.014	0.7574	a	190.336
20	5	15	21	4	18	19843.158	0.016	3.1511	b	81.778
16	2	15	15	3	12	20057.709	0.014	2.4020	b	43.368
21	1	21	20	2	18	20334.386	-0.005	0.5553	b	67.144

Table 5. continued.

$J'$	$K'_a$	Transition				Obs. Freq.	obs.- calc	$S$	Dipole	$E_u$
		$K'_c$	$J''$	$K''_a$	$K''_c$	(MHz)	(MHz)			( $\text{cm}^{-1}$ )
25	3	22	25	3	23	20464.122	0.002	0.5872	a	104.346
46	8	39	45	9	36	20598.708	0.021	7.3202	b	371.039
46	8	38	45	9	37	20618.183	0.017	7.3202	b	371.039
9	1	8	8	2	7	20873.090	-0.019	1.8425	b	14.475
25	6	20	26	5	21	20891.907	0.012	3.9294	b	124.478
25	6	19	26	5	22	21062.686	0.020	3.9287	b	124.478
9	1	8	9	1	9	21303.467	0.041	0.2137	a	14.475
5	2	3	6	1	6	21445.733	0.010	0.7302	b	7.556
4	2	3	5	1	4	21505.270	0.021	0.6445	b	6.063
54	6	48	54	6	49	21554.477	0.030	1.0311	a	471.265
15	1	15	14	2	12	22018.368	0.000	1.0309	b	35.341
41	7	35	40	8	32	22313.417	-0.002	6.5435	b	294.080
41	7	34	40	8	33	22387.468	-0.007	6.5438	b	294.082
30	7	24	31	6	25	22401.921	0.016	4.7048	b	176.150
20	1	20	19	2	17	22415.419	-0.005	0.6234	b	61.137
30	7	23	31	6	26	22449.165	0.061	4.7046	b	176.150
20	3	17	19	4	16	22927.270	0.059	3.2429	b	69.664
17	2	15	17	2	16	23067.910	0.012	0.3920	a	49.153
1	1	0	1	0	1	23420.143	-0.023	1.5000	b	1.073
29	2	27	30	1	30	23440.092	0.021	0.2271	b	134.663
5	0	5	4	1	4	23477.750	0.011	2.2149	b	4.447
16	1	16	15	2	13	23581.913	0.004	0.9495	b	39.934
19	1	19	18	2	16	23801.020	0.007	0.6985	b	55.412
35	4	31	35	4	32	23819.727	0.015	0.7176	a	200.907
2	1	1	2	0	2	23902.727	0.008	2.4743	b	1.688
35	8	28	36	7	29	23904.119	0.028	5.4797	b	236.789
36	6	31	35	7	28	23914.598	-0.002	5.7650	b	226.069
35	8	27	36	7	30	23916.656	0.008	5.4797	b	236.789
36	6	30	35	7	29	24185.405	0.012	5.7662	b	226.078
9	3	7	10	2	8	24209.701	-0.008	1.3908	b	20.336
17	1	17	16	2	14	24397.839	0.008	0.8642	b	44.810
18	1	18	17	2	15	24467.562	-0.005	0.7795	b	49.970
3	1	2	3	0	3	24640.166	0.017	3.4099	b	2.603
26	3	23	26	3	24	24768.720	-0.007	0.5508	a	112.216
21	3	19	20	4	16	24920.535	0.011	3.3551	b	75.703
31	5	27	30	6	24	25269.552	0.001	4.9825	b	167.011
45	5	40	45	5	41	25480.581	0.017	0.8512	a	328.763
4	1	3	4	0	4	25648.624	0.023	4.2915	b	3.822
55	6	49	55	6	50	25661.570	0.017	0.9890	a	487.823
26	4	23	25	5	20	25959.990	0.004	4.1883	b	116.898
10	1	9	10	1	10	25993.978	0.028	0.1944	a	17.514
3	1	3	2	1	2	25996.967	0.008	2.6666	a	2.508
3	0	3	2	0	2	26684.580	0.015	2.9994	a	1.781
3	2	2	2	2	1	26714.950*	0.052	1.6667	a	4.875
3	2	1	2	2	0	26744.010*	-0.073	1.6667	a	4.876
1	1	1	0	0	0	31849.760*	-0.008	1.0000	b	1.062
2	1	2	1	0	1	40279.490*	-0.014	1.5000	b	1.641
29	1	28	28	1	27	255185.831	0.020	28.8310	a	130.821
30	1	29	29	2	28	255697.527	-0.006	18.1072	b	139.610
30	0	30	29	1	29	255729.170	0.024	26.1978	b	133.872
28	2	27	27	1	26	256108.672	0.040	16.1246	b	122.617
30	1	30	29	0	29	256363.437	0.018	26.2016	b	133.881
29	13	17	28	13	16	258615.908	0.011	23.1730	a	259.587
29	8	22	28	8	21	258620.475	0.021	26.7938	a	178.773
29	15	15	28	15	14	258724.290	0.002	21.2419	a	302.554
29	7	22	28	7	21	258726.010	-0.097	27.3109	a	167.222
29	16	13	28	16	12	258792.256	-0.012	20.1730	a	326.294
29	17	12	28	17	11	258868.168	-0.031	19.0350	a	351.528
29	6	24	28	6	23	258918.306	0.019	27.7590	a	157.231
29	6	23	28	6	22	258925.441	0.004	27.7590	a	157.232
29	4	26	28	4	25	259360.975	0.010	28.4442	a	141.956
29	5	24	28	5	23	259365.476	0.026	28.1377	a	148.833
29	23	7	28	23	6	259464.000	-0.044	10.7589	a	533.922
16	2	14	15	1	15	259474.045	0.032	1.3800	b	43.996
29	24	6	28	24	5	259584.036	-0.020	9.1382	a	569.411
29	25	5	28	25	4	259709.560	0.071	7.4485	a	606.332

Table 5. continued.

$J'$	Transition						Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
	$K'_a$	$K'_c$	$J''$	$K''_a$	$K''_c$						
11	4	7	10	3	8	260134.456	-0.066	4.6036	b	31.988	
18	3	16	17	2	15	260458.459	0.083	5.2577	b	57.841	
29	4	25	28	4	24	260836.767	0.007	28.4473	a	142.174	
6	5	2	5	4	1	261899.605	-0.019	4.5656	b	25.561	
30	2	29	29	2	28	262249.715	0.037	29.8108	a	139.829	
29	2	27	28	2	26	262526.003	0.030	28.8205	a	134.663	
30	1	29	29	1	28	263498.111	0.041	29.8274	a	139.610	
29	3	26	28	3	25	263873.574	0.029	28.7082	a	137.692	
31	1	31	30	1	30	264425.904	0.015	30.9328	a	142.702	
31	0	31	30	0	30	264483.887	0.020	30.9332	a	142.694	
50	7	43	50	6	44	280981.325	0.064	28.8964	b	417.542	
49	7	42	49	6	43	283184.500	0.045	28.1365	b	402.621	
48	7	41	48	6	42	285153.875	0.027	27.3917	b	388.001	
47	7	40	47	6	41	286910.300	-0.038	26.6603	b	373.682	
46	4	42	45	5	41	293390.100	-0.008	9.3645	b	337.699	
39	7	32	39	6	33	295539.200	0.001	21.1602	b	269.948	
33	26	8	32	26	7	295594.699	0.030	12.5155	a	682.326	
36	2	34	35	3	33	296157.460	-0.009	15.3342	b	203.922	
39	7	33	39	6	34	296158.723	-0.003	21.1520	b	269.947	
38	7	31	38	6	32	296161.470	-0.024	20.5074	b	258.330	
38	7	32	38	6	33	296623.735	-0.037	20.5015	b	258.329	
37	7	31	37	6	32	297059.724	-0.025	19.8568	b	247.011	
36	7	29	36	6	30	297216.001	-0.025	19.2206	b	235.992	
36	7	30	36	6	31	297466.121	-0.045	19.2177	b	235.992	
35	7	28	35	6	29	297661.695	-0.050	18.5859	b	225.271	
35	7	29	35	6	30	297842.960	-0.026	18.5839	b	225.271	
35	0	35	34	1	34	297978.806	-0.015	31.2465	b	180.785	
32	7	26	32	6	27	298800.700	-0.057	16.7126	b	194.903	
19	3	16	18	2	17	298801.250	-0.074	4.1435	b	63.658	
31	7	24	31	6	25	299020.700	-0.048	16.0985	b	185.377	
31	7	25	31	6	26	299065.300	-0.071	9.9005	b	185.377	
47	4	43	46	5	42	309438.250	-0.025	36.2762	b	351.962	
40	0	40	39	1	39	340045.815	-0.013	36.2764	b	234.704	
40	1	40	39	0	39	340105.443	-0.023	36.2764	b	234.705	
48	8	41	48	7	42	340202.976	-0.018	26.3427	b	399.329	
47	8	39	47	7	40	340359.169	0.007	25.6798	b	385.035	
40	2	38	39	3	37	340405.369	-0.008	19.7751	b	249.619	
47	8	40	47	7	41	340778.017	0.094	25.6749	b	385.034	
20	4	16	19	3	17	340964.440	-0.076	6.0477	b	74.872	
46	8	38	46	7	39	341004.519	0.018	25.0163	b	371.039	
49	4	45	48	5	44	341521.050	-0.019	11.1390	b	381.371	
15	5	11	14	4	10	341931.393	-0.009	6.0859	b	54.997	
15	5	10	14	4	11	341956.342	0.099	6.0857	b	54.997	
21	4	18	20	3	17	343330.662	-0.058	6.2876	b	81.117	
12	8	4	12	7	5	346872.475*	-0.115	4.0659	b	72.603	
41	0	41	40	1	40	348447.304	-0.014	37.2806	b	246.328	
41	1	41	40	1	40	348467.894	-0.001	40.9323	a	246.328	
41	0	41	40	0	40	348473.530	-0.018	40.9323	a	246.328	
41	1	41	40	0	40	348494.137	0.012	37.2808	b	246.328	
39	6	34	38	6	33	348749.756	0.027	38.0771	a	260.068	
39	6	33	38	6	32	348917.871	0.026	38.0773	a	260.090	
39	5	35	38	5	34	349107.718	0.012	38.3554	a	251.782	
37	3	35	36	2	34	349598.675	0.065	16.7661	b	215.583	
22	4	19	21	3	18	350598.197	0.025	6.4294	b	87.674	
39	5	34	38	5	33	350685.690	0.022	38.3590	a	252.036	
41	2	39	40	3	38	350753.900	-0.009	20.8971	b	261.732	
16	5	11	15	4	12	350810.905	0.042	6.2710	b	59.756	
11	6	6	10	5	5	352675.302	-0.088	6.1011	b	47.431	
40	3	38	39	3	37	352770.932	0.008	39.7036	a	250.032	
39	3	36	38	3	35	354017.727	0.073	38.7486	a	242.405	
41	1	40	40	2	39	354334.508	0.031	29.6761	b	254.638	
39	4	35	38	4	34	354433.785	0.004	38.6153	a	246.321	
40	2	38	39	2	37	354874.352	0.004	39.7314	a	249.619	
41	2	40	40	2	39	355087.351	0.015	40.8103	a	254.638	
38	3	36	37	2	35	355214.666	0.068	17.8152	b	226.782	
40	12	29	39	12	28	356545.046	0.016	36.4011	a	354.859	

**Table 5.** continued.

$J'$	$K'_a$	Transition				Obs. Freq. (MHz)	obs.- calc (MHz)	$S$	Dipole	$E_u$ ( $\text{cm}^{-1}$ )
		$K'_c$	$J''$	$K''_a$	$K''_c$					
40	14	26	39	14	25	356597.850	-0.005	35.1010	a	394.831
40	9	32	39	9	31	356729.510	0.072	37.9761	a	306.388
40	17	23	39	17	22	356818.075	-0.092	32.7759	a	466.122
42	0	42	41	1	41	356845.808	-0.016	38.2847	b	258.231
42	1	42	41	1	41	356861.934	-0.020	41.9323	a	258.232
42	0	42	41	0	41	356866.384	-0.017	41.9323	a	258.231
42	1	42	41	0	41	356882.504	-0.027	38.2849	b	258.232
50	4	46	49	5	45	357454.500	-0.023	11.8467	b	396.513
23	4	20	22	3	19	357550.155	-0.057	6.5689	b	94.531
40	27	14	39	27	13	358265.947	-0.070	21.7756	a	799.501



**Table 6.** Sample table of the predicted transitions of the ground vibrational state of  $^{13}\text{C}_3\text{H}_5\text{N}$ . The entire table is available in electronic form on the CDS.

Transition $J' (K'_a, K'_c) - J'' (K''_a, K''_c)$	Calc. Frequency (MHz)	Exp. Error (MHz)	S	Dipole	$E_l$ $\text{cm}^{-1}$
3 (1, 3)–2 (1, 2)	25494.7	0.03	2.6666	A	1.62
3 (0, 3)–2 (0, 2)	26166.99	0.03	2.9994	A	0.87
3 (2, 2)–2 (2, 1)	26196.27	0.03	1.6667	A	3.94
3 (2, 1)–2 (2, 0)	26224.4	0.03	1.6667	A	3.94
3 (1, 2)–2 (1, 1)	26887.32	0.03	2.6666	A	1.66
8 (1, 7)–8 (0, 8)	32434.75	0.03	7.0176	B	10.44
4 (1, 4)–3 (1, 3)	33984.63	0.03	3.7498	A	2.47
4 (0, 4)–3 (0, 3)	34856.26	0.03	3.9985	A	1.75
4 (2, 3)–3 (2, 2)	34922.57	0.03	2.9999	A	4.81
4 (3, 2)–3 (3, 1)	34943.83	0.03	1.75	A	8.64
4 (3, 1)–3 (3, 0)	34944.22	0.03	1.75	A	8.64
4 (2, 2)–3 (2, 1)	34992.79	0.03	2.9999	A	4.81
9 (1, 8)–9 (0, 9)	35118.09	0.03	7.4437	B	13.03
4 (1, 3)–3 (1, 2)	35840.99	0.03	3.7498	A	2.56
10 (1, 9)–10 (0, 10)	38229.04	0.03	7.7595	B	15.91
11 (1, 10)–11 (0, 11)	41792.14	0.03	7.9693	B	19.06
7 (0, 7)–6 (1, 6)	42238.57	0.03	3.537	B	6.72
5 (1, 5)–4 (1, 4)	42467.64	0.03	4.7995	A	3.60
5 (0, 5)–4 (0, 4)	43517.43	0.03	4.997	A	2.91
5 (2, 4)–4 (2, 3)	43643.89	0.03	4.1998	A	5.98
5 (4, 2)–4 (4, 1)	43680.91	0.03	1.8	A	15.17
5 (4, 1)–4 (4, 0)	43680.91	0.03	1.8	A	15.17
5 (3, 3)–4 (3, 2)	43685.39	0.03	3.2	A	9.81
5 (3, 2)–4 (3, 1)	43686.79	0.03	3.2	A	9.81
5 (2, 3)–4 (2, 2)	43784.02	0.03	4.1998	A	5.98
5 (1, 4)–4 (1, 3)	44786.95	0.03	4.7995	A	3.76
12 (1, 11)–12 (0, 12)	45824.96	0.03	8.0828	B	22.50
17 (2, 15)–16 (3, 14)	49527.68	0.04	3.0925	B	46.57
29 (4, 26)–28 (5, 23)	49951.78	0.19	4.7505	B	137.66
13 (1, 12)–13 (0, 13)	50335.88	0.03	8.114	B	26.21
6 (1, 6)–5 (1, 5)	50942.25	0.03	5.8325	A	5.02
34 (5, 29)–33 (6, 28)	51608.89	0.57	5.5932	B	191.28
8 (0, 8)–7 (1, 7)	52102.75	0.03	4.2734	B	8.70
6 (0, 6)–5 (0, 5)	52144.02	0.03	5.9948	A	4.36
6 (2, 5)–5 (2, 4)	52359.02	0.03	5.3329	A	7.43
6 (5, 2)–5 (5, 1)	52420.32	0.03	1.8334	A	23.52
6 (5, 1)–5 (5, 0)	52420.32	0.03	1.8334	A	23.52
6 (4, 3)–5 (4, 2)	52421.45	0.03	3.3334	A	16.63
6 (4, 2)–5 (4, 1)	52421.47	0.03	3.3334	A	16.63
6 (3, 4)–5 (3, 3)	52430.34	0.03	4.5001	A	11.27
6 (3, 3)–5 (3, 2)	52434.07	0.03	4.5001	A	11.27
6 (2, 4)–5 (2, 3)	52603.27	0.03	5.333	A	7.44
12 (1, 11)–11 (2, 10)	52789.21	0.03	2.9911	B	22.26
23 (3, 20)–22 (4, 19)	52853.92	0.04	3.8771	B	86.10
6 (1, 5)–5 (1, 4)	53723.03	0.03	5.8324	A	5.25
25 (3, 23)–24 (4, 20)	54973.12	0.03	3.9388	B	99.89
14 (1, 13)–14 (0, 14)	55322.5	0.03	8.08	B	30.19
4 (1, 4)–3 (0, 3)	55599.48	0.03	2.5378	B	1.75
29 (4, 25)–28 (5, 24)	56423.08	0.3	4.81	B	137.65
40 (6, 35)–39 (7, 32)	57043.19	1.18	6.5739	B	265.10
14 (2, 12)–14 (1, 13)	57651.29	0.03	11.3523	B	32.04
13 (2, 11)–13 (1, 12)	57800.41	0.03	10.2992	B	27.89
15 (2, 13)–15 (1, 14)	57862.46	0.04	12.3609	B	36.48
40 (6, 34)–39 (7, 33)	57874.83	1.27	6.5781	B	265.10
12 (2, 10)–12 (1, 11)	58264.01	0.03	9.2292	B	24.02
16 (2, 14)–16 (1, 15)	58474.85	0.04	13.298	B	41.22
35 (5, 31)–34 (6, 28)	58679.67	0.56	5.7682	B	201.22
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**Table 7.** Sample table of the predicted transitions of the ground vibrational state of  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ . The entire table is available in electronic form on the CDS.

Transition $J' (K'_a, K'_c) - J'' (K''_a, K''_c)$	Calc. Frequency (MHz)	Exp. Error (MHz)	S	Dipole	$E_l$ $\text{cm}^{-1}$
25 (4, 21)–24 (5, 20)	25052.91	0.14	3.9927	B	108.11
4 (1, 3)–4 (0, 4)	25145.98	0.04	4.2789	B	2.97
3 (1, 3)–2 (1, 2)	25974.04	0.04	2.6666	A	1.62
44 (5, 39)–44 (5, 40)	26337.74	1.45	0.8626	A	314.10
5 (1, 4)–5 (0, 5)	26496.50	0.04	5.0804	B	4.45
3 (0, 3)–2 (0, 2)	26682.90	0.04	2.9993	A	0.89
3 (2, 2)–2 (2, 1)	26715.94	0.04	1.6667	A	3.91
3 (2, 1)–2 (2, 0)	26747.90	0.04	1.6667	A	3.91
10 (1, 9)–10 (1, 10)	26839.67	0.04	0.1948	A	16.61
3 (1, 2)–2 (1, 1)	27446.24	0.04	2.6666	A	1.67
26 (3, 23)–26 (3, 24)	27803.68	0.1	0.5397	A	111.22
20 (3, 17)–19 (4, 16)	27931.11	0.04	3.2364	B	68.60
54 (6, 48)–54 (6, 49)	27935.99	4.17	0.9907	A	470.04
35 (4, 31)–35 (4, 32)	28021.12	0.51	0.6975	A	199.84
6 (1, 5)–6 (0, 6)	28180	0.04	5.7941	B	6.22
21 (3, 19)–20 (4, 16)	28855.09	0.04	3.3275	B	74.57
17 (2, 16)–16 (3, 13)	29182.38	0.04	2.4486	B	47.32
18 (2, 16)–18 (2, 17)	29803.14	0.04	0.3601	A	53.60
7 (1, 6)–7 (0, 7)	30228.05	0.04	6.4075	B	8.28
51 (9, 43)–50 (10, 40)	30726.21	4.13	8.074	B	454.42
51 (9, 42)–50 (10, 41)	30734.36	4.13	8.0741	B	454.42
8 (3, 6)–9 (2, 7)	30838.26	0.04	1.1632	B	16.45
1 (1, 1)–0 (0, 0)	31252.54	0.04	1	B	0
46 (8, 39)–45 (9, 36)	31286.92	2.47	7.2996	B	368.82
46 (8, 38)–45 (9, 37)	31317.04	2.49	7.2997	B	368.82
45 (5, 40)–45 (5, 41)	31326.09	1.76	0.8208	A	327.53
26 (4, 23)–25 (5, 20)	31440.15	0.12	4.1679	B	115.56
41 (7, 35)–40 (8, 32)	31760.66	1.39	6.5241	B	292.13
13 (4, 10)–14 (3, 11)	31830.81	0.04	1.936	B	38.05
41 (7, 34)–40 (8, 33)	31868.63	1.41	6.5245	B	292.13
36 (6, 31)–35 (7, 28)	32103.27	0.72	5.7465	B	224.35
11 (1, 10)–11 (1, 11)	32128.36	0.04	0.1794	A	19.78
31 (5, 27)–30 (6, 24)	32152.84	0.32	4.9642	B	165.49
18 (5, 14)–19 (4, 15)	32344.14	0.04	2.7116	B	68.61
15 (2, 13)–14 (3, 12)	32472.81	0.04	2.5825	B	38.02
36 (6, 30)–35 (7, 29)	32475.37	0.75	5.7481	B	224.35
23 (6, 18)–24 (5, 19)	32633.60	0.07	3.4871	B	108.11
18 (5, 13)–19 (4, 16)	32674.01	0.04	2.7103	B	68.60
8 (1, 7)–8 (0, 8)	32674.24	0.04	6.9113	B	10.64
23 (6, 17)–24 (5, 20)	32735.07	0.07	3.4868	B	108.11
13 (4, 9)–14 (3, 12)	32824.55	0.04	1.9308	B	38.02
28 (7, 22)–29 (6, 23)	32857.27	0.17	4.262	B	156.55
28 (7, 21)–29 (6, 24)	32886.96	0.17	4.2619	B	156.55
55 (6, 49)–55 (6, 50)	33034.68	5.01	0.9473	A	486.47
33 (8, 26)–34 (7, 27)	33082.89	0.41	5.0362	B	213.92
33 (8, 25)–34 (7, 28)	33091.26	0.41	5.0362	B	213.92
27 (3, 24)–27 (3, 25)	33099.13	0.12	0.5066	A	119.24
36 (4, 32)–36 (4, 33)	33297.29	0.62	0.6595	A	210.57
38 (9, 30)–39 (8, 31)	33339.72	0.85	5.8099	B	280.22
38 (9, 29)–39 (8, 32)	33342.02	0.85	5.8099	B	280.22
31 (5, 26)–30 (6, 25)	33371.50	0.36	4.9708	B	165.49
8 (3, 5)–9 (2, 8)	33444.91	0.04	1.1449	B	16.37
43 (10, 34)–44 (9, 35)	33643.14	1.59	6.583	B	355.43
43 (10, 33)–44 (9, 36)	33643.75	1.59	6.583	B	355.43
48 (11, 38)–49 (10, 39)	34003.63	2.79	7.3557	B	439.55
48 (11, 37)–49 (10, 40)	34003.78	2.79	7.3557	B	439.55
6 (0, 6)–5 (1, 5)	34012.64	0.04	2.8771	B	5.08
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**Table 8.** Sample table of the predicted transitions of the ground vibrational state of  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ . The entire table is available in electronic form on the CDS.

Transition $J' (K'_a, K'_c) - J'' (K''_a, K''_c)$	Calc. Frequency (MHz)	Exp. Error (MHz)	S	Dipole	$E_l$ $\text{cm}^{-1}$
3 (1, 3)–2 (1, 2)	25996.96	0.03	2.6666	A	1.64
3 (0, 3)–2 (0, 2)	26684.57	0.03	2.9994	A	0.89
3 (2, 2)–2 (2, 1)	26714.90	0.03	1.6667	A	3.98
3 (2, 1)–2 (2, 0)	26744.08	0.03	1.6667	A	3.98
3 (1, 2)–2 (1, 1)	27422.00	0.03	2.6666	A	1.69
7 (1, 6)–7 (0, 7)	30532.86	0.03	6.468	B	8.29
8 (1, 7)–8 (0, 8)	32876.36	0.03	6.9975	B	10.64
4 (1, 4)–3 (1, 3)	34654.00	0.03	3.7498	A	2.51
4 (0, 4)–3 (0, 3)	35545.12	0.03	3.9984	A	1.78
4 (2, 3)–3 (2, 2)	35613.85	0.03	2.9999	A	4.88
9 (1, 8)–9 (0, 9)	35629.74	0.03	7.4166	B	13.29
4 (3, 2)–3 (3, 1)	35635.82	0.03	1.75	A	8.74
4 (3, 1)–3 (3, 0)	35636.24	0.03	1.75	A	8.74
4 (2, 2)–3 (2, 1)	35686.73	0.03	2.9999	A	4.88
4 (1, 3)–3 (1, 2)	36553.57	0.03	3.7498	A	2.60
10 (1, 9)–10 (0, 10)	38822.57	0.03	7.7246	B	16.22
11 (1, 10)–11 (0, 11)	42479.70	0.03	7.9265	B	19.44
5 (1, 5)–4 (1, 4)	43303.87	0.03	4.7995	A	3.66
7 (0, 7)–6 (1, 6)	43326.73	0.03	3.5444	B	6.84
5 (0, 5)–4 (0, 4)	44376.53	0.03	4.9969	A	2.97
5 (2, 4)–4 (2, 3)	44507.66	0.03	4.1998	A	6.06
5 (4, 2)–4 (4, 1)	44545.79	0.03	1.8	A	15.34
5 (4, 1)–4 (4, 0)	44545.79	0.03	1.8	A	15.34
5 (3, 3)–4 (3, 2)	44550.60	0.03	3.2001	A	9.93
5 (3, 2)–4 (3, 1)	44552.08	0.03	3.2001	A	9.93
5 (2, 3)–4 (2, 2)	44653.08	0.03	4.1998	A	6.07
5 (1, 4)–4 (1, 3)	45677.15	0.03	4.7995	A	3.82
12 (1, 11)–12 (0, 12)	46618.62	0.03	8.0324	B	22.94
28 (4, 24)–27 (5, 23)	49471.56	0.03	4.6101	B	131.82
24 (3, 22)–23 (4, 19)	49796.81	0.03	3.8082	B	94.57
13 (1, 12)–13 (0, 13)	51247.06	0.03	8.0569	B	26.72
6 (1, 6)–5 (1, 5)	51945.04	0.03	5.8325	A	5.11
17 (2, 15)–16 (3, 14)	51955.10	0.03	3.0976	B	47.42
6 (0, 6)–5 (0, 5)	53172.09	0.03	5.9946	A	4.45
29 (4, 26)–28 (5, 23)	53185.48	0.03	4.7418	B	140.18
34 (5, 30)–33 (6, 27)	53311.67	0.03	5.573	B	194.77
8 (0, 8)–7 (1, 7)	53383.42	0.03	4.2838	B	8.86
6 (2, 5)–5 (2, 4)	53395.05	0.03	5.3329	A	7.55
6 (5, 2)–5 (5, 1)	53458.07	0.03	1.8334	A	23.78
6 (5, 1)–5 (5, 0)	53458.07	0.03	1.8334	A	23.78
6 (4, 3)–5 (4, 2)	53459.50	0.03	3.3334	A	16.82
6 (4, 2)–5 (4, 1)	53459.52	0.03	3.3334	A	16.82
6 (3, 4)–5 (3, 3)	53468.90	0.03	4.5001	A	11.42
6 (3, 3)–5 (3, 2)	53472.82	0.03	4.5001	A	11.42
6 (2, 4)–5 (2, 3)	53648.47	0.03	5.333	A	7.56
12 (1, 11)–11 (2, 10)	54621.10	0.03	3.0024	B	22.67
6 (1, 5)–5 (1, 4)	54790.46	0.03	5.8324	A	5.35
34 (5, 29)–33 (6, 28)	55582.99	0.03	5.5872	B	194.77
23 (3, 20)–22 (4, 19)	55941.87	0.03	3.8759	B	87.67
14 (1, 13)–14 (0, 14)	56361.47	0.03	8.0174	B	30.79
4 (1, 4)–3 (0, 3)	56443.91	0.03	2.5383	B	1.78
21 (6, 16)–22 (5, 17)	57611.90	0.03	3.0489	B	94.58
25 (3, 23)–24 (4, 20)	57640.40	0.03	3.922	B	101.74
21 (6, 15)–22 (5, 18)	57645.00	0.03	3.0488	B	94.58
14 (2, 12)–14 (1, 13)	58171.43	0.03	11.3774	B	32.67
13 (2, 11)–13 (1, 12)	58288.93	0.03	10.3273	B	28.43
15 (2, 13)–15 (1, 14)	58427.15	0.03	12.3798	B	37.20
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**Table 9.** Emission lines of  $\text{CH}_3\text{CH}_2^{13}\text{CN}$  (without high blend) present in the frequency range of the Orion KL survey. Column 1 indicates the transition, Col. 2 gives the calculated frequencies, Col. 3 gives the line strength, Col. 4 the energy of the upper level, Col. 5 the observed (centroid)frequencies assuming that the radial velocities relative to LSR are  $5 \text{ km s}^{-1}$ , Col. 6 the observed temperature of main beam and Col. 7 gives the main beam temperature obtained with the model.

Transitions $J_{K_a, K_c}$	Predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
9 <sub>1,8</sub> –8 <sub>1,7</sub>	80447.460	8.89	20.4	80447.4	0.030	0.019
10 <sub>2,9</sub> –9 <sub>2,8</sub>	87133.148	9.60	27.4	87132.3	0.041	0.024
10 <sub>6,5</sub> –9 <sub>6,4</sub>	87386.059	6.40	62.7	87386.2	0.039	0.031
10 <sub>6,4</sub> –9 <sub>6,3</sub>	87386.059	6.40	62.7	†		
10 <sub>7,4</sub> –9 <sub>7,3</sub>	87389.467	5.10	77.0	87389.2	0.073	0.044
10 <sub>7,3</sub> –9 <sub>7,2</sub>	87389.467	5.10	77.0	†		
10 <sub>5,6</sub> –9 <sub>5,5</sub>	87390.833	7.50	50.6	†		
10 <sub>5,5</sub> –9 <sub>5,4</sub>	87390.840	7.50	50.6	†		
10 <sub>9,2</sub> –9 <sub>9,1</sub>	87410.354	1.90	112.2	87410.2	0.060	0.037
10 <sub>9,1</sub> –9 <sub>9,0</sub>	87410.354	1.90	112.2	†		
10 <sub>4,7</sub> –9 <sub>4,6</sub>	87411.059	8.40	40.7	†		
10 <sub>4,6</sub> –9 <sub>4,5</sub>	87411.951	8.40	40.7	†		
10 <sub>2,8</sub> –9 <sub>2,7</sub>	88230.982	9.60	27.6	88231.2	0.028	0.025
11 <sub>1,11</sub> –10 <sub>1,10</sub>	93149.851	10.9	28.0	93150.2	0.056 <sup>2</sup>	0.033
11 <sub>0,11</sub> –10 <sub>0,10</sub>	94602.308	11.0	27.4	94602.2	0.020	0.035
11 <sub>2,10</sub> –10 <sub>2,9</sub>	95799.141	10.6	32.0	95799.2	0.034	0.035
11 <sub>6,6</sub> –10 <sub>6,5</sub>	96129.640	7.73	67.3	96132.2	0.031	0.053
11 <sub>6,5</sub> –10 <sub>6,4</sub>	96129.640	7.73	67.3	†		
11 <sub>7,5</sub> –10 <sub>7,4</sub>	96131.299	6.55	81.7	†		
11 <sub>7,4</sub> –10 <sub>7,3</sub>	96131.299	6.55	81.7	†		
11 <sub>5,7</sub> –10 <sub>5,6</sub>	96138.428	8.73	55.2	96138.3	0.49	0.069
11 <sub>5,6</sub> –10 <sub>5,5</sub>	96138.446	8.73	55.2	†		
11 <sub>8,4</sub> –10 <sub>8,3</sub>	96139.380	5.18	98.2	†		
11 <sub>8,3</sub> –10 <sub>8,2</sub>	96139.380	5.18	98.2	†		
11 <sub>9,2</sub> –10 <sub>9,1</sub>	96152.023	3.64	116.8	96152.2	0.015	0.017
11 <sub>9,3</sub> –10 <sub>9,2</sub>	96152.023	3.64	116.8	†		
11 <sub>10,1</sub> –10 <sub>10,0</sub>	96168.265	1.91	137.7	96169.2	0.036	0.045
11 <sub>10,2</sub> –10 <sub>10,1</sub>	96168.265	1.91	137.7	†		
11 <sub>4,7</sub> –10 <sub>4,6</sub>	96168.855	9.55	45.3	†		
11 <sub>3,9</sub> –10 <sub>3,8</sub>	96210.322	10.2	37.6	96209.2	0.041	0.033
11 <sub>3,8</sub> –10 <sub>3,7</sub>	96294.719	10.2	37.6	96294.2	0.033	0.033
11 <sub>2,9</sub> –10 <sub>2,8</sub>	97229.062	10.6	32.3	97229.2	0.028	0.036
11 <sub>1,10</sub> –10 <sub>1,9</sub>	98165.400	10.9	29.4	98165.2	0.049	0.039
12 <sub>1,12</sub> –11 <sub>1,11</sub>	101553.324	11.9	32.8	101553.1	0.038	0.046
12 <sub>0,12</sub> –11 <sub>0,11</sub>	102952.092	12.0	32.4	102951.3	0.042	0.047
12 <sub>7,6</sub> –11 <sub>7,5</sub>	104873.951	7.92	86.7	104874.0	0.099	0.110
12 <sub>7,5</sub> –11 <sub>7,4</sub>	104873.951	7.92	86.7	†		
12 <sub>6,7</sub> –11 <sub>6,6</sub>	104874.638	9.00	72.4	†		
12 <sub>6,6</sub> –11 <sub>6,5</sub>	104874.638	9.00	72.4	†		
12 <sub>8,5</sub> –11 <sub>8,4</sub>	104881.167	6.67	103.2	104881.1	0.055	0.045
12 <sub>8,4</sub> –11 <sub>8,3</sub>	104881.167	6.67	103.2	†		
12 <sub>5,8</sub> –11 <sub>5,7</sub>	104888.446	9.92	60.3	104888.1	0.093	0.077
12 <sub>5,7</sub> –11 <sub>5,6</sub>	104888.488	9.92	60.3	†		
12 <sub>9,4</sub> –11 <sub>9,3</sub>	104893.870	5.25	121.9	104892.1	0.053	0.035
12 <sub>9,3</sub> –11 <sub>9,2</sub>	104893.870	5.25	121.9	†		
12 <sub>10,3</sub> –11 <sub>10,2</sub>	104910.813	3.67	142.7	104911.1	0.051 <sup>3</sup>	0.020
12 <sub>10,2</sub> –11 <sub>10,1</sub>	104910.813	3.67	142.7	†		
12 <sub>4,9</sub> –11 <sub>4,8</sub>	104927.146	10.7	50.4	104927.1	0.067	0.047
12 <sub>4,8</sub> –11 <sub>4,7</sub>	104930.478	10.7	50.4	104930.1	0.071	0.054
12 <sub>11,1</sub> –11 <sub>11,0</sub>	104931.294	1.92	165.8	†		
12 <sub>11,2</sub> –11 <sub>11,1</sub>	104931.294	1.92	165.8	†		
12 <sub>3,9</sub> –11 <sub>3,8</sub>	105105.880	11.2	42.7	105106.1	0.047	0.046
12 <sub>2,10</sub> –11 <sub>2,9</sub>	106257.491	11.7	37.4	106257.1	0.059	0.050
12 <sub>1,11</sub> –11 <sub>1,10</sub>	106984.906	11.9	34.6	106986.0	0.089 <sup>3</sup>	0.052
13 <sub>1,13</sub> –12 <sub>1,12</sub>	109943.507	12.9	38.1	109944.0	0.077	0.061
13 <sub>0,13</sub> –12 <sub>0,12</sub>	111262.117	13.0	37.7	111263.0	0.050	0.062
13 <sub>2,12</sub> –12 <sub>2,11</sub>	113090.192	12.7	42.5	113090.0	0.095	0.063
13 <sub>7,7</sub> –12 <sub>7,6</sub>	113617.495	9.23	92.1	113617.5	0.110	0.086
13 <sub>7,6</sub> –12 <sub>7,5</sub>	113617.495	9.23	92.1	†		
13 <sub>6,8</sub> –12 <sub>6,7</sub>	113621.178	10.2	77.8	113623.0	0.186 <sup>3</sup>	0.099
13 <sub>6,7</sub> –12 <sub>6,6</sub>	113621.179	10.2	77.8	†		
13 <sub>8,6</sub> –12 <sub>8,5</sub>	113623.430	8.08	108.6	†		

**Table 9.** continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
13 <sub>8,5</sub> -12 <sub>8,4</sub>	113623.430	8.08	108.6	1		
13 <sub>5,9</sub> -12 <sub>5,8</sub>	113641.101	11.1	65.7	113643.0	0.121 <sup>4</sup>	0.104
13 <sub>5,8</sub> -12 <sub>5,7</sub>	113641.191	11.1	65.7	1		
13 <sub>4,10</sub> -12 <sub>4,9</sub>	113691.511	11.8	55.8	113693.0	0.125 <sup>3</sup>	0.058
13 <sub>4,9</sub> -12 <sub>4,8</sub>	113697.418	11.8	55.8	113695.0	0.148 <sup>3</sup>	0.060
15 <sub>2,14</sub> -14 <sub>2,13</sub>	130319.914	14.7	54.6	130319.7	0.127	0.102
15 <sub>7,9</sub> -14 <sub>7,8</sub>	131107.549	11.7	104.3	131107.2	0.116	0.169
15 <sub>7,8</sub> -14 <sub>7,7</sub>	131107.549	11.7	104.3	1		
15 <sub>8,8</sub> -14 <sub>8,7</sub>	131109.535	10.7	120.8	1		
15 <sub>8,7</sub> -14 <sub>8,6</sub>	131109.535	10.7	120.8	1		
15 <sub>6,10</sub> -14 <sub>6,9</sub>	131119.392	12.6	90.0	131119.6	0.134	0.217
15 <sub>6,9</sub> -14 <sub>6,8</sub>	131119.396	12.6	90.0	1		
15 <sub>9,6</sub> -14 <sub>9,5</sub>	131120.630	9.60	139.5	1		
15 <sub>9,7</sub> -14 <sub>9,4</sub>	131120.630	9.60	139.5	1		
15 <sub>5,11</sub> -14 <sub>5,10</sub>	131155.172	13.3	77.9	131155.9	0.113	0.172
15 <sub>5,10</sub> -14 <sub>5,9</sub>	131155.510	13.3	77.9	1		
15 <sub>4,12</sub> -14 <sub>4,11</sub>	131233.743	13.9	68.0	131234.6	0.175	0.093
15 <sub>3,12</sub> -14 <sub>3,11</sub>	131665.685	14.4	60.3	131666.8	0.173	0.100
15 <sub>1,14</sub> -14 <sub>1,13</sub>	133238.773	14.9	52.5	133238.4	0.122	0.112
15 <sub>2,13</sub> -14 <sub>2,12</sub>	133449.945	14.7	55.3	133449.6	0.113	0.110
16 <sub>0,16</sub> -15 <sub>0,15</sub>	136023.425	15.9	56.1	136024.7	0.261 <sup>5</sup>	0.121
16 <sub>8,9</sub> -15 <sub>8,8</sub>	139853.452	12.0	127.5	139853.6	0.346	0.310
16 <sub>8,8</sub> -15 <sub>8,7</sub>	139853.452	12.0	127.5	1		
16 <sub>7,10</sub> -15 <sub>7,9</sub>	139854.203	12.9	111.0	1		
16 <sub>7,9</sub> -15 <sub>7,8</sub>	139854.203	12.9	111.0	1		
16 <sub>11,5</sub> -15 <sub>11,4</sub>	139904.511	8.44	190.1	139905.6	0.157	0.085
16 <sub>11,6</sub> -15 <sub>11,5</sub>	139904.511	8.44	190.1	1		
16 <sub>5,12</sub> -15 <sub>5,11</sub>	139916.999	14.4	84.6	139917.7	0.256	0.209
16 <sub>5,11</sub> -15 <sub>5,10</sub>	139917.612	14.4	84.6	1		
16 <sub>4,13</sub> -15 <sub>4,12</sub>	140011.723	15.0	74.7	140010.8	0.171	0.172
16 <sub>3,13</sub> -15 <sub>3,12</sub>	140571.440	15.4	67.1	140570.6	0.150	0.125
16 <sub>1,15</sub> -15 <sub>1,14</sub>	141908.026	15.9	59.3	141907.6	0.283 <sup>3</sup>	0.135
16 <sub>2,14</sub> -15 <sub>2,13</sub>	142520.417	15.8	62.1	142520.7	0.173	0.143
17 <sub>0,17</sub> -16 <sub>0,16</sub>	144244.475	16.9	63.0	144243.2	0.367 <sup>6</sup>	0.150
17 <sub>9,9</sub> -16 <sub>9,8</sub>	148606.294	12.2	153.3	148607.5	0.242	0.191
17 <sub>9,8</sub> -16 <sub>9,7</sub>	148606.294	12.2	153.3	1		
17 <sub>10,7</sub> -16 <sub>10,6</sub>	148623.395	11.1	174.2	148625.5	0.520 <sup>3</sup>	0.292
17 <sub>10,8</sub> -16 <sub>10,7</sub>	148623.395	11.1	174.2	1		
17 <sub>6,12</sub> -16 <sub>6,11</sub>	148625.291	14.9	103.8	1		
17 <sub>6,11</sub> -16 <sub>6,10</sub>	148625.308	14.9	103.8	1		
17 <sub>11,6</sub> -16 <sub>11,5</sub>	148647.317	9.88	197.3	148646.5	0.178 <sup>6</sup>	0.114
17 <sub>11,7</sub> -16 <sub>11,6</sub>	148647.317	9.88	197.3	1		
17 <sub>5,13</sub> -16 <sub>5,12</sub>	148682.284	15.5	91.7	148682.5	0.592 <sup>3</sup>	0.244
17 <sub>5,12</sub> -16 <sub>5,11</sub>	148683.353	15.5	91.7	1		
17 <sub>4,13</sub> -16 <sub>4,12</sub>	148833.482	16.1	81.9	148835.5	0.186	0.143
17 <sub>2,15</sub> -16 <sub>2,14</sub>	151579.595	16.8	69.4	151580.5	0.387 <sup>3</sup>	0.165
18 <sub>1,18</sub> -17 <sub>1,17</sub>	151706.789	17.9	70.5	151706.5	0.294	0.176
18 <sub>0,18</sub> -17 <sub>0,17</sub>	152458.988	17.9	70.3	152461.8	0.283 <sup>7</sup>	0.177
18 <sub>9,10</sub> -17 <sub>9,9</sub>	157349.515	13.5	160.9	157349.3	0.521	0.393
18 <sub>9,9</sub> -17 <sub>9,8</sub>	157349.515	13.5	160.9	1		
18 <sub>7,12</sub> -17 <sub>7,11</sub>	157351.120	15.3	125.7	1		
18 <sub>7,11</sub> -17 <sub>7,10</sub>	157351.120	15.3	125.7	1		
18 <sub>10,9</sub> -17 <sub>10,8</sub>	157365.862	12.4	181.8	157367.5	0.230	0.177
18 <sub>10,8</sub> -17 <sub>10,7</sub>	157365.862	12.4	181.8	1		
18 <sub>6,13</sub> -17 <sub>6,12</sub>	157381.436	16.0	111.4	157381.7	0.310	0.297
18 <sub>6,12</sub> -17 <sub>6,11</sub>	157381.469	16.0	111.4	1		
18 <sub>11,8</sub> -17 <sub>11,7</sub>	157389.894	11.3	204.8	157389.9	0.238 <sup>8</sup>	0.155
18 <sub>11,7</sub> -17 <sub>11,6</sub>	157389.894	11.3	204.8	1		
18 <sub>5,14</sub> -17 <sub>5,13</sub>	157451.213	16.6	99.3	157454.3	0.413	0.251
18 <sub>5,13</sub> -17 <sub>5,12</sub>	157453.015	16.6	99.3	1		
18 <sub>13,6</sub> -17 <sub>13,5</sub>	157455.918	8.61	257.4	1		
18 <sub>13,5</sub> -17 <sub>13,4</sub>	157455.918	8.61	257.4	1		
18 <sub>3,16</sub> -17 <sub>3,15</sub>	157547.788	17.5	81.7	157548.0	0.270	0.183
18 <sub>4,15</sub> -17 <sub>4,14</sub>	157580.952	17.1	89.4	157581.4	0.249	0.172
18 <sub>4,14</sub> -17 <sub>4,13</sub>	157639.476	17.1	89.4	157639.4	0.205	0.173

**Table 9.** continued.

Transitions $J_{K_a,K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
18 <sub>3,15</sub> –17 <sub>3,14</sub>	158478.787	17.5	81.9	158478.0	0.170	0.183
18 <sub>1,17</sub> –17 <sub>1,17</sub>	159100.090	17.9	74.2	159101.8	0.273	0.195
19 <sub>1,19</sub> –18 <sub>1,18</sub>	160026.236	18.9	78.2	160026.7	0.508 <sup>3</sup>	0.206
19 <sub>0,19</sub> –18 <sub>0,18</sub>	160671.057	18.9	78.1	160671.4	0.282 <sup>9</sup>	0.209
19 <sub>8,12</sub> –18 <sub>8,11</sub>	166089.105	15.6	150.2	166090.4	0.215	0.306
19 <sub>8,11</sub> –18 <sub>8,10</sub>	166089.105	15.6	150.2	†		
19 <sub>9,11</sub> –18 <sub>9,10</sub>	166093.013	14.7	168.9	†		
19 <sub>9,10</sub> –18 <sub>9,9</sub>	166093.013	14.7	168.9	†		
19 <sub>6,14</sub> –18 <sub>6,13</sub>	166139.881	17.1	119.4	166139.1	0.247	0.356
19 <sub>6,13</sub> –18 <sub>6,12</sub>	166139.941	17.1	119.4	†		
19 <sub>13,6</sub> –18 <sub>13,5</sub>	166199.966	10.1	265.4	166200.4	0.231 <sup>8</sup>	0.124
19 <sub>13,7</sub> –18 <sub>13,6</sub>	166199.966	10.1	265.4	†		
19 <sub>14,5</sub> –18 <sub>14,4</sub>	166242.063	8.68	294.9	166242.9	0.167	0.095
19 <sub>14,6</sub> –18 <sub>14,5</sub>	166242.063	8.68	294.9	†		
19 <sub>16,3</sub> –18 <sub>16,2</sub>	166340.293	5.53	360.4	166340.4	0.093	0.048
19 <sub>16,4</sub> –18 <sub>16,3</sub>	166340.293	5.53	360.4	†		
19 <sub>4,16</sub> –18 <sub>4,15</sub>	166371.655	18.2	97.4	166375.4	0.230 <sup>10,11</sup>	0.204
19 <sub>4,15</sub> –18 <sub>4,14</sub>	166456.803	18.2	97.4	166456.7	0.151	0.211
19 <sub>3,16</sub> –18 <sub>3,15</sub>	167484.077	18.5	89.9	167484.1	0.363 <sup>3</sup>	0.218
19 <sub>1,18</sub> –18 <sub>1,17</sub>	167617.052	18.9	82.2	167617.2	0.357	0.228
20 <sub>0,20</sub> –19 <sub>0,19</sub>	168883.556	19.9	86.2	168884.3	0.204	0.243
19 <sub>2,17</sub> –18 <sub>2,16</sub>	169635.277	18.8	85.2	169635.3	0.252	0.232
20 <sub>8,13</sub> –19 <sub>8,12</sub>	174835.743	16.8	158.6	174835.2	0.952	0.596
20 <sub>8,12</sub> –19 <sub>8,11</sub>	174835.743	16.8	158.6	†		
20 <sub>9,12</sub> –19 <sub>9,11</sub>	174836.800	16.0	177.3	†		
20 <sub>9,11</sub> –19 <sub>9,10</sub>	174836.800	16.0	177.3	†		
20 <sub>11,9</sub> –19 <sub>11,8</sub>	174874.303	14.0	221.2	174874.2	0.495	0.226
20 <sub>11,10</sub> –19 <sub>11,9</sub>	174874.303	14.0	221.2	†		
20 <sub>6,15</sub> –19 <sub>6,14</sub>	174900.750	18.2	127.8	174901.1	0.847 <sup>12</sup>	0.421
20 <sub>6,14</sub> –19 <sub>6,13</sub>	174900.857	18.2	127.8	†		
20 <sub>12,9</sub> –19 <sub>12,8</sub>	174905.610	12.8	246.4	†		
20 <sub>12,8</sub> –19 <sub>12,7</sub>	174905.610	12.8	246.4	†		
21 <sub>1,21</sub> –20 <sub>1,20</sub>	176638.245	20.9	94.8	176637.2	0.492	0.276
23 <sub>7,17</sub> –22 <sub>7,16</sub>	201117.777	20.9	169.8	201119.7	0.363 <sup>3</sup>	0.578
23 <sub>7,16</sub> –22 <sub>7,15</sub>	201117.787	20.9	169.8	†		
23 <sub>12,12</sub> –22 <sub>12,11</sub>	201130.205	16.7	274.1	201129.7	0.227	0.326
23 <sub>12,11</sub> –22 <sub>12,10</sub>	201130.205	16.7	274.1	†		
23 <sub>3,21</sub> –22 <sub>3,20</sub>	201163.053	22.6	125.8	201162.2	0.570 <sup>3</sup>	0.374
23 <sub>6,18</sub> –22 <sub>6,17</sub>	201199.149	21.4	155.5	201198.5	0.414	0.615
23 <sub>6,17</sub> –22 <sub>6,16</sub>	201199.658	21.4	155.5	†		
23 <sub>5,19</sub> –22 <sub>5,18</sub>	201355.689	21.9	143.4	201354.7	0.368	0.334
24 <sub>1,24</sub> –23 <sub>1,23</sub>	201501.280	23.9	122.6	201501.0	0.175	0.395
23 <sub>4,20</sub> –22 <sub>4,19</sub>	201562.025	22.3	133.6	201562.2	0.117	0.354
23 <sub>3,20</sub> –22 <sub>3,19</sub>	203831.883	22.6	126.4	203833.0	0.556 <sup>4</sup>	0.377
25 <sub>1,25</sub> –24 <sub>1,24</sub>	209777.270	24.9	132.7	209780.8	0.189 <sup>3</sup>	0.435
24 <sub>8,17</sub> –23 <sub>8,16</sub>	209830.348	21.3	196.3	209829.6	0.358	0.609
24 <sub>8,16</sub> –23 <sub>8,15</sub>	209830.348	21.3	196.3	†		
24 <sub>11,13</sub> –23 <sub>11,12</sub>	209839.700	19.0	258.9	209839.6	0.196	0.460
24 <sub>11,14</sub> –23 <sub>11,13</sub>	209839.700	19.0	258.9	†		
24 <sub>3,22</sub> –23 <sub>3,21</sub>	209845.011	23.6	135.9	209844.6	0.266	0.432
24 <sub>6,19</sub> –23 <sub>6,18</sub>	209970.955	22.5	165.5	209974.6	0.554 <sup>3</sup>	0.681
24 <sub>6,18</sub> –23 <sub>6,17</sub>	209971.771	22.5	165.5	†		
25 <sub>0,25</sub> –24 <sub>0,24</sub>	209991.968	24.9	132.6	209989.6	0.422 <sup>13</sup>	0.441
24 <sub>5,20</sub> –23 <sub>5,19</sub>	210149.174	23.0	153.5	210148.3	0.250	0.379
24 <sub>5,19</sub> –23 <sub>5,18</sub>	210173.298	23.0	153.5	210172.1	0.360	0.374
24 <sub>4,21</sub> –23 <sub>4,20</sub>	210362.161	23.3	143.7	210363.2	0.476 <sup>3</sup>	0.398
24 <sub>4,20</sub> –23 <sub>4,19</sub>	210778.244	23.3	143.7	210778.3	0.149	0.398
25 <sub>2,24</sub> –24 <sub>2,23</sub>	215371.628	24.8	139.6	215372.0	0.691 <sup>14</sup>	0.452
26 <sub>1,26</sub> –25 <sub>1,25</sub>	218048.481	25.9	143.1	218048.2	0.407	0.481
25 <sub>3,23</sub> –24 <sub>3,22</sub>	218509.862	24.6	146.4	218509.5	0.328	0.454
25 <sub>9,17</sub> –24 <sub>9,16</sub>	218560.501	21.8	225.5	218562.0	0.476	0.987
25 <sub>9,16</sub> –24 <sub>9,15</sub>	218560.501	21.8	225.5	†		
25 <sub>10,16</sub> –24 <sub>10,15</sub>	218562.285	21.0	246.4	†		
25 <sub>10,15</sub> –24 <sub>10,14</sub>	218562.285	21.0	246.4	†		
25 <sub>7,19</sub> –24 <sub>7,18</sub>	218635.678	23.0	190.3	218635.7	0.302	0.726

**Table 9.** continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
25 <sub>7,18</sub> –24 <sub>7,17</sub>	218635.709	23.0	190.3	1		
25 <sub>5,21</sub> –24 <sub>5,20</sub>	218946.860	24.0	164.0	218946.9	0.444	0.420
25 <sub>3,22</sub> –24 <sub>3,21</sub>	222137.470	24.6	147.3	222137.0	0.480	0.471
25 <sub>2,23</sub> –24 <sub>2,22</sub>	222942.719	24.8	143.1	222945.1	0.573 <sup>15</sup>	0.486
26 <sub>2,25</sub> –25 <sub>2,24</sub>	223773.541	25.8	150.4	223774.4	0.576 <sup>3</sup>	0.495
26 <sub>1,25</sub> –25 <sub>1,24</sub>	225837.819	25.8	149.8	225838.1	0.601 <sup>3</sup>	0.508
26 <sub>3,24</sub> –25 <sub>3,23</sub>	227156.395	25.6	157.3	227156.3	0.354	0.498
26 <sub>11,15</sub> –25 <sub>11,14</sub>	227320.431	21.3	280.3	227320.6	0.760	0.550
26 <sub>11,16</sub> –25 <sub>11,15</sub>	227320.431	21.3	280.3	1		
26 <sub>12,14</sub> –25 <sub>12,13</sub>	227349.990	20.5	305.6	227346.8	0.664 <sup>9</sup>	0.475
26 <sub>12,15</sub> –25 <sub>12,14</sub>	227349.990	20.5	305.6	1		
26 <sub>6,21</sub> –25 <sub>6,20</sub>	227523.781	24.6	187.0	227524.3	0.672	0.729
26 <sub>6,20</sub> –25 <sub>6,19</sub>	227525.754	24.6	187.0	1		
26 <sub>5,22</sub> –25 <sub>5,21</sub>	227748.628	25.0	174.9	227748.1	0.312	0.460
26 <sub>4,22</sub> –25 <sub>4,21</sub>	228659.559	25.4	165.2	228659.3	0.421	0.488
26 <sub>2,24</sub> –25 <sub>2,23</sub>	231662.988	25.8	154.2	231661.8	0.396	0.532
27 <sub>2,26</sub> –26 <sub>2,25</sub>	232158.356	26.8	161.5	232159.3	0.666	0.540
28 <sub>1,28</sub> –27 <sub>1,27</sub>	234578.648	27.9	165.2	234578.2	0.307	0.569
27 <sub>3,25</sub> –26 <sub>3,24</sub>	235783.549	26.7	168.6	235784.3	0.251	0.544
27 <sub>8,20</sub> –26 <sub>8,19</sub>	236085.740	24.6	229.1	236087.4	0.417	0.973
27 <sub>8,19</sub> –26 <sub>8,18</sub>	236085.741	24.6	229.1	1		
27 <sub>12,15</sub> –26 <sub>12,14</sub>	236088.731	21.7	316.9	1		
27 <sub>12,16</sub> –26 <sub>12,15</sub>	236088.731	21.7	316.9	1		
27 <sub>13,15</sub> –26 <sub>13,14</sub>	236129.081	20.7	344.3	236128.3	0.262	0.460
27 <sub>13,14</sub> –26 <sub>13,13</sub>	236129.081	20.7	344.3	1		
27 <sub>7,21</sub> –26 <sub>7,20</sub>	236160.863	25.2	212.6	236158.4	0.677 <sup>16</sup>	0.882
27 <sub>7,20</sub> –26 <sub>7,19</sub>	236160.949	25.2	212.6	1		
27 <sub>14,14</sub> –26 <sub>14,13</sub>	236179.368	19.7	373.9	236178.4	0.317	0.397
27 <sub>14,13</sub> –26 <sub>14,12</sub>	236179.368	19.7	373.9	1		
27 <sub>6,22</sub> –26 <sub>6,21</sub>	236305.018	25.7	198.3	236307.0	0.951 <sup>3</sup>	0.895
27 <sub>6,21</sub> –26 <sub>6,20</sub>	236308.004	25.7	198.3	1		
27 <sub>5,23</sub> –26 <sub>5,22</sub>	236554.279	26.1	186.3	236553.2	0.367	0.505
27 <sub>5,22</sub> –26 <sub>5,21</sub>	236622.668	26.1	186.3	236623.2	0.453	0.504
28 <sub>2,27</sub> –27 <sub>2,26</sub>	240526.926	27.8	173.1	240523.0	0.534 <sup>3</sup>	0.584
29 <sub>0,29</sub> –28 <sub>0,28</sub>	242931.345	28.9	176.9	242930.3	0.598	0.614
28 <sub>10,19</sub> –27 <sub>10,18</sub>	244788.623	24.4	280.4	244787.2	0.976 <sup>17</sup>	0.752
28 <sub>10,18</sub> –27 <sub>10,17</sub>	244788.623	24.4	280.4	1		
28 <sub>9,20</sub> –27 <sub>9,19</sub>	244798.948	25.1	259.5	244798.3	0.584	1.45
28 <sub>9,19</sub> –27 <sub>9,18</sub>	244798.948	25.1	259.5	1		
28 <sub>11,18</sub> –27 <sub>11,17</sub>	244799.670	23.7	303.4	1		
28 <sub>11,17</sub> –27 <sub>11,16</sub>	244799.670	23.7	303.4	1		
28 <sub>2,26</sub> –27 <sub>2,25</sub>	248935.100	27.8	177.7	248936.2	0.462	0.621
30 <sub>1,30</sub> –29 <sub>1,29</sub>	251095.276	29.9	188.9	251093.1	1.19 <sup>17</sup>	0.657
29 <sub>3,27</sub> –28 <sub>3,26</sub>	252976.308	28.7	192.5	252976.1	1.03 <sup>3</sup>	0.645
29 <sub>10,20</sub> –28 <sub>10,19</sub>	253530.604	25.6	292.5	253531.7	0.326	0.815
29 <sub>10,19</sub> –28 <sub>10,18</sub>	253530.604	25.6	292.5	1		
29 <sub>9,21</sub> –28 <sub>9,20</sub>	253545.867	26.2	271.7	253541.7	0.925 <sup>7</sup>	0.904
29 <sub>9,20</sub> –28 <sub>9,19</sub>	253545.867	26.2	271.7	1		
29 <sub>6,24</sub> –28 <sub>6,23</sub>	253877.615	27.8	222.3	253876.1	0.340	0.573
29 <sub>6,23</sub> –28 <sub>6,22</sub>	253884.133	27.8	222.3	253885.1	0.910 <sup>3</sup>	0.577
29 <sub>5,25</sub> –28 <sub>5,24</sub>	254175.975	28.1	210.3	254176.7	0.494	0.589
29 <sub>3,26</sub> –28 <sub>3,25</sub>	258689.348	28.7	194.3	258688.0	0.240	0.660
31 <sub>0,31</sub> –30 <sub>0,30</sub>	259409.260	30.9	201.4	259408.6	0.352	0.698
30 <sub>3,28</sub> –29 <sub>3,27</sub>	261540.638	29.7	205.0	261540.4	0.601	0.675
30 <sub>9,22</sub> –29 <sub>9,21</sub>	262293.189	27.3	284.2	262294.1	0.533	0.963
30 <sub>9,21</sub> –29 <sub>9,20</sub>	262293.189	27.3	284.2	1		
30 <sub>7,24</sub> –29 <sub>7,23</sub>	262463.576	28.4	249.1	262462.9	0.430	1.12
30 <sub>7,23</sub> –29 <sub>7,22</sub>	262463.913	28.4	249.1	1		
30 <sub>4,27</sub> –29 <sub>4,26</sub>	263084.409	29.5	213.1	263084.1	0.182	0.660
30 <sub>4,26</sub> –29 <sub>4,25</sub>	264787.920	29.5	213.5	264787.0	0.446	0.669
30 <sub>2,28</sub> –29 <sub>2,27</sub>	265968.647	29.8	202.8	265969.0	0.819 <sup>4</sup>	0.709
31 <sub>1,30</sub> –30 <sub>1,29</sub>	266639.056	30.8	209.8	266640.9	0.388	0.720
32 <sub>1,32</sub> –31 <sub>1,31</sub>	267600.896	31.9	214.2	267601.3	0.922 <sup>7</sup>	0.740
32 <sub>0,32</sub> –31 <sub>0,31</sub>	267648.851	31.9	214.2	267649.0	0.220	0.740
30 <sub>3,27</sub> –29 <sub>3,26</sub>	267765.153	29.7	207.2	267767.0	0.820 <sup>18</sup>	0.707

**Table 9.** continued.

Transitions $J_{K_a,K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
31 <sub>10,22</sub> –30 <sub>10,21</sub>	271014.330	27.8	318.1	271014.0	0.376	1.69
31 <sub>10,21</sub> –30 <sub>10,20</sub>	271014.330	27.8	318.1	<sup>1</sup>		
31 <sub>11,21</sub> –30 <sub>11,20</sub>	271015.427	27.1	341.2	<sup>1</sup>		
31 <sub>11,20</sub> –30 <sub>11,19</sub>	271015.427	27.1	341.2	<sup>1</sup>		
31 <sub>12,19</sub> –30 <sub>12,18</sub>	271037.066	26.4	366.4	271040.2	0.459	1.17
31 <sub>12,20</sub> –30 <sub>12,19</sub>	271037.066	26.4	366.4	<sup>1</sup>		
31 <sub>9,23</sub> –30 <sub>9,22</sub>	271040.923	28.4	297.3	<sup>1</sup>		
31 <sub>9,22</sub> –30 <sub>9,21</sub>	271040.923	28.4	297.3	<sup>1</sup>		
31 <sub>13,19</sub> –30 <sub>13,18</sub>	271074.792	25.5	393.8	271080.1	0.658 <sup>5</sup>	0.656
31 <sub>13,18</sub> –30 <sub>13,17</sub>	271074.792	25.5	393.8	<sup>1</sup>		
31 <sub>8,24</sub> –30 <sub>8,23</sub>	271107.321	28.9	278.6	271111.5	0.650 <sup>19</sup>	1.11
31 <sub>8,23</sub> –30 <sub>8,22</sub>	271107.335	28.9	278.6	<sup>1</sup>		
31 <sub>16,15</sub> –30 <sub>16,14</sub>	271259.769	22.7	489.0	271259.0	0.292	0.425
31 <sub>16,16</sub> –30 <sub>16,15</sub>	271259.769	22.7	489.0	<sup>1</sup>		
31 <sub>6,25</sub> –30 <sub>6,24</sub>	271477.610	29.8	247.9	271477.7	0.622	0.643
31 <sub>5,27</sub> –30 <sub>5,26</sub>	271808.357	30.2	235.9	271807.9	0.506	0.577
31 <sub>4,28</sub> –30 <sub>4,27</sub>	271843.393	30.5	226.1	271842.8	0.712 <sup>8</sup>	0.701
32 <sub>2,31</sub> –31 <sub>2,30</sub>	273858.228	31.8	223.2	273857.8	1.45 <sup>20</sup>	0.751
31 <sub>4,27</sub> –30 <sub>4,26</sub>	273902.692	30.5	226.6	273901.8	0.481	0.713
32 <sub>2,29</sub> –31 <sub>2,28</sub>	274393.861	30.8	216.0	274392.8	0.560	0.751
32 <sub>1,31</sub> –31 <sub>1,30</sub>	274796.269	31.8	223.0	274795.8	0.958 <sup>3</sup>	0.758
31 <sub>3,28</sub> –30 <sub>3,27</sub>	276802.146	30.7	220.5	276803.7	0.443	0.750
32 <sub>11,22</sub> –31 <sub>11,21</sub>	279753.114	28.2	354.6	279754.5	0.770	1.44
32 <sub>11,21</sub> –31 <sub>11,20</sub>	279753.114	28.2	354.6	<sup>1</sup>		
32 <sub>10,23</sub> –31 <sub>10,22</sub>	279756.064	28.9	331.6	279756.8	0.613	1.44
32 <sub>10,22</sub> –31 <sub>10,21</sub>	279756.064	28.9	331.6	<sup>1</sup>		
32 <sub>12,21</sub> –31 <sub>12,20</sub>	279772.360	27.5	379.9	279773.8	0.917 <sup>3</sup>	0.805
32 <sub>12,20</sub> –31 <sub>12,19</sub>	279772.360	27.5	379.9	<sup>1</sup>		
32 <sub>9,24</sub> –31 <sub>9,23</sub>	279789.080	29.5	310.7	279788.8	0.765	1.08
32 <sub>9,23</sub> –31 <sub>9,22</sub>	279789.081	29.5	310.7	<sup>1</sup>		
32 <sub>13,20</sub> –31 <sub>13,19</sub>	279808.902	26.7	407.3	279809.8	0.439	0.701
32 <sub>13,19</sub> –31 <sub>13,18</sub>	279808.902	26.7	407.3	<sup>1</sup>		
32 <sub>14,18</sub> –31 <sub>14,17</sub>	279859.545	25.9	436.8	279858.8	0.558	0.617
32 <sub>14,19</sub> –31 <sub>14,18</sub>	279859.545	25.9	436.8	<sup>1</sup>		
32 <sub>8,25</sub> –31 <sub>8,24</sub>	279865.526	30.0	292.0	279865.8	0.923	1.14
32 <sub>8,24</sub> –31 <sub>8,23</sub>	279865.549	30.0	292.0	<sup>1</sup>		

<sup>1</sup> blended with the last one<sup>2</sup> blended with  $c\text{-C}_3\text{H}_2$ <sup>3</sup> blended with unidentified line<sup>4</sup> blended with  $\text{CH}_3\text{CH}_2\text{CN}$  b type<sup>5</sup> blended with  $\text{CH}_3\text{OD}$ <sup>6</sup> blended with CCS<sup>7</sup> blended with  $\text{CH}_3\text{OCOH}$ <sup>8</sup> blended with  $\text{CH}_3\text{COCH}_3$ <sup>9</sup> blended with  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ <sup>10</sup> blended with  $\text{SO}^{18}\text{O}$ <sup>11</sup> blended with  $\text{HNC}^{18}\text{O}$ <sup>12</sup> blended with  $\text{SO}_2$   $\nu_2 = 1$ <sup>13</sup> blended with  $\text{CH}_3\text{OCH}_3$ <sup>14</sup> blended with  $t\text{-CH}_3\text{CH}_2\text{OH}$ <sup>15</sup> blended with  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ <sup>16</sup> blended with  $\text{CH}_2\text{CHCN}$   $\nu_{11} = 1$ <sup>17</sup> blended with  $\text{CH}_3\text{CHO}$ <sup>18</sup> blended with  $^{13}\text{CH}_3\text{CN}$ <sup>19</sup> blended with  $\text{HCOOH}$ <sup>20</sup> blended with  $\text{S}^{18}\text{O}$



**Table 10.** Emission lines of  $\text{CH}_3^{13}\text{CH}_2\text{CN}$  (without high blend) present in the frequency range of the Orion KL survey. Column 1 indicates the transition, Col. 2 gives the calculated frequencies, Col. 3 gives the line strength, Col. 4 the energy of the upper level, Col. 5 the observed (centroid) frequencies assuming that the radial velocities relative to LSR are  $5 \text{ km s}^{-1}$ , Col. 6 the observed temperature of main beam and Col. 7 gives the main beam temperature obtained with the model.

Transitions $J_{K_a, K_c}$	Predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
10 <sub>0,10</sub> -9 <sub>0,9</sub>	87799.440	9.98	23.3	87799.3	0.038	0.027
10 <sub>6,5</sub> -9 <sub>6,4</sub>	89122.309	6.40	62.5	89123.3	0.070	0.039
10 <sub>6,4</sub> -9 <sub>6,3</sub>	89122.309	6.40	62.5	↑		
10 <sub>7,4</sub> -9 <sub>7,3</sub>	89123.598	5.10	76.6	↑		
10 <sub>7,3</sub> -9 <sub>7,2</sub>	89123.597	5.10	76.6	↑		
10 <sub>5,6</sub> -9 <sub>5,5</sub>	89129.924	7.50	50.6	89130.3	0.039	0.052
10 <sub>5,5</sub> -9 <sub>5,4</sub>	89129.935	7.50	50.6	↑		
10 <sub>8,3</sub> -9 <sub>8,2</sub>	89130.352	3.60	92.8	↑		
10 <sub>8,2</sub> -9 <sub>8,1</sub>	89130.352	3.60	92.8	↑		
10 <sub>4,7</sub> -9 <sub>4,6</sub>	89154.636	8.40	40.9	89155.3	0.053	0.033
10 <sub>4,6</sub> -9 <sub>4,5</sub>	89155.808	8.40	40.9	↑		
10 <sub>3,7</sub> -9 <sub>3,6</sub>	89259.164	9.10	33.3	89260.3	0.033	0.024
10 <sub>2,8</sub> -9 <sub>2,7</sub>	90079.324	9.60	28.0	90078.3	0.034	0.027
10 <sub>1,9</sub> -9 <sub>1,8</sub>	91139.116	9.89	25.2	91139.3	0.037	0.029
11 <sub>1,11</sub> -10 <sub>1,10</sub>	94867.175	10.9	28.5	94867.2	0.029	0.036
11 <sub>0,11</sub> -10 <sub>0,10</sub>	96329.800	11.0	27.9	96329.2	0.036	0.038
11 <sub>2,10</sub> -10 <sub>2,9</sub>	97672.054	10.6	32.5	97671.2	0.018	0.037
11 <sub>7,5</sub> -10 <sub>7,4</sub>	98039.620	6.55	81.3	98040.2	0.111	0.073
11 <sub>7,4</sub> -10 <sub>7,3</sub>	98039.620	6.55	81.3	↑		
11 <sub>6,6</sub> -10 <sub>6,5</sub>	98040.577	7.73	67.2	↑		
11 <sub>6,5</sub> -10 <sub>6,4</sub>	98040.577	7.73	67.2	↑		
11 <sub>5,7</sub> -10 <sub>5,6</sub>	98052.972	8.73	55.3	98053.2	0.127 <sup>2</sup>	0.058
11 <sub>5,6</sub> -10 <sub>5,5</sub>	98052.998	8.73	55.3	↑		
11 <sub>9,2</sub> -10 <sub>9,1</sub>	98056.185	3.64	115.9	↑		
11 <sub>9,3</sub> -10 <sub>9,2</sub>	98056.185	3.64	115.9	↑		
11 <sub>4,8</sub> -10 <sub>4,7</sub>	98087.364	9.55	45.6	98088.2	0.041	0.037
11 <sub>4,7</sub> -10 <sub>4,6</sub>	98089.703	9.55	45.6	↑		
11 <sub>3,9</sub> -10 <sub>3,8</sub>	98134.887	10.2	38.0	98135.2	0.052	0.035
11 <sub>1,10</sub> -10 <sub>1,9</sub>	100155.864	10.9	30.0	100155.2	0.030	0.041
12 <sub>1,12</sub> -11 <sub>1,11</sub>	103419.695	11.9	33.4	103420.1	0.60	0.49
12 <sub>0,12</sub> -11 <sub>0,11</sub>	104812.940	12.0	33.0	104813.1	0.078	0.051
12 <sub>2,11</sub> -11 <sub>2,10</sub>	106487.873	11.7	37.6	106488.1	0.023	0.050
12 <sub>7,6</sub> -11 <sub>7,5</sub>	106956.683	7.92	86.4	106956.2	0.086 <sup>3</sup>	0.065
12 <sub>7,5</sub> -11 <sub>7,4</sub>	106956.683	7.92	86.4	↑		
12 <sub>6,7</sub> -11 <sub>6,6</sub>	106960.564	9.00	72.4	106961.1	0.124	0.111
12 <sub>6,6</sub> -11 <sub>6,5</sub>	106960.564	9.00	72.4	↑		
12 <sub>8,5</sub> -11 <sub>8,4</sub>	106961.311	6.67	102.7	↑		
12 <sub>8,4</sub> -11 <sub>8,3</sub>	106961.311	6.67	102.7	↑		
12 <sub>9,4</sub> -11 <sub>9,3</sub>	106971.702	5.25	121.0	106969.1	0.068 <sup>2</sup>	0.034
12 <sub>9,3</sub> -11 <sub>9,2</sub>	106971.702	5.25	121.0	↑		
12 <sub>5,8</sub> -11 <sub>5,7</sub>	106978.882	9.92	60.5	106979.0	0.077	0.080
12 <sub>5,7</sub> -11 <sub>5,6</sub>	106978.942	9.92	60.5	↑		
12 <sub>4,9</sub> -11 <sub>4,8</sub>	107024.766	10.7	50.7	107024.0	0.115 <sup>4</sup>	0.047
12 <sub>4,8</sub> -11 <sub>4,7</sub>	107029.140	10.7	50.7	107029.1	0.065	0.049
12 <sub>3,10</sub> -11 <sub>3,9</sub>	107076.493	11.2	43.1	107076.1	0.072	0.048
12 <sub>3,9</sub> -11 <sub>3,8</sub>	107235.540	11.2	43.2	107235.1	0.045	0.049
12 <sub>2,10</sub> -11 <sub>2,9</sub>	108510.623	11.7	38.0	108511.0	0.037	0.053
13 <sub>1,13</sub> -12 <sub>1,12</sub>	111957.777	12.9	38.8	111958.0	0.088	0.064
13 <sub>0,13</sub> -12 <sub>0,12</sub>	113255.691	13.0	38.4	113255.0	0.060	0.067
15 <sub>0,15</sub> -14 <sub>0,14</sub>	130052.739	14.9	50.5	130053.1	0.097	0.107
15 <sub>2,14</sub> -14 <sub>2,13</sub>	132834.311	14.7	55.5	132835.7	0.111	0.109
15 <sub>8,8</sub> -14 <sub>8,7</sub>	133712.843	10.7	120.6	133712.7	0.311 <sup>3</sup>	0.179
15 <sub>8,7</sub> -14 <sub>8,6</sub>	133712.843	10.7	120.6	↑		
15 <sub>7,9</sub> -14 <sub>7,8</sub>	133715.047	11.7	104.4	↑		
15 <sub>7,8</sub> -14 <sub>7,7</sub>	133715.047	11.7	104.4	↑		
15 <sub>6,10</sub> -14 <sub>6,9</sub>	133732.382	12.6	90.3	133732.7	0.263	0.177
15 <sub>6,9</sub> -14 <sub>6,8</sub>	133732.389	12.6	90.3	↑		
15 <sub>10,5</sub> -14 <sub>10,4</sub>	133734.965	8.33	159.5	↑		
15 <sub>10,6</sub> -14 <sub>10,5</sub>	133734.965	8.33	159.5	↑		
15 <sub>3,13</sub> -14 <sub>3,12</sub>	133901.859	14.4	61.1	133901.7	0.166	0.106
15 <sub>1,14</sub> -14 <sub>1,13</sub>	135859.654	14.9	53.3	135859.6	0.132	0.118
15 <sub>2,13</sub> -14 <sub>2,12</sub>	136295.731	14.7	56.3	136297.1	0.139	0.117

Table 10. continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
16 <sub>1,16</sub> –15 <sub>1,15</sub>	137489.348	15.9	57.4	137489.5	0.335	0.128
16 <sub>0,16</sub> –15 <sub>0,15</sub>	138423.309	15.9	57.1	138424.5	0.215	0.131
16 <sub>2,15</sub> –15 <sub>2,14</sub>	141579.488	15.7	62.3	141579.6	0.206	0.134
16 <sub>7,10</sub> –15 <sub>7,9</sub>	142637.201	12.9	111.2	142636.6	0.191	0.332
16 <sub>7,9</sub> –15 <sub>7,8</sub>	142637.201	12.9	111.2	1		
16 <sub>9,8</sub> –15 <sub>9,7</sub>	142637.443	10.9	145.8	1		
16 <sub>9,7</sub> –15 <sub>9,6</sub>	142637.443	10.9	145.8	1		
16 <sub>11,5</sub> –15 <sub>11,4</sub>	142671.590	8.44	189.0	142672.6	0.118	0.092
16 <sub>11,6</sub> –15 <sub>11,5</sub>	142671.590	8.44	189.0	1		
16 <sub>5,12</sub> –15 <sub>5,11</sub>	142716.169	14.4	85.3	142719.6	0.372 <sup>5</sup>	0.215
16 <sub>5,11</sub> –15 <sub>5,10</sub>	142717.034	14.4	85.3	1		
16 <sub>4,13</sub> –15 <sub>4,12</sub>	142824.845	15.0	75.6	142825.6	0.409 <sup>6</sup>	0.125
16 <sub>3,14</sub> –15 <sub>3,13</sub>	142838.581	15.4	68.0	142837.6	0.147	0.131
16 <sub>4,12</sub> –15 <sub>4,11</sub>	142858.508	15.0	75.6	142857.6	0.315 <sup>7</sup>	0.125
16 <sub>1,15</sub> –15 <sub>1,14</sub>	144671.483	15.9	60.5	144670.6	0.231	0.145
17 <sub>1,17</sub> –16 <sub>1,16</sub>	145974.513	16.9	64.4	145974.6	0.157	0.155
17 <sub>0,17</sub> –16 <sub>0,16</sub>	146784.555	16.9	64.2	146784.6	0.188	0.158
17 <sub>2,16</sub> –16 <sub>2,15</sub>	150304.830	16.8	69.5	150305.6	0.228	0.163
17 <sub>8,10</sub> –16 <sub>8,9</sub>	151551.211	13.2	134.7	151551.8	0.349 <sup>4</sup>	0.221
17 <sub>8,9</sub> –16 <sub>8,8</sub>	151551.211	13.2	134.7	1		
17 <sub>9,9</sub> –16 <sub>9,8</sub>	151554.928	12.2	153.1	1		
17 <sub>9,8</sub> –16 <sub>9,7</sub>	151554.928	12.2	153.1	1		
17 <sub>7,11</sub> –16 <sub>7,10</sub>	151560.856	14.1	118.5	151561.9	0.287	0.249
17 <sub>7,10</sub> –16 <sub>7,9</sub>	151560.855	14.1	118.5	1		
17 <sub>5,13</sub> –16 <sub>5,12</sub>	151660.107	15.5	92.6	151660.5	0.406 <sup>4</sup>	0.232
17 <sub>5,12</sub> –16 <sub>5,11</sub>	151661.614	15.5	92.6	1		
17 <sub>3,15</sub> –16 <sub>3,14</sub>	151769.770	16.5	75.3	151770.5	0.381 <sup>4</sup>	0.162
17 <sub>4,13</sub> –16 <sub>4,12</sub>	151839.008	16.1	82.8	151838.5	0.173	0.152
18 <sub>0,18</sub> –17 <sub>0,17</sub>	155141.711	17.9	71.6	155144.3	0.240 <sup>8</sup>	0.188
18 <sub>8,11</sub> –17 <sub>8,10</sub>	160471.756	14.4	142.4	160471.8	0.425	0.426
18 <sub>8,10</sub> –17 <sub>8,9</sub>	160471.756	14.4	142.4	1		
18 <sub>9,10</sub> –17 <sub>9,9</sub>	160472.884	13.5	160.8	1		
18 <sub>9,9</sub> –17 <sub>9,8</sub>	160471.884	13.5	160.8	1		
18 <sub>10,9</sub> –17 <sub>10,8</sub>	160484.712	12.4	181.4	160485.5	0.340	0.411
18 <sub>10,8</sub> –17 <sub>10,7</sub>	160484.712	12.4	181.4	1		
18 <sub>7,12</sub> –17 <sub>7,11</sub>	160486.105	15.3	126.2	1		
18 <sub>7,11</sub> –17 <sub>7,10</sub>	160486.105	15.3	126.2	1		
18 <sub>5,13</sub> –17 <sub>5,12</sub>	160610.877	16.6	100.3	160610.3	0.298	0.214
18 <sub>3,16</sub> –17 <sub>3,15</sub>	160693.493	17.5	83.0	160692.4	0.170	0.193
18 <sub>3,15</sub> –17 <sub>3,14</sub>	161813.575	17.5	83.2	161813.4	0.204	0.194
19 <sub>0,19</sub> –18 <sub>0,18</sub>	163498.529	18.9	79.5	163497.0	0.308 <sup>4</sup>	0.220
19 <sub>2,18</sub> –18 <sub>2,17</sub>	167693.805	18.8	85.2	167694.2		
19 <sub>9,11</sub> –18 <sub>9,10</sub>	169391.337	14.7	169.0	169392.8	0.571 <sup>3</sup>	0.439
19 <sub>9,10</sub> –18 <sub>9,9</sub>	169391.337	14.7	169.0	1		
19 <sub>8,12</sub> –18 <sub>8,11</sub>	169393.276	15.6	150.6	1		
19 <sub>8,11</sub> –18 <sub>8,10</sub>	169393.276	15.6	150.6	1		
19 <sub>10,10</sub> –18 <sub>10,9</sub>	169401.599	13.7	189.5	169401.6	0.269	0.247
19 <sub>10,9</sub> –18 <sub>10,8</sub>	169401.599	13.7	189.5	1		
19 <sub>7,13</sub> –18 <sub>7,12</sub>	169413.039	16.4	134.4	169414.2	0.391	0.347
19 <sub>7,12</sub> –18 <sub>7,11</sub>	169413.040	16.4	134.4	1		
19 <sub>12,8</sub> –18 <sub>12,7</sub>	169447.437	11.4	237.0	169449.1	0.320 <sup>4</sup>	0.163
19 <sub>12,7</sub> –18 <sub>12,6</sub>	169447.437	11.4	237.0	1		
19 <sub>6,14</sub> –18 <sub>6,13</sub>	169461.556	17.1	120.3	169461.6	0.761 <sup>9</sup>	0.375
19 <sub>6,13</sub> –18 <sub>6,12</sub>	169461.647	17.1	120.3	1		
19 <sub>5,15</sub> –18 <sub>5,14</sub>	169561.050	17.7	108.4	169561.6	0.368	0.281
19 <sub>5,14</sub> –18 <sub>5,13</sub>	169565.204	17.7	108.4	1		
19 <sub>3,17</sub> –18 <sub>3,16</sub>	169607.785	18.5	91.1	169608.2	0.296	0.271
19 <sub>4,15</sub> –18 <sub>4,14</sub>	169837.796	18.2	98.7	169838.2	0.222	0.216
19 <sub>3,16</sub> –18 <sub>3,15</sub>	171035.036	18.5	91.4	171036.6	0.448 <sup>8</sup>	0.231
22 <sub>2,20</sub> –21 <sub>2,19</sub>	200514.457	21.8	114.4	200514.7	0.166	0.394
24 <sub>1,24</sub> –23 <sub>1,23</sub>	205107.677	23.9	124.8	205107.1	0.612	0.503
23 <sub>6,18</sub> –22 <sub>6,17</sub>	205237.944	21.4	157.1	205238.4	0.320	0.651
23 <sub>6,17</sub> –22 <sub>6,16</sub>	205238.716	21.4	157.1	1		
24 <sub>0,24</sub> –23 <sub>0,23</sub>	205331.591	23.9	124.7	205332.1	0.421	0.414
23 <sub>5,19</sub> –22 <sub>5,18</sub>	205419.492	21.9	145.3	205418.4	0.248	0.354

**Table 10.** continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
23 <sub>5,18</sub> –22 <sub>5,17</sub>	205442.696	21.9	145.3	205444.7	0.379 <sup>5</sup>	0.354
23 <sub>4,20</sub> –22 <sub>4,19</sub>	205638.830	22.3	135.6	205638.4	0.340	0.357
24 <sub>2,23</sub> –23 <sub>2,22</sub>	210799.376	23.8	131.6	210799.5	0.323	0.428
24 <sub>1,23</sub> –23 <sub>1,22</sub>	213135.547	23.9	130.9	213134.6	0.359	0.429
25 <sub>1,25</sub> –24 <sub>1,24</sub>	213528.307	24.9	135.0	213529.5	0.511	0.458
25 <sub>0,25</sub> –24 <sub>0,24</sub>	213709.622	24.9	135.0	213708.3	0.647	0.459
24 <sub>3,22</sub> –23 <sub>3,21</sub>	213971.982	23.6	138.2	213970.8	0.471 <sup>3</sup>	0.432
24 <sub>10,15</sub> –23 <sub>10,14</sub>	213988.615	19.8	236.6	213990.8	0.620 <sup>3</sup>	0.667
24 <sub>10,14</sub> –23 <sub>10,13</sub>	213988.615	19.8	236.6	1		
24 <sub>9,16</sub> –23 <sub>9,15</sub>	213991.924	20.6	216.0	1		
24 <sub>9,15</sub> –23 <sub>9,14</sub>	213991.924	20.6	216.0	1		
24 <sub>11,13</sub> –23 <sub>11,12</sub>	214001.054	19.0	259.2	214001.4	0.377 <sup>5</sup>	0.470
24 <sub>11,14</sub> –23 <sub>11,13</sub>	214001.054	19.0	259.2	1		
24 <sub>8,17</sub> –23 <sub>8,16</sub>	214017.318	21.3	197.7	214017.0	0.342	0.640
24 <sub>8,16</sub> –23 <sub>8,15</sub>	214017.318	21.3	197.7	1		
24 <sub>6,19</sub> –23 <sub>6,18</sub>	214190.553	22.5	167.4	214190.8	0.494	0.688
24 <sub>6,18</sub> –23 <sub>6,17</sub>	214191.790	22.5	167.4	1		
24 <sub>16,9</sub> –23 <sub>16,8</sub>	214206.257	13.3	404.5	214207.0	0.084	0.196
24 <sub>16,8</sub> –23 <sub>16,7</sub>	214206.257	13.3	404.5	1		
24 <sub>5,19</sub> –23 <sub>5,18</sub>	214430.179	23.0	155.6	214432.0	0.406 <sup>4</sup>	0.399
24 <sub>4,21</sub> –23 <sub>4,20</sub>	214617.845	23.3	145.9	214620.7	0.469 <sup>8</sup>	0.417
24 <sub>4,20</sub> –23 <sub>4,19</sub>	215156.584	23.3	146.0	215155.8	0.554 <sup>4</sup>	0.491
24 <sub>3,21</sub> –23 <sub>3,20</sub>	217614.369	23.6	139.1	217614.5	0.648 <sup>10</sup>	0.448
26 <sub>0,26</sub> –25 <sub>0,25</sub>	222090.574	25.9	145.6	222089.4	0.467	0.482
25 <sub>3,23</sub> –24 <sub>3,22</sub>	222791.617	24.6	148.9	222790.6	0.310	0.475
25 <sub>12,14</sub> –24 <sub>12,13</sub>	222939.994	19.2	294.7	222945.1	0.572 <sup>11</sup>	0.474
25 <sub>12,13</sub> –24 <sub>12,12</sub>	222939.994	19.2	294.7	1		
25 <sub>8,18</sub> –24 <sub>8,17</sub>	222945.771	22.4	208.4	1		
25 <sub>8,17</sub> –24 <sub>8,16</sub>	222945.772	22.4	208.4	1		
25 <sub>13,13</sub> –24 <sub>13,12</sub>	222973.798	18.2	321.7	222970.7	0.618 <sup>3</sup>	0.386
25 <sub>13,12</sub> –24 <sub>13,11</sub>	222973.798	18.2	321.7	1		
25 <sub>7,19</sub> –24 <sub>7,18</sub>	223015.182	23.0	192.1	223014.4	0.573	1.05
25 <sub>7,18</sub> –24 <sub>7,17</sub>	223015.233	23.0	192.1	1		
25 <sub>14,12</sub> –24 <sub>14,11</sub>	223016.365	17.2	350.7	1		
25 <sub>14,11</sub> –24 <sub>14,10</sub>	223016.365	17.2	350.7	1		
25 <sub>6,20</sub> –24 <sub>6,19</sub>	223146.857	23.6	178.1	223148.1	0.475	0.696
25 <sub>6,19</sub> –24 <sub>6,18</sub>	223148.797	23.6	178.1	1		
25 <sub>4,22</sub> –24 <sub>4,21</sub>	223594.386	24.4	156.6	223596.9	0.263	0.462
25 <sub>4,21</sub> –24 <sub>4,20</sub>	224297.114	24.4	156.7	1		
25 <sub>3,22</sub> –24 <sub>3,21</sub>	226974.990	24.6	150.0	226974.4	0.440	0.497
26 <sub>1,25</sub> –25 <sub>1,24</sub>	229803.538	25.8	152.6	229804.3	0.448 <sup>12</sup>	0.530
26 <sub>3,24</sub> –25 <sub>3,23</sub>	231590.282	25.6	160.0	231593.2	0.610 <sup>13</sup>	0.521
26 <sub>10,17</sub> –25 <sub>10,16</sub>	231824.731	22.2	258.4	231824.3	0.289 <sup>14</sup>	0.659
26 <sub>10,16</sub> –25 <sub>10,15</sub>	231824.731	22.2	258.4	1		
26 <sub>11,15</sub> –25 <sub>11,14</sub>	231832.198	21.3	281.0	231833.0	0.173	0.645
26 <sub>11,16</sub> –25 <sub>11,15</sub>	231832.198	21.3	281.0	1		
26 <sub>9,18</sub> –25 <sub>9,17</sub>	231836.493	22.9	237.9	231836.8	0.226	0.760
26 <sub>9,17</sub> –25 <sub>9,16</sub>	231836.493	22.9	237.9	1		
26 <sub>8,19</sub> –25 <sub>8,18</sub>	231875.560	23.5	219.5	231871.8	0.349 <sup>5</sup>	0.784
26 <sub>8,18</sub> –25 <sub>8,17</sub>	231875.562	23.5	219.5	1		
26 <sub>16,11</sub> –25 <sub>16,10</sub>	232039.545	16.2	426.3	232039.3	0.103	0.262
26 <sub>16,10</sub> –25 <sub>16,9</sub>	232039.545	16.2	426.3	1		
26 <sub>17,10</sub> –25 <sub>17,9</sub>	232104.322	14.9	461.7	232108.0	0.180	0.641
26 <sub>17,9</sub> –25 <sub>17,8</sub>	232104.322	14.9	461.7	1		
26 <sub>6,21</sub> –25 <sub>6,20</sub>	232106.987	24.6	189.2	1		
26 <sub>6,20</sub> –25 <sub>6,19</sub>	232109.974	24.6	189.2	1		
26 <sub>5,22</sub> –25 <sub>5,21</sub>	232363.924	25.0	177.4	232363.3	0.199	0.484
26 <sub>5,21</sub> –25 <sub>5,20</sub>	232432.713	25.0	177.4	232432.0	0.271	0.483
26 <sub>4,23</sub> –25 <sub>4,22</sub>	232566.761	25.4	167.8	232567.0	0.169	0.508
26 <sub>4,22</sub> –25 <sub>4,21</sub>	233470.034	25.4	168.0	233467.0	0.228 <sup>4</sup>	0.512
26 <sub>3,23</sub> –25 <sub>3,22</sub>	236327.736	25.7	161.4	236328.2	0.248	0.546
27 <sub>2,26</sub> –26 <sub>2,25</sub>	236425.676	26.8	164.4	236425.7	0.374	0.564
27 <sub>1,26</sub> –26 <sub>1,25</sub>	238110.033	26.8	164.0	238111.3	0.350	0.576
28 <sub>0,28</sub> –27 <sub>0,27</sub>	238859.033	27.9	168.2	238860.3	0.474	0.576
27 <sub>3,25</sub> –26 <sub>3,24</sub>	240366.946	26.6	171.6	240368.0	0.571	0.569

Table 10. continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
27 <sub>12,15</sub> –26 <sub>12,14</sub>	240767.796	21.7	317.4	240764.2	0.790 <sup>3</sup>	0.582
27 <sub>12,16</sub> –26 <sub>12,15</sub>	240767.796	21.7	317.4	<sup>1</sup>		
27 <sub>13,15</sub> –26 <sub>13,14</sub>	240800.499	20.7	344.4	240800.4	0.251	0.514
27 <sub>13,14</sub> –26 <sub>13,13</sub>	240800.499	20.7	344.4	<sup>1</sup>		
27 <sub>8,20</sub> –26 <sub>8,19</sub>	240806.735	24.6	231.0	240806.6	0.504	0.869
27 <sub>8,19</sub> –26 <sub>8,18</sub>	240806.738	24.6	231.0	<sup>1</sup>		
27 <sub>7,21</sub> –26 <sub>7,20</sub>	240900.244	25.2	214.8	240900.4	0.826	0.938
27 <sub>7,20</sub> –26 <sub>7,19</sub>	240900.383	25.2	214.8	<sup>1</sup>		
27 <sub>6,22</sub> –26 <sub>6,21</sub>	241071.065	25.7	200.8	241074.4	0.411	0.540
27 <sub>6,21</sub> –26 <sub>6,20</sub>	241075.583	25.7	200.8	<sup>1</sup>		
27 <sub>5,23</sub> –26 <sub>5,22</sub>	241354.267	26.1	189.0	241354.4	0.740 <sup>4</sup>	0.530
27 <sub>5,22</sub> –26 <sub>5,21</sub>	241450.030	26.1	189.0	241449.4	0.916 <sup>3</sup>	0.530
27 <sub>2,25</sub> –26 <sub>2,24</sub>	245004.430	26.8	169.0	245005.2	0.862	0.604
27 <sub>3,24</sub> –26 <sub>3,23</sub>	245662.389	26.7	173.2	245661.2	0.374	0.595
29 <sub>0,29</sub> –28 <sub>0,28</sub>	247245.507	28.9	180.0	247246.9	0.627	0.639
28 <sub>13,15</sub> –27 <sub>13,14</sub>	249712.876	22.0	356.3	249710.1	0.757 <sup>8</sup>	0.539
28 <sub>13,16</sub> –27 <sub>13,15</sub>	249712.876	22.0	356.3	<sup>1</sup>		
28 <sub>7,22</sub> –27 <sub>7,21</sub>	249846.517	26.3	226.8	249846.2	0.782	1.01
28 <sub>7,21</sub> –27 <sub>7,20</sub>	249846.740	26.3	226.8	<sup>1</sup>		
28 <sub>17,12</sub> –27 <sub>17,11</sub>	249936.679	17.7	485.3	249937.2	0.110	0.280
28 <sub>17,11</sub> –27 <sub>17,10</sub>	249936.679	17.7	485.3	<sup>1</sup>		
29 <sub>2,28</sub> –28 <sub>2,27</sub>	253425.145	28.8	188.4	253424.2	0.516	0.655
28 <sub>2,26</sub> –27 <sub>2,25</sub>	253716.782	27.8	181.2	253716.1	1.19 <sup>8</sup>	0.651
29 <sub>11,19</sub> –28 <sub>11,18</sub>	258577.731	24.8	317.0	258576.1	0.342	<sup>15</sup>
29 <sub>11,18</sub> –28 <sub>11,17</sub>	258577.731	24.8	317.0	<sup>1</sup>		
29 <sub>10,20</sub> –28 <sub>10,19</sub>	258580.432	25.6	294.3	258579.0	0.342	1.23
29 <sub>10,19</sub> –28 <sub>10,18</sub>	258580.432	25.6	294.3	<sup>1</sup>		
29 <sub>12,18</sub> –28 <sub>12,17</sub>	258593.828	24.0	341.8	258594.1	0.136	0.686
29 <sub>12,17</sub> –28 <sub>12,16</sub>	258593.828	24.0	341.8	<sup>1</sup>		
29 <sub>9,21</sub> –28 <sub>9,20</sub>	258608.583	26.2	273.8	258609.0	0.271	0.942
29 <sub>9,20</sub> –28 <sub>9,19</sub>	258608.583	26.2	273.8	<sup>1</sup>		
29 <sub>7,23</sub> –28 <sub>7,22</sub>	258795.413	27.3	239.2	258797.0	0.798	1.09
29 <sub>7,22</sub> –28 <sub>7,21</sub>	258795.766	27.3	239.2	<sup>1</sup>		
29 <sub>2,27</sub> –28 <sub>2,26</sub>	262362.311	28.8	193.7	262360.3	0.596	0.694
31 <sub>1,31</sub> –30 <sub>1,30</sub>	263973.471	30.9	205.0	263973.0	0.549	0.727
31 <sub>0,31</sub> –30 <sub>0,30</sub>	264020.728	30.9	205.0	264020.0	0.677	0.726
29 <sub>3,26</sub> –28 <sub>3,25</sub>	264241.006	28.7	198.1	264240.3	0.781 <sup>4</sup>	0.693
30 <sub>3,28</sub> –29 <sub>3,27</sub>	266557.689	29.7	208.7	266556.6	0.284	0.703
30 <sub>8,23</sub> –29 <sub>8,22</sub>	267609.104	27.9	268.3	267609.9	1.10 <sup>5</sup>	1.08
30 <sub>8,22</sub> –29 <sub>8,21</sub>	267609.119	27.9	268.3	<sup>1</sup>		
30 <sub>7,24</sub> –29 <sub>7,23</sub>	267747.028	28.4	252.1	267748.0	0.605	1.16
30 <sub>7,23</sub> –29 <sub>7,22</sub>	267747.577	28.4	252.1	<sup>1</sup>		
30 <sub>5,26</sub> –29 <sub>5,25</sub>	268345.778	29.2	226.3	268344.1	1.03 <sup>4</sup>	0.659
30 <sub>4,27</sub> –29 <sub>4,26</sub>	268377.483	29.5	216.7	268376.5	0.372	0.690
31 <sub>1,30</sub> –30 <sub>1,29</sub>	271301.801	30.8	213.7	271302.7	0.260	0.747
32 <sub>1,32</sub> –31 <sub>1,31</sub>	272371.348	31.9	218.1	272369.0	0.651 <sup>16</sup>	0.769
31 <sub>13,19</sub> –30 <sub>13,18</sub>	276445.791	25.5	394.9	276445.2	0.271	0.689
31 <sub>13,18</sub> –30 <sub>13,17</sub>	276445.791	25.5	394.9	<sup>1</sup>		
31 <sub>9,23</sub> –30 <sub>9,22</sub>	276460.408	28.4	299.9	276462.0	0.258	1.07
31 <sub>9,22</sub> –30 <sub>9,21</sub>	276460.409	28.4	299.9	<sup>1</sup>		
31 <sub>6,26</sub> –30 <sub>6,25</sub>	276968.682	29.8	251.4	276969.8	0.873	0.665
31 <sub>6,25</sub> –30 <sub>6,24</sub>	276968.949	29.8	251.4	<sup>1</sup>		
31 <sub>4,28</sub> –30 <sub>4,27</sub>	277300.828	30.5	230.0	277301.4	0.330	0.731
31 <sub>5,27</sub> –30 <sub>5,26</sub>	277347.421	30.2	239.7	277343.9	0.703 <sup>4</sup>	0.702
32 <sub>2,31</sub> –31 <sub>2,30</sub>	278820.152	31.8	227.3	278820.7	1.21 <sup>17</sup>	0.781
32 <sub>1,31</sub> –31 <sub>1,30</sub>	279609.687	31.8	227.1	279608.8	0.902	0.786

<sup>1</sup> blended with the last one<sup>2</sup> blended with  $\text{CH}_3\text{OCH}_3$ <sup>3</sup> blended with  $^{13}\text{CH}_3\text{CH}_2\text{CN}$ <sup>4</sup> blended with unidentified line<sup>5</sup> blended with  $\text{CH}_3\text{C}^{15}\text{N}$ <sup>6</sup> blended with  $\text{CH}_2\text{CHCN}$   $\nu_{11} = 1$ <sup>7</sup> blended with  $^{13}\text{CH}_3\text{CN}$ <sup>8</sup> blended with  $\text{CH}_3\text{OCOH}$

- <sup>9</sup> blended with  $\text{CH}_3\text{CH}_2\text{CN}$  b type
- <sup>10</sup> blended with  $c\text{-C}_2\text{H}_4\text{O}$
- <sup>11</sup> blended with  $\text{CH}_3\text{CH}_2^{13}\text{CN}$
- <sup>12</sup> blended with  $\text{CH}_3\text{COCH}_3$
- <sup>13</sup> blended with  $\text{CH}_3\text{CHO}$
- <sup>14</sup> blended with  $\text{CH}_3^{18}\text{OH}$
- <sup>15</sup> line blended with the transition:  $J = 29-28, k = 10$
- <sup>16</sup> blended with  $\text{H}^{13}\text{CCCN } \nu_7 = 1$
- <sup>17</sup> blended with  $\text{CH}_3\text{CH}_2\text{CN}$  (high energy transition)

**Table 11.** Emission lines of  $^{13}\text{C}_3\text{H}_7\text{CN}$  (without high blend) present in the frequency range of the Orion KL survey. Column 1 indicates the transition, Col. 2 gives the calculated frequencies, Col. 3 gives the line strength, Col. 4 the energy of the upper level, Col. 5 the observed centroid frequencies assuming that the radial velocities relative to LSR are  $5 \text{ km s}^{-1}$ , Col. 6 the observed temperature of main beam and Col. 7 gives the main beam temperature obtained with the model.

Transitions $J_{K_a, K_c}$	Predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
9 <sub>2,7</sub> -8 <sub>2,6</sub>	80848.938	8.55	23.8	80849.4	0.020	0.018
10 <sub>1,10</sub> -9 <sub>1,9</sub>	86398.476	9.90	24.0	86398.2	0.048	0.026
10 <sub>2,9</sub> -9 <sub>2,8</sub>	88855.082	9.60	27.9	88855.3	0.022	0.026
10 <sub>6,5</sub> -9 <sub>6,4</sub>	89116.024	6.40	63.5	89116.3	0.036	0.034
10 <sub>6,4</sub> -9 <sub>6,3</sub>	89116.024	6.40	63.5	1		
10 <sub>7,4</sub> -9 <sub>7,3</sub>	89118.946	5.10	78.0	1		
10 <sub>7,3</sub> -9 <sub>7,2</sub>	89118.946	5.10	78.0	1		
10 <sub>5,6</sub> -9 <sub>5,5</sub>	89121.500	7.50	51.3	89121.3	0.070	0.042
10 <sub>5,5</sub> -9 <sub>5,4</sub>	89121.507	7.50	51.3	1		
10 <sub>4,7</sub> -9 <sub>4,6</sub>	89142.905	8.40	41.3	89142.3	0.051	0.030
10 <sub>4,6</sub> -9 <sub>4,5</sub>	89143.858	8.40	41.3	1		
10 <sub>3,7</sub> -9 <sub>3,6</sub>	89235.657	9.10	33.5	89236.3	0.028	0.025
10 <sub>1,9</sub> -9 <sub>1,8</sub>	91089.001	9.89	25.2	91089.3	0.046	0.30
11 <sub>1,11</sub> -10 <sub>1,10</sub>	94979.834	10.9	28.5	94981.3	0.055	0.036
11 <sub>0,11</sub> -10 <sub>0,10</sub>	96452.609	11.0	28.0	96452.3	0.048	0.038
11 <sub>7,5</sub> -10 <sub>7,4</sub>	98033.905	6.55	82.7	98033.2	0.063	0.071
11 <sub>7,4</sub> -10 <sub>7,3</sub>	98033.905	6.55	82.7	1		
11 <sub>5,7</sub> -10 <sub>5,6</sub>	98042.553	8.73	56.0	98043.2	0.146 <sup>2</sup>	0.072
11 <sub>5,6</sub> -10 <sub>5,5</sub>	98042.573	8.73	56.0	1		
11 <sub>4,8</sub> -10 <sub>4,7</sub>	98072.727	9.55	46.0	98074.2	0.053	0.040
11 <sub>4,7</sub> -10 <sub>4,6</sub>	98074.629	9.55	46.0	1		
11 <sub>3,9</sub> -10 <sub>3,8</sub>	98117.427	10.2	38.2	98118.2	0.066	0.035
11 <sub>3,8</sub> -10 <sub>3,7</sub>	98206.224	10.2	38.3	98206.2	0.113 <sup>3</sup>	0.035
11 <sub>2,9</sub> -10 <sub>2,8</sub>	99172.533	10.6	32.9	99171.2	0.045	0.040
11 <sub>1,10</sub> -10 <sub>1,9</sub>	100109.745	10.9	30.0	100110.2	0.089	0.042
12 <sub>2,11</sub> -11 <sub>2,10</sub>	106514.269	11.7	37.7	106514.1	0.050	0.051
12 <sub>7,6</sub> -11 <sub>7,5</sub>	106949.734	7.92	87.8	106951.1	0.097	0.094
12 <sub>7,5</sub> -11 <sub>7,4</sub>	106949.734	7.92	87.8	1		
12 <sub>6,7</sub> -11 <sub>6,6</sub>	106951.185	9.00	73.4	1		
12 <sub>6,6</sub> -11 <sub>6,5</sub>	106951.186	9.00	73.4	1		
12 <sub>8,5</sub> -11 <sub>8,4</sub>	106956.373	6.67	104.5	106956.1	0.086 <sup>3</sup>	0.051
12 <sub>8,4</sub> -11 <sub>8,3</sub>	106956.373	6.67	104.5	1		
12 <sub>5,8</sub> -11 <sub>5,7</sub>	106966.140	9.92	61.2	106966.1	0.085	0.084
12 <sub>5,7</sub> -11 <sub>5,6</sub>	106966.186	9.92	61.2	1		
12 <sub>9,4</sub> -11 <sub>9,3</sub>	106968.595	5.25	123.3	106969.1	0.068	0.048
12 <sub>9,3</sub> -11 <sub>9,2</sub>	106968.595	5.25	123.3	1		
12 <sub>4,9</sub> -11 <sub>4,8</sub>	107006.773	10.7	51.2	107006.1	0.136 <sup>3</sup>	0.052
12 <sub>2,10</sub> -11 <sub>2,9</sub>	108383.128	11.7	38.1	108383.0	0.068	0.054
12 <sub>1,11</sub> -11 <sub>1,10</sub>	109101.861	11.9	35.2	109102.0	0.065	0.057
13 <sub>1,13</sub> -12 <sub>1,12</sub>	112101.559	12.9	38.9	112102.0	0.082	0.065
13 <sub>0,13</sub> -12 <sub>0,12</sub>	113432.875	13.0	38.4	113430.0	0.156 <sup>3</sup>	0.068
15 <sub>7,9</sub> -14 <sub>7,8</sub>	133703.216	11.7	105.8	133705.7	0.147	0.245
15 <sub>7,8</sub> -14 <sub>7,7</sub>	133703.216	11.7	105.8	1		
15 <sub>8,8</sub> -14 <sub>8,7</sub>	133704.214	10.7	122.4	1		
15 <sub>8,7</sub> -14 <sub>8,6</sub>	133704.214	10.7	122.4	1		
15 <sub>9,7</sub> -14 <sub>9,6</sub>	133714.526	9.60	141.3	133714.7	0.310	0.200
15 <sub>9,6</sub> -14 <sub>9,5</sub>	133714.526	9.60	141.3	1		
15 <sub>6,10</sub> -14 <sub>6,9</sub>	133716.429	12.6	91.3	1		
15 <sub>6,9</sub> -14 <sub>6,8</sub>	133716.434	12.6	91.3	1		
15 <sub>5,11</sub> -14 <sub>5,10</sub>	133754.340	13.3	79.1	133754.7	0.290	0.244
15 <sub>5,10</sub> -14 <sub>5,9</sub>	133754.706	13.3	79.1	1		
15 <sub>4,12</sub> -14 <sub>4,11</sub>	133836.322	13.9	69.1	133836.7	0.152	0.101
15 <sub>3,13</sub> -14 <sub>3,12</sub>	133876.070	14.4	61.4	133875.7	0.152	0.107
15 <sub>3,12</sub> -14 <sub>3,11</sub>	134288.098	14.4	61.4	134287.1	0.170	0.107
15 <sub>1,14</sub> -14 <sub>1,13</sub>	135865.172	14.9	53.5	135864.7	0.114	0.119
15 <sub>2,13</sub> -14 <sub>2,12</sub>	136120.886	14.7	56.3	136120.8	0.149	0.118
16 <sub>1,16</sub> -15 <sub>1,15</sub>	137684.426	15.9	57.5	137685.7	0.229 <sup>3</sup>	0.130
16 <sub>0,16</sub> -15 <sub>0,15</sub>	138673.130	15.9	57.2	138673.7	0.161	0.132
16 <sub>6,11</sub> -15 <sub>6,10</sub>	142642.043	13.8	98.2	142641.6	0.183	0.216
16 <sub>6,10</sub> -15 <sub>6,9</sub>	142642.052	13.8	98.2	1		
16 <sub>11,5</sub> -15 <sub>11,4</sub>	142670.080	8.44	192.4	142669.6	0.118	0.091
16 <sub>11,6</sub> -15 <sub>11,5</sub>	142670.080	8.44	192.4	1		

**Table 11.** continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
16 <sub>5,12</sub> –15 <sub>5,11</sub>	142690.279	14.4	86.0	142690.6	0.355 <sup>4</sup>	0.223
16 <sub>5,11</sub> –15 <sub>5,10</sub>	142690.942	14.4	86.0	1		
16 <sub>4,13</sub> –15 <sub>4,12</sub>	142788.956	15.0	76.0	142788.6	0.247 <sup>3</sup>	0.126
16 <sub>1,15</sub> –15 <sub>1,14</sub>	144700.918	15.9	60.5	144701.6	0.188	0.148
16 <sub>2,14</sub> –15 <sub>2,13</sub>	145371.524	15.8	63.3	145370.7	0.131	0.146
17 <sub>1,17</sub> –16 <sub>1,16</sub>	146187.443	16.9	64.5	146185.7	0.175	0.157
17 <sub>8,10</sub> –16 <sub>8,9</sub>	151539.231	13.2	136.5	151540.1	0.200	0.222
17 <sub>8,9</sub> –16 <sub>8,8</sub>	151539.231	13.2	136.5	1		
17 <sub>7,11</sub> –16 <sub>7,10</sub>	151544.629	14.1	119.9	151545.6	0.255	0.319
17 <sub>7,10</sub> –16 <sub>7,9</sub>	151544.629	14.1	119.9	1		
17 <sub>9,9</sub> –16 <sub>9,8</sub>	151546.481	12.2	155.4	1		
17 <sub>9,8</sub> –16 <sub>9,7</sub>	151546.481	12.2	155.4	1		
17 <sub>12,6</sub> –16 <sub>12,5</sub>	151614.701	8.53	225.2	151615.5	0.251 <sup>5</sup>	0.096
17 <sub>12,5</sub> –16 <sub>12,4</sub>	151614.701	8.53	225.2	1		
17 <sub>5,13</sub> –16 <sub>5,12</sub>	151629.833	15.5	93.3	151629.5	0.587 <sup>3</sup>	0.253
17 <sub>5,12</sub> –16 <sub>5,11</sub>	151630.990	15.5	93.3	1		
17 <sub>3,15</sub> –16 <sub>3,14</sub>	151744.014	16.5	75.5	151744.5	0.59	0.208
17 <sub>4,14</sub> –16 <sub>4,13</sub>	151746.231	16.1	83.3	1		
17 <sub>2,15</sub> –16 <sub>2,14</sub>	154609.632	16.8	70.7	154609.4	0.275	0.177
18 <sub>1,18</sub> –17 <sub>1,17</sub>	154679.365	17.9	71.9	154679.4	0.208	0.188
18 <sub>8,11</sub> –17 <sub>8,10</sub>	160457.796	14.4	144.2	160458.0	0.383	0.268
18 <sub>8,10</sub> –17 <sub>8,9</sub>	160457.796	14.4	144.2	1		
18 <sub>9,10</sub> –17 <sub>9,9</sub>	160462.906	13.5	163.1	160463.0	0.269	0.261
18 <sub>9,9</sub> –17 <sub>9,8</sub>	160462.906	13.5	163.1	1		
18 <sub>7,12</sub> –17 <sub>7,11</sub>	160467.290	15.3	127.6	160467.9	0.349	0.308
18 <sub>7,11</sub> –17 <sub>7,10</sub>	160467.290	15.3	127.6	1		
18 <sub>6,13</sub> –17 <sub>6,12</sub>	160499.863	16.0	113.2	160500.5	0.409	0.401
18 <sub>6,12</sub> –17 <sub>6,11</sub>	160499.899	16.0	113.2	1		
18 <sub>11,8</sub> –17 <sub>11,7</sub>	160501.426	11.3	207.4	1		
18 <sub>11,7</sub> –17 <sub>11,6</sub>	160501.426	11.3	207.4	1		
18 <sub>3,16</sub> –17 <sub>3,15</sub>	160669.490	17.5	83.2	160671.4	0.282 <sup>7</sup>	0.193
18 <sub>4,15</sub> –17 <sub>4,14</sub>	160707.921	17.1	91.0	160708.4	0.237	0.185
18 <sub>4,14</sub> –17 <sub>4,13</sub>	160770.345	17.1	91.0	160769.3	0.311	0.184
18 <sub>1,17</sub> –17 <sub>1,16</sub>	162220.345	17.9	75.6	162220.5	0.424 <sup>6</sup>	0.209
19 <sub>0,19</sub> –18 <sub>0,18</sub>	163802.317	18.9	79.6	163802.3	0.281	0.222
19 <sub>2,18</sub> –18 <sub>2,17</sub>	167806.016	18.8	85.3	167805.3	0.368 <sup>3</sup>	0.230
19 <sub>8,12</sub> –18 <sub>8,11</sub>	169377.118	15.6	152.4	169379.1	0.375	0.370
19 <sub>8,11</sub> –18 <sub>8,10</sub>	169377.118	15.6	152.4	1		
19 <sub>9,11</sub> –18 <sub>9,10</sub>	169379.651	14.7	171.2	1		
19 <sub>9,10</sub> –18 <sub>9,9</sub>	169379.651	14.7	171.2	1		
19 <sub>7,13</sub> –18 <sub>7,12</sub>	169391.355	16.4	135.7	169392.8	0.571 <sup>2</sup>	0.398
19 <sub>7,12</sub> –18 <sub>7,11</sub>	169391.356	16.4	135.7	1		
19 <sub>10,10</sub> –18 <sub>10,9</sub>	169393.825	13.7	192.3	1		
19 <sub>10,9</sub> –18 <sub>10,8</sub>	169393.825	13.7	192.3	1		
19 <sub>5,15</sub> –18 <sub>5,14</sub>	169520.545	17.7	109.1	169520.3	0.359	0.237
19 <sub>5,14</sub> –18 <sub>5,13</sub>	169523.733	17.7	109.1	1		
19 <sub>3,17</sub> –18 <sub>3,16</sub>	169586.931	18.5	91.4	169587.2	0.418	0.227
19 <sub>4,16</sub> –18 <sub>4,15</sub>	169673.658	18.2	99.1	169673.3	0.308	0.229
19 <sub>3,16</sub> –18 <sub>3,15</sub>	170836.180	18.5	91.6	170835.2	0.244	0.320
20 <sub>1,20</sub> –19 <sub>1,19</sub>	171633.311	19.9	88.0	171632.2	0.186	0.257
19 <sub>2,17</sub> –18 <sub>2,16</sub>	173018.908	18.8	86.9	173017.8	0.356	0.247
22 <sub>3,19</sub> –21 <sub>3,18</sub>	198612.272	21.6	118.9	198613.4	0.164	0.356
22 <sub>2,20</sub> –21 <sub>2,19</sub>	200382.276	21.8	114.4	200382.2	0.149	0.374
23 <sub>2,22</sub> –22 <sub>2,21</sub>	202408.825	22.8	121.7	202408.0	0.507 <sup>8</sup>	0.391
23 <sub>6,18</sub> –22 <sub>6,17</sub>	205189.043	21.4	158.1	205190.9	0.416	0.832
23 <sub>6,17</sub> –22 <sub>6,16</sub>	205189.602	21.4	158.1	1		
23 <sub>14,9</sub> –22 <sub>14,8</sub>	205190.642	14.5	335.3	1		
23 <sub>14,10</sub> –22 <sub>14,9</sub>	205190.642	14.5	335.3	1		
23 <sub>5,18</sub> –22 <sub>5,17</sub>	205370.323	21.9	145.9	205370.8	0.337	0.361
24 <sub>1,24</sub> –23 <sub>1,23</sub>	205445.595	23.9	125.0	205444.7	0.379	0.420
23 <sub>4,20</sub> –22 <sub>4,19</sub>	205564.319	22.3	136.0	205563.4	0.215	0.377
23 <sub>4,19</sub> –22 <sub>4,18</sub>	205898.051	22.3	136.1	205899.7	0.153	0.377
23 <sub>3,20</sub> –22 <sub>3,19</sub>	207927.839	22.6	128.8	207927.1	0.860 <sup>3</sup>	0.402
24 <sub>1,23</sub> –23 <sub>1,22</sub>	213478.336	23.9	131.0	213474.6	0.698 <sup>3</sup>	0.450
25 <sub>1,25</sub> –24 <sub>1,24</sub>	213883.341	24.9	135.2	213883.3	0.290	0.464

Table 11. continued.

Transitions $J_{K_a,K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
24 <sub>9,16</sub> –23 <sub>9,15</sub>	213968.681	20.6	218.3	213970.8	0.471 <sup>2</sup>	0.702
24 <sub>9,15</sub> –23 <sub>9,14</sub>	213968.681	20.6	218.3	1		
24 <sub>10,15</sub> –23 <sub>10,14</sub>	213971.696	19.8	239.4	1		
24 <sub>10,14</sub> –23 <sub>10,13</sub>	213971.696	19.8	239.4	1		
24 <sub>8,17</sub> –23 <sub>8,16</sub>	213986.445	21.3	199.4	213990.8	0.620	0.685
24 <sub>8,16</sub> –23 <sub>8,15</sub>	213986.446	21.3	199.4	1		
24 <sub>11,14</sub> –23 <sub>11,13</sub>	213989.714	19.0	262.6	1		
24 <sub>11,13</sub> –23 <sub>11,12</sub>	213989.714	19.0	262.6	1		
24 <sub>3,22</sub> –23 <sub>3,21</sub>	213992.351	23.6	138.5	1		
24 <sub>7,18</sub> –23 <sub>7,17</sub>	214035.383	22.0	182.8	214038.3	0.486	0.693
24 <sub>7,17</sub> –23 <sub>7,16</sub>	214035.402	22.0	182.8	1		
25 <sub>0,25</sub> –24 <sub>0,24</sub>	214093.827	24.9	135.2	214092.0	0.551	0.458
24 <sub>6,19</sub> –23 <sub>6,18</sub>	214135.573	22.5	168.4	214137.0	0.526	0.716
24 <sub>6,18</sub> –23 <sub>6,17</sub>	214136.468	22.5	168.4	1		
24 <sub>17,8</sub> –23 <sub>17,7</sub>	214286.127	12.0	447.9	214285.7	0.123	0.150
24 <sub>17,7</sub> –23 <sub>17,6</sub>	214286.127	12.0	447.9	1		
24 <sub>5,20</sub> –23 <sub>5,19</sub>	214321.447	23.0	156.2	214320.8	0.335	0.398
24 <sub>4,21</sub> –23 <sub>4,20</sub>	214539.290	23.3	146.3	214539.5	0.193	0.420
24 <sub>4,20</sub> –23 <sub>4,19</sub>	214982.257	23.3	146.4	214980.8	0.454	0.422
24 <sub>3,21</sub> –23 <sub>3,20</sub>	217261.059	23.6	139.3	217260.7	0.635 <sup>9</sup>	0.450
25 <sub>2,24</sub> –24 <sub>2,23</sub>	219592.890	24.8	142.3	219591.3	0.366	0.480
25 <sub>1,24</sub> –24 <sub>1,23</sub>	221861.413	24.9	141.6	221860.7	0.316	0.494
26 <sub>0,26</sub> –25 <sub>0,25</sub>	222487.587	25.9	145.9	222488.2	0.600 <sup>3</sup>	0.512
25 <sub>10,16</sub> –24 <sub>10,15</sub>	222887.262	21.0	250.1	222888.1	0.572	1.21
25 <sub>10,15</sub> –24 <sub>10,14</sub>	222887.262	21.0	250.1	1		
25 <sub>9,17</sub> –24 <sub>9,16</sub>	222887.646	21.8	229.0	1		
25 <sub>9,16</sub> –24 <sub>9,15</sub>	222887.646	21.8	229.0	1		
25 <sub>7,19</sub> –24 <sub>7,18</sub>	222969.459	23.0	193.5	222970.7	0.618	1.01
25 <sub>7,18</sub> –24 <sub>7,17</sub>	222969.493	23.0	193.5	1		
25 <sub>13,13</sub> –24 <sub>13,12</sub>	222971.384	18.2	326.4	1		
25 <sub>13,12</sub> –24 <sub>13,11</sub>	222971.384	18.2	326.4	1		
25 <sub>6,20</sub> –24 <sub>6,19</sub>	223085.294	23.6	179.1	223085.7	0.522	0.762
25 <sub>6,19</sub> –24 <sub>6,18</sub>	223086.701	23.6	179.1	1		
25 <sub>5,21</sub> –24 <sub>5,20</sub>	223294.778	24.0	166.9	223293.2	0.709 <sup>3</sup>	0.431
25 <sub>5,20</sub> –24 <sub>5,19</sub>	223332.274	24.0	167.0	223330.7	0.615 <sup>10</sup>	0.443
25 <sub>4,22</sub> –24 <sub>4,21</sub>	223512.772	24.4	157.0	223511.9	0.663 <sup>11</sup>	0.466
25 <sub>3,22</sub> –24 <sub>3,21</sub>	226603.238	24.6	150.1	226603.1	0.323	0.500
25 <sub>2,23</sub> –24 <sub>2,22</sub>	227346.679	24.8	145.9	227346.8	0.664 <sup>7</sup>	0.516
26 <sub>1,25</sub> –25 <sub>1,24</sub>	230216.201	25.8	152.7	230216.8	0.336	0.539
26 <sub>3,24</sub> –25 <sub>3,23</sub>	231640.328	25.6	160.3	231640.5	0.319	0.528
26 <sub>10,17</sub> –25 <sub>10,16</sub>	231802.817	22.2	261.2	231806.7	0.210	0.776
26 <sub>10,16</sub> –25 <sub>10,15</sub>	231802.817	22.2	261.2	1		
26 <sub>9,18</sub> –25 <sub>9,17</sub>	231807.029	22.9	240.1	1		
26 <sub>9,17</sub> –25 <sub>9,16</sub>	231807.029	22.9	240.1	1		
26 <sub>8,19</sub> –25 <sub>8,18</sub>	231836.826	23.5	221.3	231836.8	0.232	0.793
26 <sub>8,18</sub> –25 <sub>8,17</sub>	231836.826	23.5	221.3	1		
26 <sub>5,21</sub> –25 <sub>5,20</sub>	232325.372	25.0	178.1	232325.7	0.201	0.487
26 <sub>4,23</sub> –25 <sub>4,22</sub>	232483.305	25.4	168.2	232484.5	0.230	0.513
27 <sub>2,26</sub> –26 <sub>2,25</sub>	236704.158	26.8	164.7	236702.0	0.586 <sup>3</sup>	0.571
27 <sub>1,26</sub> –26 <sub>1,25</sub>	238550.531	26.8	164.1	238548.2	0.688 <sup>3</sup>	0.584
28 <sub>1,28</sub> –27 <sub>1,27</sub>	239169.936	27.9	168.5	239169.9	0.473	0.603
28 <sub>0,28</sub> –27 <sub>0,27</sub>	239282.049	27.9	168.4	239282.0	0.768 <sup>3</sup>	0.602
27 <sub>8,20</sub> –26 <sub>8,19</sub>	240763.594	24.6	232.8	240764.2	0.818	0.876
27 <sub>8,19</sub> –26 <sub>8,18</sub>	240763.596	24.6	232.8	1		
27 <sub>7,21</sub> –26 <sub>7,20</sub>	240843.497	25.2	216.2	240843.0	0.696	1.33
27 <sub>7,20</sub> –26 <sub>7,19</sub>	240843.592	25.2	216.2	1		
27 <sub>14,13</sub> –26 <sub>14,12</sub>	240844.057	19.7	378.9	1		
27 <sub>14,14</sub> –26 <sub>14,13</sub>	240844.057	19.7	378.9	1		
27 <sub>5,23</sub> –26 <sub>5,22</sub>	241253.894	26.1	189.7	241254.4	0.553 <sup>8</sup>	0.531
27 <sub>4,24</sub> –26 <sub>4,23</sub>	241449.311	26.4	179.8	241449.4	0.916 <sup>2</sup>	0.560
28 <sub>2,27</sub> –27 <sub>2,26</sub>	245234.539	27.8	176.4	245235.6	0.728	0.618
27 <sub>3,24</sub> –26 <sub>3,23</sub>	245276.518	26.7	173.2	245276.9	0.663	0.600
29 <sub>1,29</sub> –28 <sub>1,28</sub>	247591.507	28.9	180.3	247591.1	0.650	0.648
28 <sub>10,19</sub> –27 <sub>10,18</sub>	249633.880	24.4	284.7	249634.1	1.07	0.791
28 <sub>10,18</sub> –27 <sub>10,17</sub>	249633.880	24.4	284.7	1		



**Table 11.** continued.

Transitions $J_{K_a, K_c}$	predicted Frequency	$S_{ij}$	$E_u/k$ (K)	Observed Frequency	Observed $T_{\text{mb}}$ (K)	Model $T_{\text{mb}}$ (K)
28 <sub>8,21</sub> –27 <sub>8,20</sub>	249691.465	25.7	244.8	249692.1	0.875	0.939
28 <sub>8,20</sub> –27 <sub>8,19</sub>	249691.468	25.7	244.8	1		
28 <sub>13,16</sub> –27 <sub>13,15</sub>	249706.003	22.0	361.1	249707.2	0.704	0.543
28 <sub>13,15</sub> –27 <sub>13,14</sub>	249706.003	22.0	361.1	1		
28 <sub>6,23</sub> –27 <sub>6,22</sub>	249954.742	26.7	213.8	249955.1	0.461	0.847
28 <sub>6,22</sub> –27 <sub>6,21</sub>	249959.619	26.7	213.8	1		
28 <sub>2,26</sub> –27 <sub>2,25</sub>	253822.050	27.8	181.2	253822.1	0.564	0.657
30 <sub>1,30</sub> –29 <sub>1,29</sub>	256010.058	29.9	192.6	256010.5	0.398	0.692
29 <sub>9,21</sub> –28 <sub>9,20</sub>	258567.815	26.2	276.1	258568.0	0.355	0.941
29 <sub>9,20</sub> –28 <sub>9,19</sub>	258567.815	26.2	276.1	1		
29 <sub>12,18</sub> –28 <sub>12,17</sub>	258578.344	24.0	345.9	258579.0	0.342 <sup>2</sup>	0.685
29 <sub>12,17</sub> –28 <sub>12,16</sub>	258578.344	24.0	345.9	1		
29 <sub>8,22</sub> –28 <sub>8,21</sub>	258620.477	26.8	257.2	258620.0	0.302	1.06
29 <sub>8,21</sub> –28 <sub>8,20</sub>	258620.483	26.8	257.2	1		
29 <sub>7,23</sub> –28 <sub>7,22</sub>	258725.899	27.3	240.6	258724.1	0.316	1.41
29 <sub>7,22</sub> –28 <sub>7,21</sub>	258726.141	27.3	240.6	1		
29 <sub>4,26</sub> –28 <sub>4,25</sub>	259360.994	28.4	204.3	259359.2	0.323	0.714
29 <sub>5,24</sub> –28 <sub>5,23</sub>	259365.473	28.1	214.1	259362.9	0.239	0.694
29 <sub>4,25</sub> –28 <sub>4,24</sub>	260836.777	28.4	204.6	260837.0	0.403	0.658
31 <sub>0,31</sub> –30 <sub>0,30</sub>	264483.855	30.9	205.3	264485.4	0.445	0.736
30 <sub>3,28</sub> –29 <sub>3,27</sub>	266688.918	29.7	209.0	266686.0	0.477	0.711
30 <sub>10,21</sub> –29 <sub>10,20</sub>	267464.848	26.7	310.0	267466.5	0.355	1.51
30 <sub>10,20</sub> –29 <sub>10,19</sub>	267464.848	26.7	310.0	1		
30 <sub>11,20</sub> –29 <sub>11,19</sub>	267466.842	26.0	333.2	1		
30 <sub>11,19</sub> –29 <sub>11,18</sub>	267466.842	26.0	333.2	1		
30 <sub>7,24</sub> –29 <sub>7,23</sub>	267670.433	28.4	253.5	267669.9	0.158	1.17
30 <sub>7,23</sub> –29 <sub>7,22</sub>	267670.808	28.4	253.5	1		
30 <sub>5,26</sub> –29 <sub>5,25</sub>	268218.881	29.2	227.0	268216.6	0.625	0.664
30 <sub>4,26</sub> –29 <sub>4,25</sub>	270107.598	16.3	217.5	270107.8	1.25 <sup>8</sup>	0.704
31 <sub>2,30</sub> –30 <sub>2,29</sub>	270736.607	30.8	214.2	270735.9	1.22 <sup>3</sup>	0.750
30 <sub>2,28</sub> –29 <sub>2,27</sub>	271166.987	29.8	206.8	271165.3	0.463	0.746
31 <sub>1,30</sub> –30 <sub>1,29</sub>	271812.173	30.8	213.9	271810.9	0.506	0.756
32 <sub>1,32</sub> –31 <sub>1,31</sub>	272839.201	31.8	218.4	272838.8	1.16 <sup>12</sup>	0.790
31 <sub>11,21</sub> –30 <sub>11,20</sub>	276378.367	27.1	346.5	276378.9	0.462	1.65
31 <sub>11,20</sub> –30 <sub>11,19</sub>	276378.367	27.1	346.5	1		
31 <sub>10,22</sub> –30 <sub>10,21</sub>	276380.286	27.8	323.2	1		
31 <sub>10,21</sub> –30 <sub>10,20</sub>	276380.286	27.8	323.2	1		
31 <sub>7,25</sub> –30 <sub>7,24</sub>	276617.294	29.4	266.7	276616.8	0.703	1.26
31 <sub>7,24</sub> –30 <sub>7,23</sub>	276617.868	29.4	266.7	1		
31 <sub>6,26</sub> –30 <sub>6,25</sub>	276856.499	29.8	252.4	276857.8	0.408 <sup>9</sup>	0.672
31 <sub>5,27</sub> –30 <sub>5,26</sub>	277212.157	30.2	240.3	277211.4	0.233	0.708
31 <sub>4,28</sub> –30 <sub>4,27</sub>	277233.840	30.5	230.4	277232.7	0.500	0.738
32 <sub>2,31</sub> –31 <sub>2,30</sub>	279211.176	31.8	227.6	279210.2	0.502	0.790

<sup>1</sup> blended with the last one<sup>2</sup> blended with  $\text{CH}_3^{13}\text{CH}_2\text{CN}$ <sup>3</sup> blended with unidentified line<sup>4</sup> blended with  $\text{CH}_2\text{CHCN}$ <sup>5</sup> blended with HDO<sup>6</sup> blended with  $\text{CH}_3\text{CH}_2\text{CN}$  b type<sup>7</sup> blended with  $\text{CH}_3\text{CH}_2^{13}\text{CN}$ <sup>8</sup> blended with  $\text{CH}_3\text{OCOH}$ <sup>9</sup> blended with  $g^-$ - $\text{CH}_3\text{CH}_2\text{OH}$ <sup>10</sup> blended with  $^{13}\text{CH}_3\text{OH}$ <sup>11</sup> blended with  $\text{CH}_3\text{OCH}_3$ <sup>12</sup> blended with  $^{34}\text{SHD}$