A line confusion-limited millimeter survey of Orion KL[★]

III. Sulfur oxide species

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ABSTRACT

Context. We present a study of the sulfur-bearing species detected in a line confusion-limited survey towards Orion KL performed with the IRAM 30-m telescope in the frequency range 80–281 GHz.

Aims. This study is part of an analysis of the line survey divided into families of molecules. Our aim is to derive accurate physical conditions, as well as molecular abundances, in the different components of Orion KL from observed SO and SO₂ lines.

Methods. As a starting point, we assumed local thermodynamic equilibrium (LTE) conditions obtain rotational temperatures. We then used a radiative transfer model, assuming either LVG or LTE excitation to derive column densities of these molecules in the different components of Orion KL.

Results. We have detected 68 lines of SO, ³⁴SO, ³³SO, and S¹⁸O and 653 lines of SO₂, ³⁴SO₂, ³³SO₂, SO¹⁸O, and SO₂ $\nu_2 = 1$. We provide column densities for all of them and also upper limits for the column densities of S¹⁷O, ³⁶SO, ³⁴S¹⁸O, SO¹⁷O, and ³⁴SO₂ $\nu_2 = 1$ and for several undetected sulfur-bearing species. In addition, we present 2' × 2' maps around Orion IRc2 of SO₂ transitions with energies from 19 to 131 K and also maps with four transitions of SO, ³⁴SO, and ³⁴SO₂. We observe an elongation of the gas along the NE-SW direction. An unexpected emission peak appears at 20.5 km s⁻¹ in most lines of SO and SO₂. A study of the spatial distribution of this emission feature shows that it is a new component of a few arcseconds (~5'') in diameter, which lies ~4'' west of IRc2. We suggest the emission from this feature is related to shocks associated to the BN object.

Conclusions. The highest column densities for SO and SO₂ are found in the high-velocity plateau (a region dominated by shocks) and in the hot core. These values are up to three orders of magnitude higher than the results for the ridge components. We also find high column densities for their isotopologues in both components. Therefore, we conclude that SO and SO₂ are good tracers, not only of regions affected by shocks, but also of regions with warm dense gas (hot cores).

Key words. astrochemistry – ISM: abundances – ISM: clouds – ISM: molecules – radio lines: ISM

1. Introduction

The hot core phase of massive star formation shows a particularly rich chemistry that results from gas-phase chemical reactions and dust grain mantle evaporation. During cloud collapse, depletion of molecules onto dust surfaces takes place. When a new protostar forms, the surrounding gas and dust are heated and molecules sublime from the grain mantles, giving rise to new species in the warm gas and to enhanced abundances of pre-existing species. The existence of molecular outflows and associated shocked regions also plays an important role in the chemical evolution, because they heat up the gas significantly and modify its chemistry.

Orion KL is the closest high-mass star-forming region (≈414 pc, Menten et al. 2007). It is one of the most studied regions owing to its chemical complexity and high gas temperature, which lead to a dense and bright line spectrum. In the Orion KL cloud it is useful to differentiate five distinct components, characterized by different physical and chemical conditions (Blake et al. 1987; Persson et al. 2007; Tercero et al. 2010, and references therein): i) the hot core (HC) with

10'' diameter, which contains a high abundance of complex species (Wilson et al. 2000). It is characterized by line widths of $7 \leq \Delta v \leq 15$ km s⁻¹ at $v_{\text{LSR}} \approx 5$ km s⁻¹. It contains dense and warm gas with $T_K \approx 200$ K and $n(\text{H}_2) \approx 10^7$ cm⁻³. ii) The plateau (PL), a component with 30'' diameter, is affected by shocks with typical line widths of $\Delta v \approx 20$ –25 km s⁻¹ at $v_{\text{LSR}} \approx 6$ km s⁻¹. Typical temperatures and densities are $T_K \approx 150$ K and $n(\text{H}_2) \approx 10^6$ cm⁻³, respectively. iii) The high velocity plateau, HVP, (component affected by shocks, with similar temperature and density to the PL) with line widths of $\Delta v \approx 30$ –55 km s⁻¹ at $v_{\text{LSR}} \approx 11$ km s⁻¹. iv) The compact ridge (CR), with 15'' diameter, centered on $v_{\text{LSR}} \approx 7.5$ km s⁻¹ with line widths of ~4 km s⁻¹. Temperatures are about 110 K and densities $\approx 10^6$ cm⁻³. And v) an extended component, the extended ridge (ER) or ambient cloud, whose emission is characterized by low temperature and density (60 K and 10^5 cm⁻³, respectively), and line widths similar to the compact ridge, but centered on a velocity of $v_{\text{LSR}} \approx 9$ km s⁻¹. The luminosity of the Orion Becklin-Neugebauer/Kleinmann-Low complex is $\sim 10^5 L_\odot$ (Gezari et al. 1998). From the model proposed by Wynn-Williams et al. (1984) and without observational evidence, IRc2 was thought to be the main source of luminosity, heating, and dynamics within the region. However, with the detection of two radio continuum point

[★] Appendix A is available in electronic form at
<http://www.aanda.org>

sources, *B* (coincident with the BN Object) and *I* (centroid of the Orion SiO maser), it was concluded that the intrinsic luminosity of IRC2 is only a fraction ($L \simeq 1000 L_{\odot}$) of the total luminosity of the complex (Gezari et al. 1998), with source *I* being the main contributor.

In this paper, we continue our analysis of the line survey towards Orion IRC2 in the frequency range 80–281 GHz, first presented by Tercero et al. (2010). Here we concentrate on SO, SO₂, and their isotopologues; we model the different cloud components (hot core, plateau, ridge) and derive their physical and chemical conditions, such as column densities and temperatures. Since Gottlieb & Ball (1973) discovered SO in Orion A, there have been many studies of this molecule, as well as SO₂, in this region, including studies of the gas kinematics (Plambeck et al. 1982), molecular abundances (Blake et al. 1987), and spatial distribution (Sutton et al. 1995). Also we find several interferometric studies of these two molecules such as those from Wright et al. (1996) and Beuther et al. (2005). Sulfur-bearing species are especially sensitive to physical and chemical variations during the lifetime of a hot core (Viti et al. 2001), and therefore are considered good probes of their time evolution (Hatchell et al. 1998). As such, they can be used as tools for investigating the chemistry and physical properties of complex star-forming regions (SFRs) located in dense molecular clouds. On the other hand, it is known that some molecules (SiO, H₂CS, SO, SO₂) show increased abundances in regions affected by shocks (Bachiller et al. 1996) as a result of the action of outflows on the surrounding gas. The study of molecular lines from shocked areas provides valuable information about chemical processes and the physical conditions of the shocked components.

The observations are described in Sect. 2. We present more than 700 detected lines of SO, SO₂, their isotopologues, and their vibrationally excited states. In Sect. 3 we present the data and compute rotational temperatures as a first local thermodynamic equilibrium (LTE) approximation. In addition, we present maps of eight emission lines of SO₂, SO, ³⁴SO₂, and ³⁴SO in the 1.3 mm window, over a 2' × 2' region around Orion IRC2 (Sect. 3.4). Unlike other studies of SO, we use a non-LTE radiative transfer code (LVG) to derive physical and chemical parameters (Sect. 4). We provide column density calculations for SO and SO₂, and isotopic abundance ratios, which have been improved over previous works due to the much larger number of available lines and to the up-to-date information on the physical properties of the region and molecular constants. Discussions on our results are included in Sect. 5, while Sect. 6 summarizes the main conclusions.

2. Observations

We continue our analysis of the line survey towards Orion IRC2 covering frequency ranges 80–115.5 GHz, 130–178 GHz, and 197–281 GHz, first presented by Tercero et al. (2010). The observations were carried out using the IRAM 30-m radiotelescope during September 2004 (1.3 mm and 3 mm windows), March 2005 (full 2 mm window), and April 2005 (completion of the 1.3 mm and 3 mm windows). Four SiS receivers operating at 1.3, 2, and 3 mm were used simultaneously, with image sideband rejections within ~13 dB (1.3 mm receivers), 12–16 dB (2 mm receivers), and 20–27 dB (3 mm receivers). System temperatures were in the range 200–800 K for the 1.3 mm receivers, 200–500 K for the 2 mm receivers, and 100–350 K for the 3 mm receivers, depending on the particular frequency, weather conditions, and source elevation. For the spectra between 172–178 GHz, the system temperature was significantly

Table 1. IRAM 30 m telescope efficiency data along the covered frequency range.

Frequency (GHz)	η_{MB}	HVPBW (")
86	0.82	29.0
100	0.79	22.0
145	0.74	17.0
170	0.70	14.5
210	0.62	12.0
235	0.57	10.5
260	0.52	9.5
279	0.48	9.0

higher, 1000–4000 K, owing to proximity of the atmospheric water line at 183.31 GHz. The intensity scale was calibrated using two absorbers at different temperatures and using the atmospheric transmission model (ATM, Cernicharo 1985; Pardo et al. 2001).

Pointing and focus were regularly checked on the nearby quasars 0420-014 and 0528+134. Observations were made in the balanced wobbler-switching mode, with a wobbling frequency of 0.5 Hz and a beam throw in azimuth of $\pm 240''$. No contamination from the off position affected our observations, except for a marginal amount at the lowest elevations (25°) for molecules showing low-*J* emission along the extended ridge. Two filter banks with 512×1 MHz channels and a correlator providing two 512 MHz bandwidths and 1.25 MHz resolution were used as backends. We pointed the observations towards IRC2 at $\alpha(\text{J2000}) = 5^{\text{h}}35^{\text{m}}14.5^{\text{s}}$, $\delta(\text{J2000}) = -5^{\circ}22'30.0''$.

The data were processed using the IRAM GILDAS software¹ (developed by the Institut de Radioastronomie Millimétrique). In our analysis we only considered lines with intensities ≥ 0.02 K, covering three or more channels. Spectra with Gaussian line fits are shown in units of antenna temperature T_{A}^* corrected for atmospheric absorption and spillover losses. Figures with results from LVG/LTE analysis are shown in units of main beam temperature T_{MB} , which is defined as

$$T_{\text{MB}} = (T_{\text{A}}^* / \eta_{\text{MB}}), \quad (1)$$

where η_{MB} is the main beam efficiency. Table 1 shows the half power beam width (HVPBW) and the mean beam efficiencies over the covered frequency range. For further information about the data reduction and line identification, see Tercero et al. (2010).

We also used the 30-m telescope to map a 2' × 2' region around IRC2 at 1.3 mm. In this two-dimensional (2D) line survey (Marcelino et al., in prep.), we covered the 1.3 mm window using the nine pixel HERA receiver array (216–250 GHz) and the EMIR single-pixel heterodyne receivers (200–216 and 250–282 GHz). We also mapped a small fraction of the 3 mm band taking advantage of simultaneous observations with the E230 and E090 receivers. Fully sampled maps over 140×140 arcsec², centered on the position of IRC2, were performed in the on-the-fly (OTF) mapping mode, scanning both in α and δ with a 4'' spacing, and using position-switching to an emission-free reference position at an offset ($-600''$, $0''$) with respect to IRC2. The observations presented here were obtained in February and December 2008 (HERA), February 2010, and January 2012 (EMIR). We used local oscillator settings at frequencies of 109.983, 221.600, 226.100, 235.100, 239.100,

¹ <http://www.iram.fr/IRAMFR/GILDAS>

and 258.000 GHz, depending on the observed transition. We used short Wobbler-switching observations on the central position with a slightly different frequency for each setting, in order to remove all features arising from the image side band. We used the WILMA spectrometer backend, with a total bandwidth of 4 GHz (EMIR), 1 GHz (HERA), and a spectral resolution of 2 MHz, corresponding to velocity resolutions of 5.4 km s^{-1} at 3 mm and 2.7–2.3 at 1.3 mm. Weather conditions were the typically good winter conditions (with opacities ~ 0.1 – 0.2 at 1.3 mm and 1.3–2 mm of precipitable water vapor) resulting in system temperatures of 230–250 K (EMIR) and 300–400 K (HERA), except for observations in February 2010, when conditions were $\tau \sim 0.3$ – 0.4 and 5 mm of pwv. In this case, system temperatures of 150 K and 300–400 K were obtained at 110 and 239 GHz, respectively. Pointing was checked every hour on strong and nearby quasars, and found to have errors of typically less than 3–4 arcsec.

The basic data reduction consisted of fitting and removing first-order polynomial baselines, checking for image sideband contamination and emission from the reference position. HERA data needed further reduction analysis due to the different performance of each pixel in the array. Spectra from all pixels were averaged to obtain a uniform map gridding of $4''$, taking their different flux calibration and internal pointing errors into account (see Marcelino et al., in prep. for details).

3. Results

In total, the survey covers a bandwidth of 168 GHz, and of the 15 200 detected spectral features, about 10 700 have been identified and attributed to 45 molecules, including 191 isotopologues and vibrationally excited states (Tercero et al. 2010). We identify 20 lines of SO, 21 lines of ^{34}SO , 13 lines of ^{33}SO , and 14 lines of S^{18}O . We also detect 166 lines of SO_2 , 129 lines of $^{34}\text{SO}_2$, 85 lines of $^{33}\text{SO}_2$, 129 lines of SO^{18}O , 74 lines of SO^{17}O , and 78 lines of $\text{SO}_2 \nu_2$. Observed transitions of SO have a range of energy E_{up} between 16 and 100 K and a full width at half maximum (FWHM) of 40 km s^{-1} . In the case of SO_2 the energy range for the observed transitions is 12–1480 K and FWHM of 30 – 40 km s^{-1} for transitions $J < 25$ and $\text{FWHM} \sim 10$ – 20 km s^{-1} for transitions $J > 25$. All these identifications are shown in Tables A.8 and A.9. Those tables list the spectroscopic parameters² of each transition, together with the observed line properties of the detected lines.

SO was the first molecule with a $^3\Sigma$ electronic ground-state detected in space by radio techniques (Gottlieb & Ball 1973). Its rotational levels are characterized by the rotational angular momentum quantum number, N , and the total angular momentum

quantum number, J , which includes the contribution of the angular momentum of two unpaired electrons. For ^{33}S and ^{17}O , the nuclear quadrupolar momentum couples with the rotation to produce a hyperfine splitting of the rotational levels. Selection rules for the electric dipole transitions are: $\Delta N = \pm 1$, $\Delta F = 0$, ± 1 , and $\Delta J = 0$, ± 1 , in the absence of external fields. In the case of intermediate coupling, transitions are allowed for $\Delta N = \pm 3$. The magnetic dipole transitions occur with the selection rules: $\Delta N = 0$, ± 2 and $\Delta J = 0$, ± 1 . However, these transitions are extremely weak compared to the electric dipole transitions. We have estimated that the magnetic dipole allowed transitions SO will have intensities ~ 1 – 6 mK , i.e., lines within the confusion limit of Orion ($T_{\text{A}}^* = 20 \text{ mK}$).

SO_2 is an asymmetric molecule. The rotational energy levels are characterized by the three quantum numbers J , K_{-1} , and K_{+1} . Since triatomic molecules are planar, the dipole moment components can only occur in the a - and b -axis directions. The selection rules for a -type transitions are $\Delta J = 0$, ± 1 , $\Delta K_{-1} = 0$, ± 2 , and $\Delta K_{+1} = \pm 1$, ± 3 . For b -type transitions: $\Delta J = 0$, ± 1 , $\Delta K_{-1} = \pm 1$, ± 3 , and $\Delta K_{+1} = \mp 1$, ∓ 3 . SO_2 has its dipole moment along the b axis of the molecule. The nuclear quadrupolar momentum of ^{33}S and ^{17}O also couples with the rotation leading to hyperfine structure.

As a starting point, we fitted each observed line with Gaussian profiles using CLASS to derive the contribution of each cloud spectral component (see Sect. 3.1). We assumed that the emission is optically thin and the observed lines are thermalized at a given temperature that was derived from rotational diagrams (see Goldsmith & Langer 1999), providing rotational temperatures for the different components of the cloud (Sect. 3.3). In Sect. 4 we use a radiative transfer code for a more advanced analysis of the LTE and non-LTE emission of SO and SO_2 species.

3.1. Line profiles

Figures 1–4 show the line profiles of some observed transitions of SO and SO_2 , together with Gaussian fit results. To avoid degeneration, we fixed radial velocities (v_{LSR}) considering the characteristic values of each component of Orion KL. And we left the line width, the integrated intensity, and the antenna temperature as free parameters in the fits (in the results, we took the typical ranges of line widths into account for each component found in the bibliography, discarding those with large differences). In addition to the contribution from the usual components listed above, we also observe an unexpected emission peak centered on a velocity of $\approx 20.5 \text{ km s}^{-1}$. We discuss its origin in Sects. 3.2 and 5.2.

We have detected 20 rotational transitions of SO, eight of which are blended with lines of other species. Figure 1 shows the contribution of the different cloud components to the emerging profile. We tried to fit the lines by considering only one plateau instead of two (at high and low velocity). First we centered this single plateau component on a velocity around 6 – 7 km s^{-1} , but with this we could not fit the part of the line profiles covering high ($> 20 \text{ km s}^{-1}$) velocities. With an increase in the line width of the fit, we reproduced this part of the profiles, but we overestimated the part of the lines that covers negative velocities. We found the opposite behavior if we fixed the single plateau component at higher velocities. Therefore we deduced that the best fits were obtained by considering two plateau components: one at low velocity, PL, ($\sim 6.5 \text{ km s}^{-1}$) and the other at high velocity, HVP, ($\sim 12 \text{ km s}^{-1}$). We observe that the emission mainly arises from these both plateau components. For transitions with angular momentum quantum number $N \lesssim 5$, the strongest emission

² Spectroscopic parameters for SO (dipole moment $\mu = 1.535 \text{ D}$) have been obtained from Clark & DeLucia (1976), Tiemann (1982), Lovas et al. (1992), Cazzoli et al. (1994), Klaus et al. (1996), Bogey et al. (1997), Powell & Lide (1964), and Martin-Drumel (2012). For ^{34}SO and S^{18}O ($\mu = 1.535 \text{ D}$) from Tiemann (1974), Tiemann (1982), Lovas et al. (1992), Klaus et al. (1996), Bogey et al. (1982), and Powell & Lide (1964). And for ^{33}SO ($\mu = 1.535 \text{ D}$) from Klauss et al. (1996), Lovas et al. (1992), and Powell & Lide (1964). In the case of SO_2 and $^{33}\text{SO}_2$ ($\mu = 1.633 \text{ D}$), the spectroscopic parameters were taken from Müller et al. (2000) and Patel et al. (1970). For $^{34}\text{SO}_2$ ($\mu = 1.633 \text{ D}$) from Belov et al. (1998) and Patel et al. (1979). For the isotopologue SO^{18}O ($\mu_a = 0.0328 \text{ D}$, $\mu_b = 1.633 \text{ D}$) obtained from Belov et al. (1998) and for SO^{17}O ($\mu_a = 0.02 \text{ D}$, $\mu_b = 1.633 \text{ D}$) from Müller et al. (2000). For the vibrational state $\text{SO}_2 \nu_2 = 1$, ($\mu = 1.626 \text{ D}$) from Müller & Brünken (2005) and from Patel et al. (1979), and for $^{34}\text{SO}_2 \nu_2 = 1$, ($\mu = 1.626 \text{ D}$) from Maki & Kuritsyn (1990).

Fig. 1. Gaussian fits to the observed SO lines. Dashed line for the plateau, cyan (solid line) for the high-velocity plateau, black for hot core, green for extended ridge, and red for the contribution of the component at 20.5 km s^{-1} . The total fit is shown in magenta. The data are the black histogram spectra.

Fig. 2. Gaussian fits for the SO₂ lines (2 mm data). The total fit is shown in magenta. Plateau is represented with the dashed line, high-velocity plateau in cyan (solid line), hot core in black, compact ridge in blue, extended ridge in green, and 20.5 km s^{-1} component in red. The data are the black histogram spectra.

Fig. 3. Gaussian fits for the SO₂ lines (1.3 mm data). The total fit is shown in magenta. Plateau is represented with the dashed line, high-velocity plateau in cyan (solid line), hot core in black, compact ridge in blue, extended ridge in green, and 20.5 km s⁻¹ component in red. The data are the black histogram spectra.

Fig. 4. Gaussian fits for the SO₂ lines (3 mm data). The total fit is shown in magenta. Plateau is represented with the dashed line, high-velocity plateau in cyan (solid line), hot core in black, compact ridge in blue, extended ridge in green, and 20.5 km s⁻¹ component in red. The data are the black histogram spectra.

is found from the HVP, while for $N \geq 5$ PL presents the highest contribution to the emission. The contribution from the ER is very small. In this LTE analysis of SO, we have not considered the compact ridge component since its contribution is difficult to distinguish from the contribution from the HC. The parameters obtained from Gaussian fits for some of the SO lines are listed in Table A.1.

For SO₂ we have clearly identified 166 rotational transitions (see Figs. 2–4). As indicated by their broad line profiles, we see that most of the emission comes from the plateau components, especially for transitions $J < 20$ where the HVP plays an important role. However, for transitions $J > 20$ the HC

dominates. The parameters obtained for each component from Gaussian fits for SO₂ lines are listed in Tables A.2 and A.3. Comparing this with SO lines, we see that the line profiles of both species are very similar.

3.2. The 20.5 km s⁻¹ feature and absorption at 15 km s⁻¹

Unlike the other species detected in the survey, we clearly observe an emission peak at ≈ 20.5 km s⁻¹ in most SO and SO₂ lines. From Gaussian fits, we find that the line widths are ~ 7.5 km s⁻¹. This feature presents an increase in the line

Fig. 5. Integrated line intensities of the 20.5 km s⁻¹ component as a function of the line frequency for SO transitions.

intensity with frequency (i.e., with smaller beam). Figure 5 shows the integrated intensity, W , as a function of the frequency for the 20.5 km s⁻¹ component for SO lines. We see that, for the same line width, W increases with frequency with a dependence as ν^2 . This means that the size of the region responsible for this velocity component is only a few arcseconds in diameter (<9'', smaller than the IRAM 30-m beam at the highest frequencies). The emission of this component could come from the interaction of the outflow with the ambient cloud; however, it should be noted that while in Orion-KL the v_{LSR} of the different components varies approximately between 3 and 10 km s⁻¹, Scoville et al. (1983) inferred that the *BN* (Becklin-Neugebauer) object in Orion presents a significantly higher LSR velocity of around 21 km s⁻¹, therefore another possibility is that this feature located at 20.5 km s⁻¹ arises from the *BN* source.

On the other hand, between the main emission peak of the line profiles of SO and SO₂ and this emission peak at 20.5 km s⁻¹, we observe a dip at ≈ 15 km s⁻¹. Tercero et al. (2011) also find a velocity component at 15.5 km s⁻¹ in SiS emission lines ($\nu = 0$), and one component of the SiO maser emission ($\nu = 1$). Since the opacity is high for some lines of SO and SO₂, as well as for SiO, another possibility is that this dip may be the result of self-absorption. This could suggest that the SO and SO₂ dips at 15.5 km s⁻¹ are produced by the same gas observed in SiS. In Sect. 5 we draw firmer conclusions about the origin of the dip at 15.5 km s⁻¹ and of the peak at 20.5 km s⁻¹ from maps of SO and SO₂.

3.3. Rotational diagrams

The results from the Gaussian fits have been used to build rotational diagrams for each species. This method involves the representation of the upper level column density normalized by the statistical weight of each rotational level versus the upper level energy, assuming optically thin emission filling the beam (see, e.g., Goldsmith & Langer et al 1999). The expression used to obtain the rotational diagrams, taking an optical depth (C_τ) different to unity into account, is

$$\ln(\gamma_u W/g_u) = \ln(N) - \ln(C_\tau) - \ln(Z) - (E_u/kT), \quad (2)$$

where W is the integrated line intensity, g_u is the statistical weight of each level, N the column density, Z the partition

function, E_u the level energy, k the Boltzman constant, T the temperature considering LTE, and γ_u a constant that depends on the transition frequency and the Einstein coefficient A_{ul} (see Goldsmith & Langer 1999 for more details). Each cloud component is considered separately in the analysis. The rotational diagrams, shown in Figs. A.1 and A.2, were obtained considering only lines without contamination from other species. The rotational temperatures obtained from SO₂ lines are plateau (PL) = 120 ± 20 K, hot core (HC) = 190 ± 60 K, high-velocity plateau (HVP) = 110 ± 20 K, compact ridge (CR) = 80 ± 30 K, extended ridge (ER) = 83 ± 40 and 20.5 km s⁻¹ component = 90 ± 20 K. The results from SO lines are (PL) = 130 ± 20 K, (HC) = 288 ± 90 K, (HVP) = 111 ± 15 K, (ER) = 107 ± 40 K, and 20.5 km s⁻¹ component = 51 ± 10 K. These results are shown in Table A.4, together with the derived column densities and the optical depths. For each component, the obtained rotational temperatures for both molecules are consistent with each other, except for the HC where we obtain a large difference between both temperatures. This could indicate a temperature gradient in the hot core, or simply that the obtained rotational temperature could be overestimated due to the high scatter in the SO data. It would be necessary to have values of this species at higher energies in order to obtain firmer conclusions. We observe that HVP presents a similar rotational temperature to the component of the plateau with lower velocity (PL). For the CR, we obtained a low temperature, probably due to the beam dilution, which is not corrected for in the rotational diagrams. From the diagrams, we also deduce that the new component at 20.5 km s⁻¹ is not a very warm region.

3.4. 2' × 2' maps around IRc2

From the 2D line survey data of Orion KL, (Marcelino et al., in prep.), we produced integrated intensity maps of several SO and SO₂ transitions over different velocity ranges. Figure 7 shows the transitions 4_(2,2)–3_(1,3), 11_(1,11)–10_(0,10), and 14_(3,11)–14_(2,12) of SO₂; Fig. 6 shows the transitions 6₆–5₅ and 3₂–2₁ of SO; and Fig. 8 shows the transition 6₇–5₆ of ³⁴SO and the transition 28_(3,25)–28_(2,26) of ³⁴SO₂. Velocity intervals in the figures have been chosen to represent different source components. For all species and transitions, the strongest contribution arises from the velocity ranges 3–7 km s⁻¹ and 10–14 km s⁻¹, belonging to the HC and the HVP, respectively. The range 3–7 km s⁻¹ also includes PL velocities. These maps show elongated emission along the direction NE-SW. This agrees with Plambeck et al. (2009), who find (from SiO $J = 2-1$ observations with an angular resolution of 0.45'') that the strongest emission arises from a bipolar outflow covering velocities from –13 to 16 km s⁻¹ along the NE-SW direction. This distribution is clearly seen in the maps of ³⁴SO and of SO (see lower panel in Fig. 6), especially in the ranges 7–10 km s⁻¹ (ridge) and 10–14 km s⁻¹ (HVP). Since the line widths corresponding to the HVP are the widest, with $FWHM \sim 30-40$ km s⁻¹, altogether this suggests that the gas of the HVP is expanding in the direction NE-SW. On the other hand, the spatial distribution of ³⁴SO₂ is less extended and usually shows a peak to the NE of IRc2 (also seen in SO₂ and SO at velocities 3–7 km s⁻¹). For this species, the NE-SW distribution is better traced by the 20.5 component. This different behavior should be due to the high energy level ($E_{\text{up}} = 402.1$ K) compared to the other mapped transitions, revealing the most compact and hottest regions in the KL cloud. Also evident on the maps is the new component at 20.5 km s⁻¹. From Figs. 7 and 6 we observe that its emission peak is located between the HC and BN positions.

Fig. 6. SO-integrated intensity maps over different velocity ranges (indicated at the bottom of each panel in km s^{-1}). Row 1 shows the transition 3_2-2_1 ($E_{\text{up}} = 21.1$ K, $A_{\text{ul}} = 1.1 \times 10^{-5} \text{ s}^{-1}$, $S = 1.5$). The interval between contours is 8 K km s^{-1} and the minimum contour is 15 K km s^{-1} . Row 2 shows the transition 6_6-5_5 ($E_{\text{up}} = 56.5$ K, $A_{\text{ul}} = 2.2 \times 10^{-4} \text{ s}^{-1}$, $S = 5.8$). The interval between contours is 20 K km s^{-1} and the minimum contour is 15 K km s^{-1} . The white cross indicates the position of the hot core and the black cross the position of the compact ridge.

Fig. 7. SO₂-integrated intensity maps over different velocity ranges (indicated at the bottom of each panel in km s^{-1}). Row 1 shows the transition $4_{(2,2)}-3_{(1,3)}$ (energy $E_{\text{up}} = 19$ K, Einstein coefficient $A_{\text{ul}} = 7.7 \times 10^{-5} \text{ s}^{-1}$, and line strength $S = 1.7$), row 2 the transition $11_{(1,11)}-10_{(0,10)}$ ($E_{\text{up}} = 60.4$ K, $A_{\text{ul}} = 1.1 \times 10^{-4} \text{ s}^{-1}$, $S = 7.7$), and the last row shows the transition $14_{(3,11)}-14_{(2,12)}$ ($E_{\text{up}} = 119$ K, $A_{\text{ul}} = 1.1 \times 10^{-4} \text{ s}^{-1}$, $S = 8.1$). The interval between contours is 10 K km s^{-1} , the minimum contour is 5 K km s^{-1} and the maximum 155 K km s^{-1} . The white cross indicates the position of the hot core and the black cross the position of the compact ridge.

4. Analysis

4.1. LVG models of the SO lines

In this section we analyze the non-LTE excitation and radiative transfer of SO lines. Following the study started by Tercero et al. (2010), we use an LVG (large velocity gradient) code, MADEX, developed by Cernicharo (2012) assuming that the width of the lines is due to the existence of large velocity gradients across

the cloud, so that the radiative coupling between two relatively close points is negligible, and the excitation problem is local. The LVG models are based on the Goldreich & Kwan (1974) formalism. The final considered fit is the one that reproduces more line profiles better from transitions covering a wide energy range, within a $\sim 30\%$ of the uncertainty in line intensity. For each component of the cloud, we assume uniform physical conditions (kinetic temperature, density, line width, radial velocity,

Fig. 8. ^{34}SO and $^{34}\text{SO}_2$ -integrated intensity maps over different velocity ranges (indicated at the bottom of each panel in km s^{-1}). *Row 1* shows the transition 6_7-5_6 of ^{34}SO ($E_{\text{up}} = 46.7$ K, $A_{\text{ul}} = 2.2 \times 10^{-4} \text{ s}^{-1}$). The contour interval is 7 K km s^{-1} and the minimum contour is 8 K km s^{-1} . *Row 2* shows the transition $28_{(3,25)}-28_{(2,26)}$ of $^{34}\text{SO}_2$ ($E_{\text{up}} = 402.1$ K, $A_{\text{ul}} = 1.5 \times 10^{-4} \text{ s}^{-1}$). The interval between contours is 0.9 K km s^{-1} , and the minimum contour is 1.2 K km s^{-1} . The white cross indicates the position of the hot core and the black cross the position of the compact ridge.

and source size) that we choose taking into account the parameters obtained from the Gaussians fits of the line profiles, the rotational diagrams (with the derived rotational temperatures), and the mapped transitions.

Only for the HC do we consider LTE, which means that most transitions will be thermalized to the same temperature ($T_{\text{rot}} \approx T_K$). If this condition was not satisfied, but we kept considering LTE approximation, the temperatures would be overestimated, and this would produce a variation in the column densities. We cannot estimate whether they would be overestimated or underestimated since we do not know the population of each level. However, the HC of Orion presents a condition of temperature ($T_K > 200$ K) and density ($n(\text{H}_2) \approx 10^7 \text{ cm}^{-3}$), which make the LTE assumption in this component feasible. Corrections for beam dilution are also applied for each line depending on the different beam sizes at different frequencies. Therefore, we fix all the above parameters (see Table 2) leaving only as a free parameter the column density for each component. For the density, $n(\text{H}_2)$, we have adopted fixed values taken from typical values quoted in the literature. In order to determine the uncertainty of the values of hydrogen density and of temperature (T_K), we have run several models varying only the values for these parameters and fixing the rest.

Comparing the intensity differences between the spectra and the obtained line profiles for each case of T and n , we deduce an uncertainty of 20 and 15% for the temperature and the hydrogen density, respectively. Although the parameter which could introduce higher uncertainty in the line profiles is the considered source size for each component, due to it varies depending on the molecular emission used for its determination. We fixed this parameter, as well as the hydrogen density, taking into account also the values used by Tercero et al. (2011) in her models of SiO and SiS. Other sources of uncertainty in the model predictions arise from the spatial overlap of the different cloud components. However, it has been possible to model their contribution thanks to the wide range of frequency and to the large number of lines from different isotopologues. We also find as a source of uncertainty the modest angular resolution of any single-dish line survey, pointing errors (errors as small as $2''$ could introduce important changes in the contribution from each cloud component to

the observed line profiles, especially at 1.3 mm), and line opacity effects. This last source of uncertainty becomes important when lines arising from the plateau are optically thick, causing an underestimation of the column densities of the components that are surrounded by the plateau (compact ridge, hot core, and the 20.5 km s^{-1} component) along the line of sight (Schultz et al. 1999). In Tercero et al. (2010), these sources of uncertainty are explained in more detail. We estimate an uncertainty in our model intensity predictions of 25% for SO and ^{34}SO , and 35% for SO_2 , $^{34}\text{SO}_2$, ^{33}SO , S^{18}O , $^{33}\text{SO}_2$, and SO^{18}O lines (higher uncertainty for SO_2 with respect to SO because of considering LTE instead of LVG approximation).

4.1.1. SO

To model the rotational lines of SO (listed in Table A.8), we used the collisional rates from Lique et al. (2006) for collisions with H_2 . Figure 9 shows our best fit model. The component with the highest SO column density is the HVP, with $N(\text{SO}) = (5 \pm 1) \times 10^{16} \text{ cm}^{-2}$ (see Table 3), although in the HC we also find a high column density with $N(\text{SO}) = (9 \pm 3) \times 10^{15} \text{ cm}^{-2}$. We find that the PL and the 20.5 km s^{-1} component also contribute to the emission, but with a column density that is one order of magnitude lower than the HVP. We did not need to consider any contribution from the CR for SO. We could fit the narrow component by considering only the contribution from a single ridge (the extended ridge) at a temperature $T_K = 60$ K. This agrees with the previous SO analysis in Sect. 3.1.

The model indicates that some SO lines with emission coming mainly from the HVP are optically thick. The optical depths are $\tau = 1.1-1.4$ for the transitions 6_5-5_4 and 6_6-5_5 , and $\tau = 1.4-1.8$ for the transitions 5_6-4_5 and 6_7-5_6 . This means that the column densities obtained for the HC and 20.5 km s^{-1} components, which are surrounded by the plateau, must be considered as lower limits, because the gas in the plateau components can absorb the emission from them. The HVP column density also has to be considered as a lower limit due to this opacity effect. We have also calculated the SO column density from the column density of ^{34}SO , whose lines are optically thin, and from the solar abundance ratio $^{32}\text{S}/^{34}\text{S} = 23$ (Anders & Grevesse 1989).

Table 2. Physical parameters adopted for the Orion KL cloud components.

Component	Source diameter ($''$)	Offset (IRc2) ($''$)	$n(\text{H}_2)$ cm^{-3}	T_K (K)	Δv_{FWHM} (km s^{-1})	v_{LSR} (km s^{-1})
Extended ridge (ER)	120	0	10^5	60	4	8.5
Compact ridge (CR)	15	7	10^6	110	3	8
High-velocity plateau (HVP)	30	4	10^6	100	30	11
Plateau (PL)	20	0	5×10^6	150	25	6
Hot core (HC)	10	2	1.5×10^7	220	10	5.5
20.5 km s^{-1} component	5	2	5×10^6	90	7.5	20.5

Fig. 9. Observed lines of SO (black histogram) and best fit LVG model results (red).

As we expected, Table 3 shows that the column densities of SO obtained from ^{34}SO are higher than those obtained from the fits. This confirms the presence of opacity effects on SO lines. We notice that the SO lines 2_1-1_2 , 5_4-4_4 , 6_5- , and 9_8-8_8 present a poor fit. This is because of the low Einstein coefficients A_{ul} and, mainly, to the low line strengths S ($< 4 \times 10^{-6} \text{ s}^{-1}$ and < 0.35 , respectively) of these lines, which provides small fits. The profile lines that we observe for these transitions are probably caused by stronger emission from other species.

Compared with values obtained in previous studies, such as those of Turner et al. (1991) or Blake et al. (1987), who derived (from source-averaged) $N(\text{SO}) \sim 3 \times 10^{16} \text{ cm}^{-2}$ in the plateau and $N \sim 3 \times 10^{15} \text{ cm}^{-2}$ in the HC, we see our results agree. If we compare these results with our obtained column densities from

^{34}SO , we see that the plateau remains in agreement with these previous studies, but our column density in the HC is one order of magnitude higher.

From the spatial distribution of the SO emission (Fig. 6), we find the integrated intensity peak to be in the velocity ranges $3-7 \text{ km s}^{-1}$ and $10-14 \text{ km s}^{-1}$ for both transitions. These ranges correspond to emission arising mainly from the HC and the HVP, respectively, which agrees with the results obtained for the column densities in these regions. The transition with lowest energy (upper panel) shows a concentric emission distribution around IRc2, while for the transition with higher energy, the emission distribution is elongated toward NE-SW direction. We also observe that, for high energies, the emission peak in the velocity range $3-7 \text{ km s}^{-1}$ is shifted toward the NE of the HC.

Fig. 10. Observed lines of ^{34}SO (black histogram) and best fit LVG model results (red).

4.1.2. ^{34}SO , ^{33}SO , and S^{18}O

Figure 10 shows our best fit model for several rotational lines of ^{34}SO , which are listed in Table A.8. We find that the HVP is also responsible for most of the emission, together with the PL and the 20.5 km s^{-1} component. According to our models, all transitions are optically thin with $\tau < 0.4$, therefore this result is not considered to be a lower limit. The 20.5 km s^{-1} component presents a similar column density to the HVP, and as for SO , its contribution is greater for higher J . In the HC we also find a strong contribution to the emission, however in the ER we find the lowest column density with $N(^{34}\text{SO}) = (7 \pm 2) \times 10^{12} \text{ cm}^{-2}$.

For the case of ^{33}SO we observe in Fig. A.3 that lines are partially blended with other species, which produces a large uncertainty in the derived fit. In addition, the hyperfine structure is noticeable in these transitions, adding more complexity to the line profiles. The fits for this isotopologue were done by adopting the calculated frequencies, intensities, and energies for hyperfine levels up to $N = 30$ provided by the CDMS catalogs. We obtain similar column densities for all components, with $N(^{33}\text{SO}) = (3\text{--}6) \times 10^{14} \text{ cm}^{-2}$ (see Table 3).

As was the case for ^{33}SO , some lines of S^{18}O are blended with other species (Fig. A.4 and Table A.8). In this case we also find similar column densities for all the components, $N(\text{S}^{18}\text{O}) = (1\text{--}5) \times 10^{14} \text{ cm}^{-2}$, except for the CR, the ER, and the 20.5 km s^{-1} component, where we do not find contribution to the emission.

4.1.3. S^{17}O , ^{36}SO , and $^{34}\text{S}^{18}\text{O}$

Owing to the presence of other more intense species, we have detected neither S^{17}O nor ^{36}SO in this survey, but from our data we derive upper limits for their column densities of $N(\text{S}^{17}\text{O}) < 1.3 \times 10^{14} \text{ cm}^{-2}$ and $N(^{36}\text{SO}) < 1.6 \times 10^{14} \text{ cm}^{-2}$, respectively. We note that C^{36}S was detected by Mauersberger et al. (1996) in Orion. They found $^{32}\text{S}/^{36}\text{S} \approx 3500$ which is consistent with our upper limit. We have not detected $^{34}\text{S}^{18}\text{O}$ either; however, assuming the same physical conditions as those for the main isotopologue, we obtain an upper limit for its column density of $N(^{34}\text{S}^{18}\text{O}) < 1.4 \times 10^{14} \text{ cm}^{-2}$.

Table 3. Column densities, N , for SO and its isotopologues obtained from LVG model fits.

Component	SO	^{34}SO	SO^a	^{33}SO	S^{18}O
	$N \times 10^{15}(\text{cm}^{-2})$	$N \times 10^{15}(\text{cm}^{-2})$	$N \times 10^{15}(\text{cm}^{-2})$	$N \times 10^{15}(\text{cm}^{-2})$	$N \times 10^{15}(\text{cm}^{-2})$
Extended ridge (ER)	0.018 ± 0.005	0.007 ± 0.002	0.16 ± 0.05	...	...
High-velocity plateau (HVP)	45 ± 10	4 ± 1	92 ± 23	0.25 ± 0.06	0.24 ± 0.08
Plateau (PL)	5 ± 1	3.0 ± 0.8	69 ± 19	0.5 ± 0.2	0.10 ± 0.04
Hot core (HC)	9 ± 3	2.2 ± 0.5	20 ± 11	0.4 ± 0.1	0.5 ± 0.2
20.5 km s $^{-1}$ component	5 ± 1	3.5 ± 0.8	81 ± 19	0.6 ± 0.2	...

Notes. ^(a) Values calculated from the solar abundance ratio $^{32}\text{S}/^{34}\text{S} = 23$ and from the column densities obtained for ^{34}SO (optically thin lines).

Table 4. Column densities, N , for SO₂ and its isotopologues, obtained from LTE model analysis.

Component	SO ₂	$^{34}\text{SO}_2$	SO ₂ ^(a)	$^{33}\text{SO}_2$	SO ¹⁸ O	SO ¹⁷ O	SO ₂ $v_2 = 1$	$^{34}\text{SO}_2$ $v_2 = 1$
	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)	$N \times 10^{15}$ (cm $^{-2}$)
Extended ridge	0.23 ± 0.06	0.10 ± 0.04	2.3 ± 0.7	0.04 ± 0.001	0.020 ± 0.007	0.007 ± 0.003	0.013 ± 0.003	...
Compact ridge	1.2 ± 0.4	0.5 ± 0.2	12 ± 2	0.07 ± 0.02	0.03 ± 0.01	0.007 ± 0.003	0.20 ± 0.05	0.05 ± 0.02
High-velocity plateau	130 ± 50	7 ± 2	161 ± 46	1.0 ± 0.3	0.9 ± 0.3	0.10 ± 0.04	0.4 ± 0.1	0.06 ± 0.02
Plateau	10 ± 3	0.6 ± 0.2	14 ± 3	0.5 ± 0.2	0.06 ± 0.02	0.03 ± 0.01	...	...
Hot core	100 ± 40	10 ± 4	230 ± 60	4 ± 1	1.5 ± 0.5	0.9 ± 0.3	4 ± 1	0.7 ± 0.2
20.5 km s $^{-1}$ comp.	0.17 ± 0.06	0.04 ± 0.01	0.8 ± 0.2	0.009 ± 0.003	...	...	...	...

Notes. ^(a) Values calculated from the solar abundance ratio $^{32}\text{S}/^{34}\text{S} = 23$ and from the column densities obtained for $^{34}\text{SO}_2$ (optically thin lines).

4.2. LTE models of the SO₂ lines

Due to the lack of collisional rates for levels with energies higher than 90 K, we have assumed LTE excitation to derive the SO₂ column densities. As stated before, this can overestimate or underestimate the calculated column densities. Given that we have collisional rates for SO, we ran our SO models again but considering LTE approximation, in order to compare the results. We observed that the new fits underestimated the line profiles, especially for low transitions. Probably this also happens with the SO₂ case, so we should consider our SO₂ column densities as lower limits. Table A.9 lists the 166 observed rotational lines. Figures 11–14 show a sample of 90 observed lines (ordered by increasing energy) with our best fits overlaid.

The main contribution to the emission of SO₂ comes from the HVP (affecting mainly the lines with energies $E < 400$ K), with a column density of $N(\text{SO}_2) = (1.3 \pm 0.5) \times 10^{17} \text{ cm}^{-2}$. The hottest region (the HC) also presents a similar high value, $N(\text{SO}_2) = (1.0 \pm 0.4) \times 10^{17} \text{ cm}^{-2}$. We find that the CR presents a column density of $N(\text{SO}_2) \sim 10^{15} \text{ cm}^{-2}$, whereas the 20.5 km s $^{-1}$ component presents the lowest contribution to the emission (Table 4).

If we compare our results for SO₂ with those of SO, we find that SO₂ column densities are about one order of magnitude larger in all components, except in the 20.5 km s $^{-1}$ component, where SO presents a higher contribution to the emission. As for SO, we also calculated the SO₂ column densities from $^{34}\text{SO}_2$ (optically thin lines) and the $^{32}\text{S}/^{34}\text{S}$ solar abundance ratio (Table 4). Except for the plateau components, we obtain that the column densities of SO₂ obtained from $^{34}\text{SO}_2$ are larger than those obtained from fits, suggesting they are opacity effects on the SO₂ lines. Comparing with previous results, Blake et al. (1987) obtained (source-averaged) that SO₂ presents a column density in the plateau, $N \sim 10^{16} \text{ cm}^{-2}$. Schilke et al. (2001) derived (beam-averaged) for the same region $N(\text{SO}_2) = 9.7 \times 10^{16} \text{ cm}^{-2}$, which is very similar to our result in the HVP. For the HC, Sutton et al. (1995) found (also

source-averaged) a column density, $N(\text{SO}_2) \sim 9 \times 10^{16} \text{ cm}^{-2}$. Our results agree with these values; however, the large number of transitions that we observed let us determine more accurately that it is the lower temperature plateau component, i.e. the HVP, which contributes more to the emission of SO₂.

From the spatial distribution of the SO₂ emission (Fig. 7), we find the maximum integrated line intensity between the velocity ranges 3–7 km s $^{-1}$ and 10–14 km s $^{-1}$, as well as for SO. These velocity ranges correspond to emission of the HC and the HVP, respectively, which agrees with the column density results obtained above. The emission peak is located towards the NE of IRC2 for the range 3–7 km s $^{-1}$, while the emission peak for the HVP range is located $\sim 4''$ to the SW of IRC2. Emission from the 20.5 km s $^{-1}$ component presents similar integrated intensity to the ridge (range of 7–10 km s $^{-1}$). On the other hand, the map of $^{34}\text{SO}_2$ (Fig. 8) shows the strongest peak emission located northeast of IRC2 for all velocity ranges, although extended emission is seen to the southwest of IRC2, between 10 km s $^{-1}$ and 22 km s $^{-1}$. The $^{34}\text{SO}_2$ transition shown in Fig. 8 has an upper energy level of ~ 400 K and therefore may trace only the hottest component of the gas.

4.2.1. $^{34}\text{SO}_2$

We have detected 130 rotational lines of $^{34}\text{SO}_2$ (Table A.9). A sample of more than 30 lines is shown in Fig. 15.

This isotopologue, whose lines are optically thin, has the highest contribution to its emission from the HC, with $N(^{34}\text{SO}_2) = (1.0 \pm 0.4) \times 10^{16} \text{ cm}^{-2}$. The other components with high column densities are the HVP and the PL with $N(^{34}\text{SO}_2) = (7 \pm 2) \times 10^{15} \text{ cm}^{-2}$ and $N(^{34}\text{SO}_2) = (6 \pm 2) \times 10^{14} \text{ cm}^{-2}$, respectively. Particularly interesting is the column density found in the ER, which presents the same order of magnitude as the PL. The same behavior is also observed in the isotopologues $^{33}\text{SO}_2$ and SO^{18}O , where the column densities in the ER are only 3 to 12 times lower than in PL. This could

Fig. 11. Observed lines (black histogram) of SO₂ with upper state energies lower than 400 K, ordered by increasing energy from top left to bottom right. Best fit LTE model results are overlaid in red.

be due to the strong emission emerging from the HVP and HC affecting the excitation of the energy levels of this isotopologue in the ER, which means that line photons emitted from the inner components will be scattered by the lower density gas in the ER component (radiative scattering). For the compact ridge, we find the emission contributes mainly to the lines at low frequencies. The column density for ³⁴SO₂ obtained in the 20.5 km s⁻¹ component is about 100 times lower than for ³⁴SO (see Table 4).

4.2.2. ³³SO₂, SO¹⁸O, and SO¹⁷O

Figure A.5 shows transitions of ³³SO₂ in the frequency range covered at 1.3, 2, and 3 mm. Several of these are blended with

other species, which makes the derived fits a bit biased. As for ³³SO, hyperfine structure affects the line profiles; however, we did not consider it in the ³³SO₂ model, so the derived column densities could be underestimated.

The most important contribution to the emission of ³³SO₂ comes from the hot core, with $N(^{33}\text{SO}_2) = (4 \pm 1) \times 10^{15} \text{ cm}^{-2}$, and from the HVP. The lowest contribution to the emission arises from the 20.5 km s⁻¹ component, with $N(^{33}\text{SO}_2) = (9 \pm 3) \times 10^{12} \text{ cm}^{-2}$.

For SO¹⁸O (Fig. A.6), the highest column density is also found in the HC, with $N(\text{SO}^{18}\text{O}) = (1.5 \pm 0.5) \times 10^{15} \text{ cm}^{-2}$. The HVP also presents an important contribution to the emission across the frequency range, whereas the PL mainly affects

Fig. 12. Observed lines of SO₂ (black histogram) with upper state energies lower than 400 K (continued), ordered by increasing energy from *top left to bottom right*. Best fit LTE model results are overlaid in red.

lines at 2 mm. The weakest contribution is from the ER, with $N(\text{SO}^{18}\text{O}) \sim 10^{13} \text{ cm}^{-2}$.

Figure A.7 shows the spectra that contain some frequencies of SO¹⁷O, together with our best model. The maximum contribution to the emission of this isotopologue arises from the hot core with $N(\text{SO}^{17}\text{O}) = (8 \pm 3) \times 10^{14} \text{ cm}^{-2}$. We find that the PL and HVP also contribute to the emission, but about four to eight times less than the HC. However, because all lines are weak ($T_{\text{MB}} < 0.3 \text{ K}$) and blended with other species, we should consider these results as upper limits.

4.2.3. SO₂ $\nu_2 = 1$

Figure 16 shows some of the detected lines of vibrationally excited SO₂ ν_2 , which are also listed in Table A.9. The hot core is responsible for most of the emission of this vibrational mode, with a column density one order of magnitude higher than in the other components. From the column densities in the HC for SO₂ in its ground and vibrationally excited states, we can estimate a vibrational temperature, considering that

$$\frac{\exp(-E_{\nu_x}/T_{\text{vib}})}{f_{\nu}} = \frac{N(\text{SO}_2 \nu_x)}{N(\text{SO}_2)}, \quad (3)$$

where E_{ν_x} is the energy of the vibrational state ($E_{\nu_2} = 745.1 \text{ K}$), T_{vib} is the vibrational temperature, $N(\text{SO}_2 \nu_x)$ is the column density of SO₂ in the excited vibrational state, $N(\text{SO}_2)$ the total column density, and f_{ν} is the vibrational partition function, given by

$$f_{\nu} = 1 + \exp(-E_{\nu_3}/T_{\text{vib}}) + 2 \exp(-E_{\nu_2}/T_{\text{vib}}) + \exp(-E_{\nu_1}/T_{\text{vib}}). \quad (4)$$

Taking into account that $N(\text{SO}_2) = N_{\text{(ground)}} \times f_{\nu}$, we only need the energy of the vibrational state and the calculated column densities to derive the vibrational temperature.

We obtain $T_{\text{vib}} = (230 \pm 40) \text{ K}$ for SO₂ $\nu_2 = 1$. This value is similar to the kinetic temperature we assumed for the HC component (220 K). It is unlikely that the $\nu_2 = 1$ level at 745 K above the ground is excited by collisions. The main pumping mechanism could be IR radiation from the HC. A similar situation was found by Tercero et al. (2010) for OCS and other species.

4.2.4. ³⁴SO₂ $\nu_2 = 1$

Figure A.8 shows some observed lines of ³⁴SO₂ $\nu_2 = 1$. The strongest emission comes from the hot core with $N(^{34}\text{SO}_2 \nu_2 = 1) = (7 \pm 2) \times 10^{14} \text{ cm}^{-2}$, although we also find a small contribution from the HVP and the CR, with $N(^{34}\text{SO}_2 \nu_2 = 1) \sim 5 \times 10^{13} \text{ cm}^{-2}$ for both. These contributions mainly affect the lines at 2 mm. Since all the lines we detect are very weak and mixed with other species, we should consider these results as upper limits.

4.3. Isotopic and molecular abundances

From the derived column densities of SO, SO₂, and their isotopologues, we can estimate abundance ratios. These are shown in Table A.5. We compare these ratios with solar isotopic abundance values from Anders & Grevesse (1989).

³²S/³⁴S: from the SO₂ lines we obtain a column density ratio for the PL of $^{32}\text{S}/^{34}\text{S} = 16 \pm 10$, in agreement with previous studies ($^{32}\text{S}/^{34}\text{S} \approx 16$ by Johansson et al. 1984, $^{32}\text{S}/^{34}\text{S} \approx 13$ –16 by

Fig. 13. Observed lines of SO₂ (black histogram) with upper state energies between 400 K and 700 K, ordered by increasing energy from *top left* to *bottom right*. Best fit LTE model results are overlaid in red.

Fig. 14. Observed lines of SO₂ (black histogram) with energies higher than 700 K, ordered by increasing energy from *top left* to *bottom right*. Best fit LTE model results are overlaid in red.

Fig. 15. Observed lines of $^{34}\text{SO}_2$ (black histogram). Best fit LTE model results are shown in red. Boxes with black, blue and green borders correspond to lines observed at 1.3, 2, and 3 mm, respectively.

Blake et al. 1987, and $^{32}\text{S}/^{34}\text{S} = 15 \pm 5$ by Tercero et al. 2010). For the HVP, $^{32}\text{S}/^{34}\text{S} = 20 \pm 13$, which is similar to the value for the solar isotopic abundance ratio and to the result deduced by Persson et al. (2007) where $^{32}\text{S}/^{34}\text{S} \approx 23 \pm 7$. From the SO lines, with the exception of the HVP, we obtain low ratios for $^{32}\text{S}/^{34}\text{S}$ in comparison with the solar abundance, which could be due to opacity effects on the SO lines.

$^{32}\text{S}/^{33}\text{S}$: from $N(\text{SO})/N(^{33}\text{SO})$ we obtain $^{32}\text{S}/^{33}\text{S} = 180 \pm 80$ for the HVP. This value agrees with the solar isotopic abundance ratio, 127, from Anders & Grevesse (1989). For the other three components, the obtained ratios are very low compared to the solar abundance, probably also due to the opacity effects for SO lines. These values should be considered as lower limits. We find similar behavior for the ratio $N(\text{SO}_2)/N(^{33}\text{SO}_2)$.

Fig. 16. Observed lines of $\text{SO}_2 \nu_2 = 1$ (black histogram). Best fit LTE model results are shown in red.

$^{34}\text{S}/^{33}\text{S}$: from $N(^{34}\text{SO}_2)/N(^{33}\text{SO}_2)$ we obtain $^{34}\text{S}/^{33}\text{S} = 4 \pm 3$ for the 20.5 km s^{-1} component and $^{34}\text{S}/^{33}\text{S} = 3\text{--}7$ for the ridge (ER and CR), the HVP, and the HC. These values are similar to the solar abundance ratio (5.5). From $N(^{34}\text{SO})/N(^{33}\text{SO})$ the obtained ratio is $^{34}\text{S}/^{33}\text{S} = 6 \pm 3$ for the HC and both plateau components.

$^{16}\text{O}/^{18}\text{O}$: our results for this ratio in the plateau agree with those obtained by Tercero et al. (2010), who derived $^{16}\text{O}/^{18}\text{O} = 250 \pm 135$ in the plateau from a study of OCS in this region. The compact ridge also presents similar ratio to that obtained by them. However, all these values are lower than the solar isotopic abundance (≈ 500).

SO/SO_2 : in Fig. 18 we present the ratio $N(\text{SO})/N(\text{SO}_2)$ for the different components, as well as for the different isotopologues of SO and SO_2 . We find that SO_2 is more abundant than SO in all components, except in the 20.5 km s^{-1} component. In the HVP, SO_2 is three times more abundant than SO, while in the

HC is up to 11 times more. However, in the 20.5 km s^{-1} component, SO is ~ 30 times more abundant than SO_2 .

$^{34}\text{SO}/^{34}\text{SO}_2$: in the region affected by shocks, this ratio implies that $^{34}\text{SO}_2$ is more abundant (~ 1.7 times) than ^{34}SO . In the hot core, we also find that $^{34}\text{SO}_2$ is more abundant (5 times) than ^{34}SO , whereas in the ER the ratio is much larger ($^{34}\text{SO}_2$ is 14 times more abundant). As was found for SO/SO_2 , the main difference is in the 20.5 km s^{-1} component, where ^{34}SO is ~ 100 times more abundant than $^{34}\text{SO}_2$.

Table A.6 shows the molecular abundances, X , of SO and SO_2 with respect to hydrogen in each component. They were derived using H_2 column density by means of the C^{18}O column density, from the isotopic abundance $^{16}\text{O}/^{18}\text{O}$, and assuming that CO is a good tracer of H_2 and therefore their abundance ratio is roughly constant. The column densities for H_2 are 7.5×10^{22} , 7.5×10^{22} , 2.1×10^{23} , 6.2×10^{22} , $4.2 \times 10^{23} \text{ cm}^{-2}$, and 1.0×10^{23} for the ER, CR, PL, HVP, HC, and the 20.5 km s^{-1} component,

respectively (see Tercero et al. 2011). We observe that the highest abundance of SO is obtained in the HVP, whereas in the HC and in the PL this abundance is ~ 30 times lower. The extended ridge presents the lowest abundance of sulfur monoxide. The abundance of this molecule in the 20.5 km s^{-1} component is about twice larger than in the HC. SO_2 is also more abundant in the HVP (between 8 and 600 times more abundant than in the rest of components). With respect to hydrogen, SO_2 is about one order of magnitude more abundant than SO in the HC and in the ER, while in both plateaus sulfur dioxide is only two-three times more abundant than SO.

4.4. Other sulfur-bearing molecules

We provide here upper limits for the column densities of several sulfur-bearing molecules not detected in our survey. We have assumed the same spectral components as for SO and SO_2 (HC, PL, HVP, CR, and ER) and an LTE approximation, due to the lack of available collision rates. Table 2 shows the adopted temperature values, among other parameters, for each component, and Table A.7 shows the results obtained, the dipole moment of each species, and references for the spectroscopic constants. The upper limit of column density for each species were obtained summing the contribution of all the components.

SO^+ : first detected in the interstellar medium towards the supernova remnant IC443 (Turner et al. 1992), it was proposed as a tracer of dissociative shocks, although later surveys carried out in dark clouds, SFRs, and high velocity molecular outflows suggest that this reactive ion is not associated with shock chemistry (Turner et al. 1994). SO^+ presents a high abundance in PDRs like NGC 7023 and in the Orion Bar (Fuentes et al. 2003). In Orion KL, we obtain an upper limit to its column density of $N(\text{SO}^+) \leq 2.5 \times 10^{14} \text{ cm}^{-2}$, providing an abundance ratio of $N(\text{SO})/N(\text{SO}^+) \geq 2080$. This result implies that UV radiation does not play an important role in this region.

(*cis*)- HOSO^+ : it is the most stable isomeric form of this ion. This species has not yet been detected in the interstellar medium, but its large dipole moment (1.74 D), its easy formation through H_3^+ reacting with SO_2 and the fact that it does not react with H_2 make this ion an excellent candidate for being detected, mainly in hot regions where the parent SO_2 is very abundant. The upper limit calculated for this ion is $N(\text{cis-HOSO}^+) \leq 3.6 \times 10^{13} \text{ cm}^{-2}$.

SSO: this molecule has not been detected yet in the interstellar medium, but it is a plausible candidate, since the oxides SO and SO_2 are particularly abundant, especially in SFRs. Disulfur monoxide (SSO) was spectroscopically studied first by Meschi & Myers (1959) who detected rotational transitions in the ground vibrational state and in the $\nu_2 = 1$ state. Later, Thorwirth et al. (2006) carried out a millimeter and submillimeter wave investigation of SSO in the ground vibrational state to frequencies as high as 470 GHz. We have not detected SSO in our line survey, but we obtain an upper limit for its column density of $N(\text{SSO}) \leq 7.6 \times 10^{14} \text{ cm}^{-2}$, providing an abundance ratio of $N(\text{SO})/N(\text{SSO}) \geq 1155$.

OSiS: silicon oxysulfide was first characterized in the gas phase at high spectral resolution by Thorwirth et al. (2011). It possesses a large dipole moment ($\mu_a = 1.47 \text{ D}$) and its bond distances are very short in comparison with those of SiO and SiS. It has not been detected yet in the interstellar medium, and we obtained an upper limit for the column density of this molecule in Orion KL of $N(\text{OSiS}) \leq 6.3 \times 10^{13} \text{ cm}^{-2}$. Tercero et al. (2010) found that in Orion KL the total column density for SiS in the ground state is $N(\text{SiS}) = (1.4 \pm 0.4) \times 10^{15} \text{ cm}^{-2}$. This result provides an abundance ratio of $N(\text{SiS})/N(\text{OSiS}) \geq 22$.

S_3 : thiozone is a bent chain with a bond to the apex S whose rotational spectrum was first measured by McCarthy et al. (2004a). S_3 has not yet been observed in the interstellar medium; however, it is an excellent candidate for astronomical detection in rich interstellar sources. In addition, S_3 may also exist in the atmosphere of Io, where S_2 has already been detected in the ultraviolet. Owing to the presence of more intense lines from other species we have not detected S_3 in our line survey. We provide an upper limit for its column density of $N(\text{S}_3) \leq 1 \times 10^{15} \text{ cm}^{-2}$.

S_4 : tetrasulfur is a singlet planar trapezoid whose rotational spectrum was observed for the first time by McCarthy et al. (2004a). S_4 has a substantial dipole moment, 0.87 D, hence an intense rotational spectrum across the entire radio band. The upper limit column density we calculated for this molecule is $N(\text{S}_4) \leq 7 \times 10^{14} \text{ cm}^{-2}$.

CH_3SOCH_3 : Barnes et al. (1994) obtained this molecule in the laboratory while investigating the gas-phase reaction of OH with the oxidation of dimethyl sulfide at room temperature. Dimethyl sulfoxide has not been observed yet in the interstellar medium, but we provide an upper limit for its column density of $N(\text{CH}_3\text{SOCH}_3) \leq 1 \times 10^{14} \text{ cm}^{-2}$.

H_2CSO : sulfine was first identified in 1976 as a product of the pyrolysis of a variety of sulfur-bearing precursors. H_2CSO is a planar molecule of C_s symmetry. Joo et al. (1995) analyzed its infrared spectrum at high resolution. We provide an upper limit for the column density for this undetected molecule in the interstellar medium of $N(\text{H}_2\text{CSO}) \leq 3 \times 10^{13} \text{ cm}^{-2}$.

HNSO : thionylimide is a semi-stable molecule that adopts a *cis*-planar structure of C_s symmetry in the ground state. HNSO is the simplest molecule in the group of organic nitrogen-sulfur compounds. We calculated an upper limit for its column density of $N(\text{HNSO}) \leq 4.1 \times 10^{14} \text{ cm}^{-2}$, which provides an abundance ratio $N(\text{SO})/N(\text{HNSO}) \geq 2600$.

o- H_2S_2 : the rotational spectrum of disulfane (H_2S_2) has been measured in the far-infrared, millimeter, and submillimeter (Winnewisser et al. 1966). The density of its spectrum is enhanced by the presence of low-lying torsional and S-S stretching modes. We did not observe this molecule in our line survey but we provide an upper limit for its column density of $N(\text{o-H}_2\text{S}_2) \leq 1.6 \times 10^{14} \text{ cm}^{-2}$.

SSH and H_2SO_4 : these molecules have not yet been detected in the interstellar medium. The calculated upper limits for their column densities are $N(\text{SSH}) \leq 7.1 \times 10^{13} \text{ cm}^{-2}$ and $N(\text{H}_2\text{SO}_4) \leq 1.3 \times 10^{14} \text{ cm}^{-2}$, respectively.

CH_3SSH : methyl hydrodisulfide has not been observed in the interstellar medium. Tyblewski et al. (1986) studied its rotational spectrum, together with that of CH_3SSD , between 18 and 40 GHz providing rotational constants. We derive an upper limit for its column density of $N(\text{CH}_3\text{SSH}) \leq 2.6 \times 10^{14} \text{ cm}^{-2}$.

(*tr*)- HCSSH : the spectrum of dithioformic acid has been studied by Bak et al. (1978), who assigned the rotational transitions of this species in its ground state to a *trans* and *cis* rotamer. We provide an upper limit for the column density of (*tr*)- HCSSH (more stable) $N \leq 3.6 \times 10^{13} \text{ cm}^{-2}$.

5. Discussion

There have been many spectral line surveys of Orion KL aimed at determining the physical and chemical structure of this region (e.g., Blake et al. 1987, Sutton et al. 1995; Schilke et al. 2001). The survey analyzed here was first presented by Tercero et al. (2010), covers the widest frequency range of all of them (80–281 GHz). Due to this wide range and to the large number of observed transitions of SO, and particularly of SO_2 , it has

Fig. 17. Observed lines of SO₂ (black histogram) with energies higher than 700 K, ordered by increasing energy from *top left to bottom right*. Best fit LTE model results considering a hot core at $T_K = 220$ K (green curve) and with a hot core at $T_K = 280$ K (red curve).

been possible not only to determine the structure of the cloud (gas temperature, gas density, size of components, etc.) with better accuracy (the 3 mm window shows best the coldest regions, such as the ER, whereas the 1.3 mm window probes the warmest regions), but also to demonstrate the need for considering a density and temperature gradient in the HC of Orion KL. From rotational diagrams, we found a large difference (~ 100 K) between the rotational temperatures of SO and SO₂, indicating the possibility of a hotter inner region to the HC. We draw the same conclusion from the fits for SO₂ lines with energies $E > 400$ K. To obtain better fits for lines with energies $E > 700$ K, we considered a high column density for the HC, which overestimates in the fit for the lines with energy around 400 K (see Figs. 12 and 13). But by considering an additional inner component to the HC with higher temperature, it would probably be possible to obtain a better fit to the lines with high energies, while avoiding overestimation of lines with intermediate energies. To test this possibility, we fit the SO₂ line profiles with energies $E > 700$ K considering a hotter ($T_K = 280$ K) HC (affecting only the highest energy transitions), with $n(\text{H}_2) = 5 \times 10^6 \text{ cm}^{-3}$, located at 5.5 km s^{-1} , and with $\Delta v_{\text{FWHM}} = 7 \text{ km s}^{-1}$. For a SO₂ column density of $(4 \pm 1) \times 10^{16} \text{ cm}^{-2}$, we improve the line profile fits of these high energies transitions (see Fig. 17). This shows the existence of a temperature and density gradient in the HC of Orion KL. However, its structure should be determined accurately with observations of SO and SO₂ (and mainly of its isotopologues³, which are optically thin) at higher frequencies with telescopes such as APEX.

On the other hand, the large number of observed lines of the ³⁴S and ³³S isotopologues has allowed us to calculate column

densities and isotopic and molecular abundances that are key to understanding the chemical evolution of this region.

5.1. SO and SO₂ as tracers of shocks and hot gas

In Sect. 4 we showed that an important contribution to the emission of SO and SO₂ comes from the HC component of Orion KL. In Fig. 18 we plotted the ratio of $N(\text{SO})/N(\text{SO}_2)$ for the different components, as well as for the different isotopologues of SO and SO₂. The figure shows that the column density of SO₂ in the HC is higher than that for SO. We should take into account that our column densities for SO₂ may have been slightly underestimated because of using an LTE model to infer the column density (instead of LVG, as was used for SO). For that reason, we considered a higher uncertainty (35%) in the model intensity predictions for SO₂, than for SO (20%), as said previously. Moreover, the opacity may affect SO and SO₂ differently, which would in turn affect their column density ratio. But if we consider the result of the ratio ³⁴SO/³⁴SO₂ in the hot core, we observe that SO₂ continues to be more abundant than SO. This could indicate that SO₂ is a better tracer of warm gas than SO.

Our results are consistent with predictions from chemical models of hot cores (e.g., Hatchell et al. 1998). Viti et al. (2004a) modeled the evaporation of ices near massive stars and found that SO₂ becomes more abundant than SO in the hot core from 31,500 years after the formation of a high-mass star. For shorter timescales, SO is much more abundant than SO₂. Thus, the SO/SO₂ ratio could be regarded as a chemical clock (which should decrease with time), and our results showing a lower SO/SO₂ ratio for the HC component seem to suggest a late stage for the hot core evolution in Orion KL.

³ The energies of the observed isotopologues in this survey are < 680 K.

Fig. 18. Ratio $N(\text{SO})/N(\text{SO}_2)$ for each component and for the different isotopologues of SO and SO_2 .

On the other hand, the ratio of SO/SO_2 is higher in the PL and the HVP than in the HC and the ER (see Fig. 18), and in particular for the PL, this ratio reaches values close to or even higher than 1. Since SO is a well-known outflow tracer (e.g., Chernin et al. 1994; Codella & Scappini 2003; Lee et al. 2010; Tafalla et al. 2010), and SO seems to be more enhanced than SO_2 in shocks (from an observational point of view, e.g., Codella & Bachiller 1999; Jiménez-Serra et al. 2005, and from a theoretical point of view, e.g., Viti et al. 2004b; Benedettini et al. 2006, for timescales $\sim 10\,000$ yr), it seems very feasible that the high SO/SO_2 ratios measured in the (high velocity) plateau are the consequence of a definite enhancement of the SO abundance with respect to SO_2 , due to shocks propagating into the surrounding medium of Orion KL.

5.2. Nature of the 15 km s^{-1} dip and 20.5 km s^{-1} velocity component

To properly fit the SO and SO_2 spectra in Orion KL, a new velocity component at 20.5 km s^{-1} had to be included in the model (see Sect. 3.2). In addition, a possible dip at 15.5 km s^{-1} in the SO and SO_2 spectra has been identified. The dip at 15.5 km s^{-1} could be self-absorption due to the high opacity of the observed transitions. However, in all cases, the line strength S is uncorrelated with the amount of absorption. For example, the transition $11_{(1,11)}-10_{(0,10)}$ of SO_2 , with a line strength of $S = 7.7$ and Einstein coefficient $A_{ul} = 1.1 \times 10^{-4}\text{ s}^{-1}$, would be expected to display more self-absorption and therefore a lower integrated intensity than the transition $4_{(2,2)}-3_{(1,3)}$ with $S = 1.7$ and $A_{ul} = 7.7 \times 10^{-5}\text{ s}^{-1}$, but we see the opposite (especially in the range at $14.5-16.5\text{ km s}^{-1}$). In addition, we obtain in Fig. 7 a high integrated intensity in the velocity range $14-18\text{ km s}^{-1}$, when the integrated intensity in the ranges $10-14\text{ km s}^{-1}$ and $18-22\text{ km s}^{-1}$ is also large. Altogether, this suggests that the emission at 15 km s^{-1} is only the sum of contributions of emission coming from the HVP and the 20.5 km s^{-1} component.

With respect to the nature of the emission at 20.5 km s^{-1} , Fig. 18 shows that the column density ratio of SO/SO_2 of this component is about two to three orders of magnitude higher than the other velocity components in Orion KL. This is also true for the $^{34}\text{SO}/^{34}\text{SO}_2$ and $^{33}\text{SO}/^{33}\text{SO}_2$ ratios, suggesting that it is not an opacity effect. Such a high ratio could be due in part to filling factor problems, if the 20.5 km s^{-1} component is much more

compact in SO_2 than in SO^4 , and/or could be the result of applying a different method (LVG for SO vs LTE for SO_2) to infer the column densities. However, the large difference compared to the other components suggests that it is a definite chemical effect, and since the SO/SO_2 ratio is higher in regions associated with shocks such as the HVP and the PL (Sect. 5.1), the 20.5 km s^{-1} component could be related to shocks as well, maybe associated with the explosive dynamical interaction that took place in Orion KL (Gómez et al. 2005; Zapata et al. 2011a) and more specifically to shocks associated with the BN object. This is consistent with the fact that the BN object in Orion presents significantly high CO and ^{13}CO emission at $\sim 20\text{ km s}^{-1}$ (Scoville et al. 1983). Observations combining both single-dish and interferometric data are required to definitely identify the spatial region in Orion KL emitting the bulk of emission at 20 km s^{-1} .

6. Summary and conclusions

This study is part of a series of papers with the goal of analyzing the physical and chemical conditions of Orion KL. The study is divided into different molecular families, and here we have focused on the emission lines of SO and SO_2 and their isotopologues. We have analyzed the IRAM 30-m line survey of Orion KL observed by Tercero et al. (2010), which covers the frequency range 80–281 GHz. We identified more than 700 rotational transitions of these molecules, including lines from the vibrational state $v_2 = 1$ of SO_2 and the isotopologue SO^{17}O , detected for the first time in the interstellar medium. This large sample has let us improve our knowledge about the physical and chemical conditions in Orion KL, especially due to the observation of a large number of SO_2 transitions at high energies. The analysis of SO and SO_2 was carried out using an LTE and LVG radiative transfer model, taking the physical structure of the source into account (hot core, compact ridge, extended ridge, and plateau components).

First, we fit SO and SO_2 lines with Gaussian profiles to obtain an approximate T_{rot} value in each component. We detected a

⁴ In fact, interferometric maps of ^{34}SO in Orion KL reveal emission only from 1 to 15 km s^{-1} (Beuther et al. 2005), indicating that the emission from the 20 km s^{-1} component has probably been filtered out by the interferometer. Given the minimum baseline of the interferometric observations (Beuther et al. 2005), the largest angular scale detectable is $\sim 6''$ (following the Appendix in Palau et al. 2010), similar to the size adopted in this work for the 20.5 km s^{-1} component.

dip at $\sim 15 \text{ km s}^{-1}$ in most of the lines and an emission peak centered on 20.5 km s^{-1} . For the dip at 15 km s^{-1} , we discarded self-absorption as a possible cause, concluding instead that the weak emission is due to the sum of small contributions coming from the HVP and from the 20.5 km s^{-1} feature, which corresponds to an unresolved component ($\sim 5''$ diameter), with line width of $\sim 7.5 \text{ km s}^{-1}$ and with an especially high column density of SO in comparison to SO_2 . Its rotational temperature is $50 \pm 10 \text{ K}$ from SO lines and $90 \pm 20 \text{ K}$ from SO_2 lines. For the rest of the components, the rotational temperatures obtained from SO_2 lines are: plateau (PL) = $120 \pm 20 \text{ K}$, hot core (HC) = $190 \pm 60 \text{ K}$, (HVP) = $110 \pm 20 \text{ K}$, compact ridge (CR) = $80 \pm 30 \text{ K}$, and extended ridge (ER) = $83 \pm 40 \text{ K}$. The results from SO lines are: (PL) = $130 \pm 20 \text{ K}$, (HC) = $288 \pm 90 \text{ K}$, (HVP) = $111 \pm 15 \text{ K}$, and (ER) = $107 \pm 40 \text{ K}$.

The second part of the analysis was carried out using a radiative transfer code. For the case of SO, we analyzed its non-LTE excitation, however, for SO_2 we assumed LTE excitation due to the lack of collisional rates for energies higher than 90 K (we observe SO_2 lines with energies up to 1500 K). We found that most of the emission of SO_2 and SO arises from the HVP, with column densities of $N(\text{SO}_2) = (1.3 \pm 0.3) \times 10^{17} \text{ cm}^{-2}$ and $N(\text{SO}) = (5 \pm 1) \times 10^{16} \text{ cm}^{-2}$, respectively, and from the hot core, in particular in the case of SO_2 , whose column density is similar to that obtained in the HVP. These values are up to three orders of magnitude higher than the column densities obtained for the ridge components. These results let us conclude that SO and SO_2 are good tracers not only of shock-affected areas, but also of hot dense gas. In addition, from the ratios $^{34}\text{SO}/^{34}\text{SO}_2$, $^{33}\text{SO}/^{33}\text{SO}_2$, and $\text{S}^{18}\text{O}/\text{SO}^{18}\text{O}_2$ in the different components of the cloud, we observe that in the HVP (region affected by shocks) sulfur dioxide is up to five times more abundant than SO. The same trend is found in the hot core.

We have also carried out $2' \times 2'$ mapping around Orion IRc2 in a number of lines of SO, SO_2 , and their ^{34}S isotopologues. In Sect. 3.4 we presented maps of three transitions of SO_2 (Fig. 7), two transitions of SO (Fig. 6), one transition of ^{34}SO and one of $^{34}\text{SO}_2$ (Fig. 8). We plotted different velocity ranges for each transition to explore the spatial distribution of the emission. In agreement with our column density results, we found the maximum integrated intensities in the range containing the hot core ($3\text{--}7 \text{ km s}^{-1}$) and in the range $10\text{--}14 \text{ km s}^{-1}$ (corresponding to the HVP), whose emission peak is centered approximately $4''$ to the southwest of IRc2. In all mapped transitions, but especially in those of SO and ^{34}SO , we observe an elongation of the gas along the NE-SW direction. In these maps, we also detected a strong emission in the velocity range located at 20.5 km s^{-1} . From the spatial distribution of this feature and from the analysis of the line profiles, we suggest that this emission is probably related to shocks associated to the BN source or to a gas cloulet ejected in the explosive event that could have taken place in Orion KL.

In this paper, we have also demonstrated the need to consider a temperature and density gradient in the hot core of Orion KL, with a comparison between fits of SO_2 line profiles at high energies, assuming two different temperatures ($T_K = 220 \text{ K}$ and $T_K = 280 \text{ K}$) in the hot core. Only with the low temperature it was not possible to obtain good line fits for $E > 700 \text{ K}$, without avoiding overestimation for lines with intermediate energies. In addition, the large difference between the rotational temperatures in the hot core and the need to consider a large contribution to the SO_2 isotopologue emission in the extended ridge support the conclusion of the presence of temperature and density gradients in Orion KL. However, it would be necessary to

also consider emission lines (mainly from isotopologues) spanning a wider frequency range with observations from other telescopes, such as APEX, in order to determine these gradients accurately. Moreover, to describe this molecular cloud in greater detail while avoiding spectral confusion would require interferometric observations with higher spectral resolution and higher sensitivity (such as those provided by ALMA).

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Appendix A: Figures and tables

Table A.1. SO emission line parameters obtained from Gaussian fits.

Species/ Transition	v_{LSR} (km s ⁻¹)	Plateau Δv (km s ⁻¹)	T_{A}^* (K)	High-velocity plateau v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)	Hot core v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)	Extended ridge v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)	20.5 km s ⁻¹ component v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)
SO 2 ₂ -1 ₁	6.8	27 ± 3	3.86	10.8	34 ± 1	5.00	5.5	11.2 ± 0.3	2.20	8.8	6.5 ± 0.4	1.10	20.5	8.5 ± 0.5	0.91
SO 2 ₃ -1 ₂	6.6	27 ± 1	6.70	11.7	35 ± 1	11.0	5.5	10.5 ± 0.5	4.20	8.5	5.6 ± 0.2	1.51	21.0	7.5 ± 0.4	0.93
SO 3 ₂ -2 ₁	6.8	27 ± 5	7.00	11.8	34 ± 2	7.15	5.3	11.5 ± 0.8	3.70	9.0	5.4 ± 0.2	1.50	20.5	7.5 ± 0.4	1.58
SO 3 ₄ -2 ₃	6.0	27 ± 3	10.45	11.4	37 ± 4	16.0	5.9	9.0 ± 0.3	3.70	...	...	...	20.5	7.5 ± 0.3	1.50
SO 4 ₃ -3 ₂	6.6	23 ± 1	11.50	11.0	36 ± 4	13.2	5.5	8.4 ± 0.5	7.10	...	...	...	21.6	7.5 ± 0.4	2.25
SO 4 ₄ -3 ₃	6.0	25 ± 2	18.00	11.9	36 ± 3	17.9	4.5	10.0 ± 0.2	5.00	...	...	...	21.5	7.5 ± 0.3	4.00
SO 5 ₄ -4 ₃	6.7	24 ± 5	10.93	12.7	37 ± 1	12.0	5.7	9.5 ± 0.4	10.0	...	...	...	21.5	7.5 ± 0.5	2.88
SO 5 ₅ -4 ₄	6.4	28 ± 4	18.00	12.9	42 ± 4	11.0	3.9	9.4 ± 0.5	5.50	...	...	...	20.0	8.3 ± 0.6	5.00
SO 5 ₆ -4 ₅	6.3	28 ± 4	16.95	13.5	39 ± 2	14.0	4.3	9.3 ± 0.4	8.50	8.3	5.9 ± 0.3	2.00	...	...	...
SO 6 ₅ -5 ₄	6.0	29 ± 3	20.00	12.5	36 ± 1	10.5	3.5	7.5 ± 0.6	6.30	9.0	4.0 ± 0.2	3.49	...	...	...
SO 6 ₆ -5 ₅	6.7	35 ± 3	12.62	11.7	35 ± 2	8.99	...	...	...	8.5	6.1 ± 0.5	1.26	...	...	...
SO 6 ₇ -5 ₆	6.0	33 ± 4	20.00	13.3	37 ± 4	16.0	1.5	12.0 ± 0.5	8.80	...	...	...	21.5	8.5 ± 0.5	5.24

Notes. The fit errors are provided by CLASS. v_{LSR} is the LSR central velocity, Δv is the line width, and T_{A}^* is the antenna temperature.

Table A.2. SO₂ parameters from Gaussian fits (lines at 1.3 mm).

Transition	Plateau			High-velocity plateau			Hot core			Compact ridge			Extended ridge			20.5 km s ⁻¹ component		
	v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*
1.3 mm																		
3 _(2,2) -2 _(1,1)	6.4	26 ± 1	5.50	12.9	35 ± 3	5.00	5.0	10.0 ± 0.2	6.60	...	...	...	...	...	...	21.0	8.0 ± 0.4	3.50
4 _(2,2) -3 _(1,3)	6.0	25 ± 1	6.00	12.6	32 ± 5	4.60	4.5	8.0 ± 0.4	5.47	...	...	...	...	...	...	22	7.5 ± 0.5	2.60
4 _(3,1) -4 _(2,2)	6.0	25 ± 1	2.40	11.5	32 ± 3	3.60	3.7	8.9 ± 0.4	1.61	...	...	...	...	...	...	21.0	8.0 ± 0.3	0.69
5 _(2,4) -4 _(1,3)	5.9	26 ± 1	7.00	12.8	38 ± 5	6.40	3.8	12.2 ± 0.3	7.90	...	...	...	...	...	...	20.5	8.0 ± 0.3	3.86
6 _(4,2) -7 _(3,5)	6.0	24 ± 2	1.00	11.5	29 ± 1	1.40	5.0	7.0 ± 0.5	3.30	...	...	...	...	...	...	20.5	8.0 ± 0.3	0.14
7 _(2,6) -6 _(1,5)	6.0	25 ± 1	5.00	12.8	35 ± 2	3.50	5.0	11.0 ± 0.2	2.50	...	...	...	...	...	...	20.5	7.5 ± 0.4	2.00
7 _(3,5) -7 _(2,6)	6.0	23 ± 2	3.00	12.9	33 ± 2	3.30	4.5	9.6 ± 0.3	0.55	...	...	...	...	...	...	20.5	7.5 ± 0.4	0.60
7 _(4,4) -8 _(3,5)	6.3	24 ± 1	2.80	11.6	33 ± 1	1.42	4.4	7.7 ± 0.5	1.40	...	...	...	...	...	...	20.5	7.5 ± 0.4	0.43
11 _(1,11) -10 _(0,10)	6.0	30 ± 4	7.00	12.0	35 ± 1	9.50	4.0	11.9 ± 0.2	9.00	...	...	...	...	...	...	20.5	7.5 ± 0.5	2.70
11 _(2,10) -11 _(1,11)	6.0	25 ± 3	7.00	12.9	33 ± 4	4.40	5.0	8.4 ± 0.3	7.00	...	...	...	...	...	...	21.0	7.5 ± 0.4	2.00
11 _(3,9) -11 _(2,10)	6.0	25 ± 2	3.56	12.7	35 ± 6	4.30	5.7	9.0 ± 0.3	3.02	...	...	...	...	...	...	21.0	8.0 ± 0.3	1.31
11 _(5,7) -12 _(4,8)	6.2	25 ± 2	1.23	11.7	31 ± 1	1.10	5.5	7.5 ± 0.5	0.88	...	...	...	...	...	...	20.5	7.0 ± 0.5	0.21
13 _(1,13) -12 _(0,12)	6.0	25 ± 3	11.00	12.7	38 ± 3	10.6	5.9	10.0 ± 0.2	9.15	...	...	...	...	...	...	21.0	8.0 ± 0.2	2.99
13 _(3,11) -13 _(2,12)	6.0	28 ± 1	10.50	10.8	30 ± 1	10.4	...	...	...	...	...	...	...	...	...	...	...	...
14 _(3,11) -14 _(2,12)	6.6	27 ± 4	6.50	12.9	32 ± 1	5.0	4.5	9.3 ± 0.2	10.0	...	...	...	...	...	...	21.5	7.5 ± 0.3	2.30
14 _(6,8) -15 _(5,11)	6.9	25 ± 2	1.60	...	...	...	5.0	7.2 ± 0.4	1.54	...	...	...	...	...	...	19.3	7.5 ± 0.3	0.37
15 _(3,13) -15 _(2,14)	6.0	24 ± 2	4.20	11.6	35 ± 1	3.90	5.5	8.6 ± 0.2	1.92	...	...	...	...	...	...	21.0	7.5 ± 0.4	1.30
16 _(1,15) -15 _(2,14)	5.9	25 ± 3	4.00	12.6	33 ± 2	4.30	4.8	10.0 ± 0.1	4.89	...	...	...	...	...	...	21.5	7.5 ± 0.3	2.05
16 _(1,15) -16 _(0,16)	6.0	24 ± 2	3.50	12.3	34 ± 3	3.30	5.7	13.0 ± 0.5	4.42	...	...	...	...	...	...	20.5	7.5 ± 0.4	1.67
16 _(3,13) -16 _(2,14)	6.0	25 ± 3	5.79	12.0	34 ± 3	2.50	4.9	9.0 ± 0.3	5.57	...	...	...	...	...	...	21.0	7.5 ± 0.4	1.50
18 _(3,15) -18 _(2,16)	6.0	24 ± 1	4.50	12.3	32 ± 1	5.00	4.5	10.3 ± 0.2	5.10	...	...	...	...	...	...	20.5	7.5 ± 0.3	1.98
20 _(3,17) -20 _(2,18)	6.0	28 ± 3	5.00	12.5	41 ± 3	3.60	4.8	9.1 ± 0.3	6.09	...	...	...	...	...	...	20.5	8.5 ± 0.2	1.54
20 _(7,13) -21 _(6,16)	6.0	20 ± 1	0.40	11.5	24 ± 2	0.45	5.2	6.0 ± 0.6	0.77	...	...	...	...	...	...	...	...	...
24 _(3,21) -24 _(2,22)	6.0	27 ± 3	3.00	11.5	36 ± 1	0.98	5.3	8.8 ± 0.3	4.38	...	...	...	...	...	...	20.5	7.5 ± 0.3	0.60
26 _(3,23) -26 _(2,24)	6.9	25 ± 4	3.50	...	...	...	5.0	7.8 ± 0.5	3.95	...	...	...	...	...	...	...	...	...
28 _(4,24) -28 _(3,25)	6.3	23 ± 3	2.65	12.4	27 ± 1	1.85	4.0	8.7 ± 0.3	3.76	...	...	...	...	...	...	...	...	...

Notes. The fit errors are provided by CLASS. v_{LSR} is the LSR central velocity, Δv is the line width, and T_{A}^* is the antenna temperature. The units of v_{LSR} , Δv , and T_{A}^* are km s⁻¹, km s⁻¹, and K, respectively, in all the cases.

Table A.3. SO₂ parameters from Gaussian fits (lines at 2–3 mm).

Transition	Plateau			High-velocity plateau			Hot core		Compact ridge		Extended ridge		20.5 km s ⁻¹ component		
	v_{LSR} (km s ⁻¹)	Δv (km s ⁻¹)	T_{A}^* (K)	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*	v_{LSR}	Δv	T_{A}^*
2 mm															
$2_{(2,0)}-2_{(1,1)}$	6.0	22 ± 2	4.00	11.7	32 ± 2	3.00	5.5	9.0 ± 0.3	...	...	...	...	20.5	7.5 ± 0.3	1.15
$3_{(2,2)}-3_{(1,3)}$	6.0	25 ± 4	4.40	12.5	32 ± 2	4.10	5.5	9.1 ± 0.3	5.37	...	...	...	20.5	7.5 ± 0.2	1.00
$5_{(1,5)}-4_{(0,4)}$	6.0	24 ± 1	6.09	11.7	33 ± 1	6.40	5.5	8.0 ± 0.2	2.97	...	...	...	21.0	7.0 ± 0.2	1.50
$5_{(2,4)}-5_{(1,5)}$	6.0	26 ± 1	5.00	12.0	32 ± 3	8.00	5.5	9.2 ± 0.9	5.51	...	...	...	20.5	7.5 ± 0.3	1.00
$6_{(2,4)}-6_{(1,5)}$	6.0	25 ± 1	5.94	11.6	33 ± 3	5.50	5.5	11.1 ± 0.3	3.05	0.40	...	...	20.5	7.5 ± 0.2	1.80
$7_{(1,7)}-6_{(0,6)}$	6.0	25 ± 3	8.00	12.0	33 ± 2	10.0	5.8	9.0 ± 0.1	8.16	...	...	...	20.5	7.5 ± 0.1	3.00
$7_{(2,6)}-7_{(1,7)}$	6.0	25 ± 1	6.00	12.3	34 ± 3	6.60	5.5	8.8 ± 0.1	6.32	...	...	...	21.0	7.5 ± 0.3	2.10
$8_{(2,6)}-8_{(1,7)}$	6.0	23 ± 1	5.70	12.7	34 ± 3	6.00	5.7	7.0 ± 0.4	5.48	...	5.1 ± 0.3	1.52	...	...	...
$10_{(0,10)}-9_{(1,9)}$	6.0	25 ± 1	11.0	11.9	35 ± 2	8.00	4.0	10.0 ± 0.5	5.00	4.49	...	...	20.5	7.5 ± 0.1	2.50
$12_{(1,11)}-12_{(0,12)}$	6.0	25 ± 1	3.92	12.1	33 ± 3	4.20	5.5	11.7 ± 0.7	2.46	...	6.1 ± 0.5	0.84	20.5	7.5 ± 0.3	1.40
$14_{(1,13)}-14_{(0,14)}$	6.0	25 ± 1	6.00	11.7	32 ± 5	6.93	5.0	10.0 ± 0.3	4.50	7.3	4.5 ± 0.5	1.96	20.5	7.5 ± 0.2	2.00
$14_{(2,12)}-14_{(1,13)}$	6.2	23 ± 2	6.50	11.9	34 ± 5	6.40	5.8	8.2 ± 0.2	4.89	...	5.4 ± 0.3	1.44	20.5	7.5 ± 0.2	2.00
$16_{(2,14)}-16_{(1,15)}$	6.0	25 ± 3	6.00	11.6	33 ± 3	5.50	5.5	10.2 ± 0.2	4.05	7.0	6.0 ± 0.2	0.20	20.5	7.5 ± 0.2	1.80
$18_{(2,16)}-18_{(1,17)}$	6.0	24 ± 3	6.50	11.6	32 ± 2	6.00	5.0	10.3 ± 0.2	3.00	7.5	6.1 ± 0.2	1.72	20.5	7.5 ± 0.3	1.59
3 mm															
$8_{(1,7)}-8_{(0,8)}$	6.0	22 ± 1	3.67	11.3	32 ± 1	4.40	5.5	9.1 ± 0.2	1.15	8.0	5.5 ± 0.4	2.21	...	7.5 ± 0.4	0.90
$8_{(3,5)}-9_{(2,8)}$	6.0	24 ± 2	0.82	11.7	30 ± 3	1.10	5.8	10.0 ± 0.2	0.83	...	...	...	...	...	...
$10_{(1,9)}-10_{(0,10)}$	6.0	24 ± 1	3.98	11.4	32 ± 3	6.00	5.5	10.9 ± 0.1	3.50	...	8.6	5.5 ± 0.4	1.19	7.5 ± 0.2	1.50

Notes. The fit errors are provided by CLASS. v_{LSR} is the LSR central velocity, Δv is the line width, and T_{A}^* is the antenna temperature. The units of v_{LSR} , Δv , and T_{A}^* are km s⁻¹, km s⁻¹, and K, respectively, in all the cases.

Table A.4. Rotational temperatures, T_{rot} , and column densities, N , obtained from rotational diagrams.

Component	$T_{\text{rot}}(\text{SO})$ (K)	$N(\text{SO}) \times 10^{15}$ (cm^{-2})	$C_{\tau}(\text{SO})$	$T_{\text{rot}}(\text{SO}_2)$ (K)	$N(\text{SO}_2) \times 10^{15}$ (cm^{-2})	$C_{\tau}(\text{SO}_2)$
Extended ridge (ER)	107 ± 40	0.017 ± 0.001	1.00–1.02	83 ± 40	0.023 ± 0.009	1.04–1.15
Compact ridge (CR)	...	...	...	80 ± 30	1.2 ± 0.2	1.00–1.63
High-velocity plateau (HVP)	111 ± 15	3.9 ± 0.5	1.01–2.12	110 ± 20	9.5 ± 0.6	1.0–1.60
Plateau (PL)	130 ± 20	4.6 ± 0.2	1.01–1.11	120 ± 20	13 ± 1	1.01–1.69
Hot core (HC)	288 ± 90	18 ± 1	1.02–1.64	190 ± 60	33 ± 3	1.00–1.71
20.5 km s^{-1} comp.	51 ± 10	0.014 ± 0.02	1.06–1.36	90 ± 20	4.6 ± 0.1	1.00–1.58

Notes. C_{τ} is the range of optical depths in each component.

Table A.5. Isotopologue ratios and molecular ratios.

Ratio	Extended ridge (ER)	Compact ridge (CR)	High-velocity plateau (HVP)	Plateau (PL)	Hot core (HC1)	20.5 km s^{-1} component	Solar isotopic abundance
Isotopologues ratios							
$\text{SO}_2/^{34}\text{SO}_2$	2 ± 1	2 ± 1	20 ± 13	16 ± 10	10 ± 8	5 ± 3	23
$\text{SO}_2/^{33}\text{SO}_2$	7 ± 4	17 ± 10	137 ± 90	19 ± 13	29 ± 19	20 ± 14	127
$\text{SO}_2/\text{SO}^{18}\text{O}$	12 ± 8	40 ± 26	151 ± 100	164 ± 100	67 ± 48	...	500
$\text{SO}_2/\text{SO}^{17}\text{O}$	34 ± 27	180 ± 110	1300 ± 900	334 ± 200	111 ± 80	...	2625
$^{34}\text{SO}_2/^{33}\text{SO}_2$	3 ± 2	7 ± 4	7 ± 4	1.2 ± 0.8	3 ± 2	4 ± 3	5.5
$^{34}\text{SO}_2/\text{SO}^{18}\text{O}$	5 ± 3	17 ± 11	8 ± 5	10 ± 6	7 ± 5	...	...
$^{33}\text{SO}_2/\text{SO}^{18}\text{O}$	2 ± 1	2 ± 1	1.1 ± 0.7	8 ± 6	2 ± 1	...	...
$\text{SO}/^{34}\text{SO}$	3 ± 1	...	11 ± 5	1.7 ± 0.8	4 ± 2	1.4 ± 0.6	23
$\text{SO}/^{33}\text{SO}$	...	...	180 ± 80	10 ± 5	26 ± 14	8 ± 4	127
$\text{SO}/\text{S}^{18}\text{O}$	...	...	188 ± 90	50 ± 30	18 ± 9	...	500
$^{34}\text{SO}/^{33}\text{SO}$	...	...	16 ± 7	6 ± 3	6 ± 3	6 ± 3	5.5
$^{34}\text{SO}/\text{S}^{18}\text{O}$	...	...	17 ± 8	30 ± 15	4 ± 2	...	...
$^{33}\text{SO}/\text{S}^{18}\text{O}$	...	...	1.1 ± 0.6	5 ± 3	0.7 ± 0.5	...	...
Molecular ratios							
SO/SO_2	0.08 ± 0.05	...	0.3 ± 0.2	0.5 ± 0.3	0.09 ± 0.06	29 ± 16	...
$^{34}\text{SO}/^{34}\text{SO}_2$	0.07 ± 0.04	...	0.6 ± 0.3	5 ± 3	0.2 ± 0.1	97 ± 49	...
$^{33}\text{SO}/^{33}\text{SO}_2$	...	...	0.3 ± 0.1	1.0 ± 0.6	0.10 ± 0.05	71 ± 40	...
$\text{S}^{18}\text{O}/\text{SO}^{18}\text{O}$	...	...	0.3 ± 0.1	2 ± 1	0.3 ± 0.2	...	...

Table A.6. Molecular abundances, X .

Region	Species	X ($\times 10^{-8}$)
Extended Ridge ^a	SO	0.02
	SO ₂	0.31
Compact Ridge ^b	SO	...
	SO ₂	1.60
Plateau ^c	SO	2.38
	SO ₂	4.76
High velocity Plateau ^d	SO	72.5
	SO ₂	210
Hot core ^e	SO	2.14
	SO ₂	23.8
20.5 km s^{-1} component ^f	SO	5.00
	SO ₂	0.17

Notes. Derived molecular abundances, X , assuming: ^(a) $N_{\text{H}_2} = 7.5 \times 10^{22} \text{ cm}^{-2}$, ^(b) $N_{\text{H}_2} = 7.5 \times 10^{22} \text{ cm}^{-2}$, ^(c) $N_{\text{H}_2} = 2.1 \times 10^{23} \text{ cm}^{-2}$, ^(d) $N_{\text{H}_2} = 6.2 \times 10^{22} \text{ cm}^{-2}$, ^(e) $N_{\text{H}_2} = 4.2 \times 10^{23} \text{ cm}^{-2}$, ^(f) $N_{\text{H}_2} = 1.0 \times 10^{23} \text{ cm}^{-2}$.

Table A.7. Column density upper limits for undetected sulfur-bearing molecules in Orion KL.

Molecule	Column density $\leq N \times 10^{14}$ (cm ⁻²)	Dipole moment (D)	References for spectroscopic constants
SO ⁺	2.5	2.30	1
(<i>cis</i>)-HOSO ⁺	0.36	$\mu_a = 1.74$ $\mu_b = 0.49$	2
SSO	7.6	$\mu_a = 0.87$ $\mu_b = 1.18$	3, 4
OSiS	0.63	1.47	5
S ₃	10	0.51	6
S ₄	7.0	0.87	6
H ₂ SO ₄	1.3	$\mu_c = 2.96$	7
CH ₃ SOCH ₃	1.0	$\mu_b = 3.94$ $\mu_c = 0.4$	8, 9
H ₂ CSO	0.3	$\mu_a = 2.95$ $\mu_b = 0.50$	10, 11
HNSO	4.1	$\mu_a = 0.89$ $\mu_b = 0.18$	12, 13
o-H ₂ S ₂	1.6	0.69	14
SSH	0.71	$\mu_a = 1.16$ $\mu_b = 0.83$	1
CH ₃ SSH	2.6	$\mu_a = 1.08$ $\mu_b = 1.22$ $\mu_c = 0.76$	15
(<i>tr</i>)-HCSSH	0.36	1.53	16

References. (1) CDMS catalog; (2) Lattanzi et al. (2011); (3) Thorwirth et al. (2006); (4) Meschi et al. (1959); (5) Thorwirth et al. (2011); (6) Thorwirth et al. (2005); (7) Sedo et al. (2008); (8) Dreizler & Dendl (1964); (9) Margules et al. (2010); (10) Joo et al. (1995); (11) Penn & Olsen (1976); (12) Joo et al. (1996); (13) Kirchhoff (1969); (14) Behrend et al. (1990); (15) Tyblewski et al. (1997); (16) Bak et al. (1978).

Fig. A.1. Rotational diagrams for the plateau, high-velocity plateau, and hot core components. Black dots for SO_2 and green dots for SO . The black and green lines are the best linear fits to the SO_2 and SO points, respectively.

Fig. A.2. Rotational diagrams for the compact ridge, extended ridge, and 20.5 km s⁻¹ component. Black dots for SO₂ and green dots for SO. The black and green lines are the best linear fits to the SO₂ and SO points, respectively.

Fig. A.3. Observed lines of ^{33}SO (black histogram) and best fit LVG model results (red).

Fig. A.4. Observed lines of S^{18}O (black histogram) and best fit LVG model results (red).

Fig. A.5. Observed lines of $^{33}\text{SO}_2$ (black histogram) and best fit LTE model (red). Boxes in black, blue, and green correspond to frequencies at 1.3, 2, and 3 mm, respectively.

Fig. A.6. Observed lines of SO^{18}O (black histogram) and best fit LTE model (red).

Fig. A.7. Observed lines of SO^{17}O (black histogram) and best fit LTE model (red).

Fig. A.8. Observed lines of $^{34}\text{SO}_2$ $v_2 = 1$ (black histogram) and best fit LTE model (red).

Table A.8. Observed lines of SO and its isotopologues.

Species	Transition $N_J-N'_J$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)	Blended with
SO	2 ₂ -1 ₁	86 093.958	1.50	19.3	86 094.4	7.4	11.73	
SO	2 ₃ -1 ₂	99 299.887	2.93	38.6	99 300.4	7.4	22.52	
SO	5 ₄ -4 ₄	100 029.550	0.36	38.6	100 030.5	6.2	5.90	CH ₃ CH ₂ CN
SO	3 ₂ -2 ₁	109 252.181	1.51	21.1	109 252.5	8.1	18.38	
SO	6 ₅ -5 ₅	136 634.660	0.28	50.7	136 636.4	5.2	7.98	CH ₃ OCH ₃
SO	3 ₄ -2 ₃	138 178.654	3.94	15.9	138 178.9	8.5	29.4	
SO	4 ₃ -3 ₂	158 971.811	2.69	28.7	158 972.6	7.5	30.99	
SO	4 ₄ -3 ₃	172 181.403	3.75	33.8	172 182.7	6.7	39.33	
SO	7 ₆ -6 ₆	174 928.886	0.22	64.9	174 931.4	4.7	9.43	HCOOCH ₃
SO	5 ₄ -4 ₃	206 176.013	3.78	38.6	206 177.5	6.8	31.82	
SO	8 ₇ -7 ₇	214 357.054	0.19	81.2	214 359.9	5.0	6.95	CH ₃ OCH ₃ , ¹³ CH ₃ CN CH ₃ CH ₂ CN v_{13}/v_{21}
SO	5 ₅ -4 ₄	215 220.650	4.80	44.1	215 223.6	4.9	33.22	
SO	5 ₆ -4 ₅	219 949.389	5.95	35.0	219 951.1	6.7	38.65	
SO	2 ₁ -1 ₂	236 452.293	0.012	15.8	236 455.1	5.4	1.02	H ₂ C ³⁴ S
SO	3 ₂ -2 ₃	246 404.588	0.012	21.1	246 406.9	6.2	1.62	³³ SO
SO	6 ₅ -5 ₄	251 825.759	4.84	50.7	two peaks 251 826.5 251 829.5	8.1 4.6	35.11 35.11	CH ₃ OH
SO	9 ₈ -8 ₈	254 573.628	0.16	99.7	two peaks 254 571.5 254 577.4	11.5 4.6	6.30 8.92	HCOOCH ₃
SO	6 ₆ -5 ₅	258 255.826	5.83	56.5	258 255.2	9.7	25.94	
SO	6 ₇ -5 ₆	261 843.705	6.95	47.6	two peaks 261 844.5 261 849.5	9.0 2.4	40.10 41.06	
SO	4 ₃ -3 ₄	267 197.745	0.0095	28.7	267 202.5	3.7	4.47	HCN $v_2 = 1$
³⁴ SO	2 ₂ -1 ₁	84 410.684	1.50	19.2	84 411.4	6.5	0.96	
³⁴ SO	5 ₄ -4 ₄	96 781.825	0.36	38.1	96 783.4	4.1	0.27	
³⁴ SO	2 ₃ -1 ₂	97 715.405	2.93	9.1	97 716.3	6.3	2.93	HCOOCH ₃
³⁴ SO	3 ₂ -2 ₁	106 743.363	1.51	20.9	106 744.4	6.1	2.17	H ₃₉ α
³⁴ SO	6 ₅ -5 ₅	132 432.200	0.28	49.9	132 437.5	-3.0	0.96	HCOOCH ₃
³⁴ SO	3 ₄ -2 ₃	135 775.651	3.94	15.6	135 777.4	5.1	6.29	
³⁴ SO	4 ₃ -3 ₂	155 506.801	2.69	28.4	155 508.7	5.3	5.11	
³⁴ SO	4 ₄ -3 ₃	168 815.109	3.75	33.4	168 817.5	4.8	6.01	
³⁴ SO	7 ₆ -6 ₆	169 787.430	0.22	63.8	169 791.6	1.6	0.77	NH ₂ CHO
³⁴ SO	4 ₅ -3 ₄	175 352.753	4.94	24.0	175 354.9	5.3	10.3	
³⁴ SO	5 ₄ -4 ₃	201 846.655	3.78	38.1	201 849.3	5.1	6.35	
³⁴ SO	8 ₇ -7 ₇	208 292.093	0.19	79.9	208 297.1	1.8	0.46	
³⁴ SO	5 ₅ -4 ₄	211 013.019	4.80	43.5	211 015.7	5.2	12.1	
³⁴ SO	5 ₆ -4 ₅	215 839.916	5.95	34.4	215 842.2	5.8	13.4	CH ₃ CH ₂ CN v_{13}/v_{21} HCOOCH ₃ $v_t = 1$
³⁴ SO	2 ₁ -1 ₂	237 107.766	0.01	15.8	237 112.6	2.9	0.25	U line
³⁴ SO	3 ₂ -2 ₃	246 135.724	0.01	20.9	246 137.8	6.5	0.07	CH ₃ CH ₂ ¹³ CN
³⁴ SO	6 ₅ -5 ₄	246 663.394	4.83	49.9	246 666.3	5.5	10.9	
³⁴ SO	9 ₈ -8 ₈	247 598.441	0.16	98.0	247 598.5	8.9	0.62	(CH ₃) ₂ CO
³⁴ SO	6 ₆ -5 ₅	253 207.017	5.83	55.7	253 210.3	5.1	11.8	CH ₃ OH
³⁴ SO	6 ₇ -5 ₆	256 877.810	6.95	46.7	256 880.2	6.2	15.5	
³⁴ SO	4 ₃ -3 ₄	265 866.874	0.01	28.4	265 884.5	-10.9	34.8	HCN
³³ SO	2 ₂ -1 ₁	85 225.608	1.50	19.3	85 224.3	13.6	0.06	
³³ SO	5 ₄ -4 ₄	98 350.735	0.36	38.3	98 353.5	0.6	<0.02	
³³ SO	2 ₃ -1 ₂	98 483.142	2.93	9.2	98 484.3	5.5	0.18	U
³³ SO	3 ₂ -2 ₁	107 956.681	1.51	21.0	107 955.2	13.1	0.20	(CH ₃) ₂ CO
³³ SO	6 ₅ -5 ₅	134 463.407	0.28	50.3	...	...	...	CH ₃ CH ₂ CN ($v = 0$ and v_{13}/v_{21})
³³ SO	3 ₄ -2 ₃	136 939.179	3.94	15.7	136 941.4	4.1	0.70	HC ₃ N $v_5 + v_7$
³³ SO	4 ₃ -3 ₂	157 183.674	2.69	28.5	...	...	...	CH ₃ OH
³³ SO	4 ₄ -3 ₃	170 444.835	3.75	33.6	...	...	...	CH ₃ CH ₂ CN
³³ SO	7 ₆ -6 ₆	172 273.415	0.22	64.4	172 267.6	19.1	0.64	U line

Notes. Emission lines of SO and its isotopologues in the frequency range of the 30-m Orion KL survey. Column 1 indicates the species; Col. 2 the quantum numbers of the line transition; Col. 3 gives the assumed rest frequencies; Col. 4 the line strength; Col. 5 the energy of the upper level; Col. 6 observed frequency assuming a v_{LSR} of 9.0 km s⁻¹; Col. 7 the observed radial velocities; Col. 8 the peak line antenna temperature; and Col. 9 the blended species.

Table A.8. continued.

Species	Transition $N_J-N'_{J'}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)	Blended with
³³ SO	4 ₅ -3 ₄	176 927.358	4.94	24.2	176 926.4 176 932.5	10.6 0.5	2.15 2.66	
³³ SO	5 ₄ -4 ₃	203 942.465	3.78	38.3	203 940.6	11.7	2.74	H ₂ CCO
³³ SO	8 ₇ -7 ₇	211 225.385	1.87	80.5	...	...	...	H ₂ CO
³³ SO	5 ₅ -4 ₄	213 050.062	4.80	43.8	213 052.3	5.9	2.09	SO ₂ , H ₂ ¹³ CO
³³ SO	5 ₆ -4 ₅	217 829.254	5.95	34.7	217 834.6	1.6	3.23	SiS
³³ SO	2 ₁ -1 ₂	236 786.517	0.01	15.8	...	...	...	
³³ SO	3 ₂ -2 ₃	246 260.056	0.01	21.0	...	...	...	CH ₃ CH ₂ CN
³³ SO	6 ₅ -5 ₄	249 162.733	4.83	50.3	249 162.5	9.3	4.05	CH ₃ CH ₂ CN $\nu_{20} = 1$
³³ SO	9 ₈ -8 ₈	250 972.610	0.16	98.8	...	...	...	CH ₃ OH
³³ SO	6 ₆ -5 ₅	255 651.300	5.83	56.1	255 654.1	5.7	3.71	H ¹³ CCCN
³³ SO	6 ₇ -5 ₆	259 281.738	6.95	47.1	259 286.5	3.5	4.16	CH ₃ OH
³³ SO	4 ₃ -3 ₄	266 504.551	0.01	28.5	266 510.4	2.4	0.18	
S ¹⁸ O	5 ₄ -4 ₄	87 876.593	0.36	36.6	87 877.5	5.9	0.03	(CH ₃) ₂ CO
S ¹⁸ O	2 ₃ -1 ₂	93 267.376	2.94	8.7	93 268.5	5.4	0.17	(CH ₃) ₂ CO
S ¹⁸ O	3 ₂ -2 ₁	99 803.663	1.51	20.5	99 804.5	6.5	0.07	HCCCN $\nu_6 = 1$
S ¹⁸ O	4 ₃ -3 ₂	145 874.497	2.69	27.5	...	...	...	CH ₃ CH ₂ CN ν_{13}/ν_{21}
S ¹⁸ O	7 ₆ -6 ₆	155 591.913	0.23	60.9	...	...	...	CH ₃ CH ₂ CN ν_{13}/ν_{21}
S ¹⁸ O	4 ₄ -3 ₃	159 428.315	3.75	32.4	159 429.9	6.0	0.54	
S ¹⁸ O	4 ₅ -3 ₄	166 285.312	4.95	22.9	166 286.7	6.5	0.52	
S ¹⁸ O	5 ₅ -4 ₄	199 280.161	4.80	42.0	199 283.5	4.0	0.68	HC ¹³ CCN
S ¹⁸ O	5 ₆ -4 ₅	204 387.945	5.95	32.7	...	...	...	SO ₂
S ¹⁸ O	9 ₈ -8 ₈	228 271.646	0.16	93.1	228 271.3	9.5	0.21	HCOOCH ₃
S ¹⁸ O	6 ₅ -5 ₄	232 265.872	4.83	47.8	232 267.3	7.2	0.64	HCOOCH ₃
S ¹⁸ O	2 ₁ -1 ₂	239 102.492	0.11	15.7	...	...	...	CH ₃ CN
S ¹⁸ O	6 ₆ -5 ₅	239 128.519	5.83	53.4	...	...	...	CH ₃ CN
S ¹⁸ O	6 ₇ -5 ₆	243 039.305	6.95	44.4	243 042.5	5.1	1.34	CH ₂ DCN
S ¹⁸ O	3 ₂ -2 ₃	245 638.780	0.01	20.5	245 641.5	5.7	0.24	
S ¹⁸ O	4 ₃ -3 ₄	262 447.093	0.01	27.5	262 448.5	7.4	0.12	HCOO ¹³ CH ₃
S ¹⁸ O	10 ₉ -9 ₉	265 637.956	0.01	112.1	265 642.6	3.8	0.08	
S ¹⁸ O	7 ₆ -6 ₅	273 858.128	5.87	60.9	273 861.3	5.5	0.85	HCOOCH ₃
S ¹⁸ O	7 ₇ -6 ₆	278 972.690	6.86	66.8	278 976.6	4.8	1.02	CH ₃ OH

Table A.9. Observed lines of SO₂, its isotopologues, and vibrationally excited states.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ 34 _{8,26} –35 _{7,29}	82 409.542	5.20	704.4	82 410.5	5.5	0.08
SO ₂ 13 _{4,10} –14 _{3,11}	82 951.936	1.93	123.0	82 952.5	7.0	2.18
SO ₂ 8 _{1,7} –8 _{0,8}	83 688.092	6.38	36.7	83 688.5	7.5	11.0
SO ₂ 32 _{5,27} –31 _{6,26}	84 320.877	5.05	549.4	84 321.5	6.8	0.25
SO ₂ 43 _{7,37} –42 _{8,34}	85 247.002	6.77	992.8	85 248.5	3.7	0.03
SO ₂ 39 _{9,31} –40 _{8,32}	86 153.761	5.97	916.2	¹	...	...
SO ₂ 8 _{3,5} –9 _{2,8}	86 639.090	1.13	55.2	86 639.4	7.9	2.65
SO ₂ 20 _{2,18} –21 _{1,21}	86 828.940	0.27	207.8	86 830.4 ²	4.0	0.25
SO ₂ 32 _{5,29} –32 _{6,26}	87 926.274	5.16	579.2	³	...	...
SO ₂ 44 _{10,34} –45 _{9,37}	90 005.126	6.73	1155.7	90 005.5	7.8	0.02
SO ₂ 25 _{3,23} –24 _{4,20}	90 548.146	3.26	320.9	90 549.5	4.5	1.16
SO ₂ 18 _{5,13} –19 _{4,16}	91 550.440	2.69	218.7	91 551.5 ⁴	5.5	2.55
SO ₂ 23 _{6,18} –24 _{5,19}	94 064.694	3.46	342.2	94 065.5	6.4	0.81
SO ₂ 38 _{6,32} –37 _{7,31}	97 466.369	6.00	772.6	97 467.6	5.2	0.09
SO ₂ 7 _{3,5} –8 _{2,6}	97 702.334	0.94	47.8	97 703.5 ^{5,6}	5.4	3.61
SO ₂ 33 _{3,31} –32 _{4,28}	97 994.088	2.01	535.8	97 996.5 ⁷	1.6	0.24
SO ₂ 28 _{7,21} –29 _{6,24}	98 976.292	4.23	493.7	98 977.5	5.3	0.43
SO ₂ 29 _{4,26} –28 _{5,23}	99 392.512	4.37	440.7	99 393.5	6.0	0.76
SO ₂ 2 _{2,0} –3 _{1,3}	100 878.107	0.16	12.6	100 878.5	7.8	1.21
SO ₂ 33 _{8,26} –34 _{7,27}	102 690.061	4.99	673.0	102 690.4	8.0	0.15
SO ₂ 49 _{8,42} –48 _{9,39}	102 707.256	7.73	1286.5	102 708.6	5.1	0.02
SO ₂ 3 _{1,3} –2 _{0,2}	104 029.419	2.01	7.7	104 030.0	7.3	12.5
SO ₂ 16 _{2,14} –15 _{3,13}	104 033.582	2.99	137.5	⁸	...	...
SO ₂ 10 _{1,9} –10 _{0,10}	104 239.299	6.70	54.7	104 239.5 ^{5,6}	8.4	14.0
SO ₂ 38 _{9,29} –39 _{8,32}	106 674.825	5.76	880.2	106 676.5 ⁹	4.3	0.13
SO ₂ 27 _{3,25} –26 _{4,22}	107 060.210	3.10	369.4	107 061.5 ¹⁰	5.4	1.38
SO ₂ 12 _{2,8} –13 _{3,11}	107 843.470	1.70	111.0	107 844.5	6.1	3.98
SO ₂ 42 _{4,38} –43 _{3,41}	108 915.425	0.76	887.0	¹¹	...	...
SO ₂ 39 _{6,34} –38 _{7,31}	108 955.919	6.14	808.3	108 956.6	7.1	0.08
SO ₂ 17 _{5,13} –18 _{4,14}	109 757.585	2.48	202.1	109 758.5 ^{11,12}	6.5	2.78
SO ₂ 43 _{10,34} –44 _{9,35}	110 363.835	6.52	1115.1	¹³	...	...
SO ₂ 31 _{3,29} –30 _{4,26}	111 755.021	2.42	476.9	111 756.4	5.3	0.49
SO ₂ 44 _{7,37} –43 _{8,36}	111 875.546	6.95	1033.8	111 876.6	6.2	0.04
SO ₂ 29 _{3,27} –28 _{4,24}	114 565.369	2.81	421.4	114 566.5	6.0	0.75
SO ₂ 22 _{6,16} –23 _{5,19}	115 317.555	3.24	321.1	115 318.5	6.5	1.25
SO ₂ 42 _{10,32} –43 _{9,35}	130 679.975	6.31	1075.5	130 680.5	7.8	0.04
SO ₂ 31 _{4,28} –30 _{5,25}	130 859.427	4.49	497.0	130 860.5	6.5	0.84
SO ₂ 12 _{1,11} –12 _{0,12}	131 014.841	6.64	76.4	131 015.5	7.5	12.7
SO ₂ 16 _{5,11} –17 _{4,14}	131 274.861	2.26	186.4	131 276.4	5.5	2.89
SO ₂ 14 _{2,12} –14 _{1,13}	132 744.832	11.7	108.1	132 745.5	7.5	18.1
SO ₂ 8 _{2,6} –8 _{1,7}	134 004.812	5.69	43.1	134 005.5	7.5	17.1

Notes. Emission lines of SO₂, its isotopologues, and its vibrationally excited states present in the frequency range of the 30-m Orion KL survey. Column 1 indicates the species and the quantum numbers of the line transition, Col. 2 gives the assumed rest frequencies, Col. 3 the line strength, Col. 4 the energy of the upper level, Col. 5 observed frequency assuming a v_{LSR} of 9.0 km s⁻¹, Col. 6 the observed radial velocities, and Col. 7 the peak line antenna temperature. ⁽¹⁾ Blended with HCOOCH₃ $\nu_7 = 1$. ⁽²⁾ Blended with CH₂DCN. ⁽³⁾ Blended with HNCO. ⁽⁴⁾ Blended with CH₃CH₂CN. ⁽⁵⁾ Blended with HCOOCH₃. ⁽⁶⁾ Blended with CH₃CH₂CN ν_{13}/ν_{21} . ⁽⁷⁾ Blended with CH₃OCH₃. ⁽⁸⁾ Blended with the previous transition. ⁽⁹⁾ Blended with g⁺–CH₃CH₂OH. ⁽¹⁰⁾ Blended with CH₃C¹⁵N. ⁽¹¹⁾ Blended with SiS. ⁽¹²⁾ Blended with NH₂CHO. ⁽¹³⁾ Blended with CH₃CN. ⁽¹⁴⁾ Blended with OCS. ⁽¹⁵⁾ Blended with H₂CO. ⁽¹⁶⁾ Blended with CH₃OH. ⁽¹⁷⁾ Blended with U line. ⁽¹⁸⁾ Blended with ³³SO₂. ⁽¹⁹⁾ Blended with CH₃¹³CH₂CN. ⁽²⁰⁾ Blended with SO¹⁸O. ⁽²¹⁾ Blended with S¹⁸O. ⁽²²⁾ Blended with ³³SO. ⁽²³⁾ Blended with ³⁴SO₂. ⁽²⁴⁾ Blended with CH₃CN $\nu_8 = 1$. ⁽²⁵⁾ Blended with HC₃N $\nu_7 = 2$. ⁽²⁶⁾ Blended with CH₃CHO. ⁽²⁷⁾ Blended with NO. ⁽²⁸⁾ Blended with ³⁰SiO. ⁽²⁹⁾ Blended with NS. ⁽³⁰⁾ Blended with ¹³CH₃CH₂CN. ⁽³¹⁾ Blended with ¹³CH₃OH. ⁽³²⁾ Blended with CH₂CHCN. ⁽³³⁾ Blended with HC¹³CCN. ⁽³⁴⁾ Blended with (CH₃)₂CO. ⁽³⁵⁾ Blended with H₂CS. ⁽³⁶⁾ Blended with t-CH₃CH₂OH. ⁽³⁷⁾ Blended with H¹⁵NCO. ⁽³⁸⁾ Blended with HCC¹³CN. ⁽³⁹⁾ Blended with ¹³CH₃CN. ⁽⁴⁰⁾ Blended with CH₂¹³CHCN. ⁽⁴¹⁾ Blended with CH₃CH₂C¹⁵N. ⁽⁴²⁾ Blended with OC³³S. ⁽⁴³⁾ Blended with CH₃CH₂CN $\nu_{20} = 1$. ⁽⁴⁴⁾ Blended with SO. ⁽⁴⁵⁾ Blended with H₂CCO. ⁽⁴⁶⁾ Blended with CCH. ⁽⁴⁷⁾ Blended with CH₂CHCN $\nu_{11} = 1$. ⁽⁴⁸⁾ Blended with NH₂CHO $\nu_{12} = 1$. ⁽⁴⁹⁾ Blended with SO₂. ⁽⁵⁰⁾ Blended with H₂C³⁴S. ⁽⁵¹⁾ Blended with ³⁴SO. ⁽⁵²⁾ Blended with H¹³CN. ⁽⁵³⁾ Blended with H¹³COOCH₃. ⁽⁵⁴⁾ Blended with CH₂CHCN $\nu_{11} = 2$. ⁽⁵⁵⁾ Blended with H₂¹³CS. ⁽⁵⁶⁾ Blended with HC₃N. ⁽⁵⁷⁾ Blended with CH₃¹³CN. ⁽⁵⁸⁾ Blended with g[–]–CH₃CH₂OH. ⁽⁵⁹⁾ Blended with SO₂ $\nu_2 = 1$. ⁽⁶⁰⁾ Blended with CH₂CHCN $\nu_{15} = 1$. ⁽⁶¹⁾ Blended with H₃₀ α . ⁽⁶²⁾ Blended with HC₃N $\nu_7 = 1$. ⁽⁶³⁾ Blended with HN¹³CO. ⁽⁶⁴⁾ Blended with H¹³CO⁺. ⁽⁶⁵⁾ Blended with CS $\nu = 1$. ⁽⁶⁶⁾ Blended with HC₃N $\nu_6 = 1$. ⁽⁶⁷⁾ Blended with H₆₅ ϵ . ⁽⁶⁸⁾ Blended with HCOO¹³CH₃. ⁽⁶⁹⁾ Blended with the next transition. ⁽⁷⁰⁾ Blended with CH₃CH₂¹³CN. ⁽⁷¹⁾ Blended with HNC¹⁸O. ⁽⁷²⁾ Blended with DCOOCH₃. ⁽⁷³⁾ Blended with CH₃OD. ⁽⁷⁴⁾ Blended with SiO. ⁽⁷⁵⁾ Blended with H¹³CCCN. ⁽⁷⁶⁾ Blended with SHD. ⁽⁷⁷⁾ Blended with c-C₂H₄O. ⁽⁷⁸⁾ Blended with CH₃OH $\nu_7 = 1$. ⁽⁷⁹⁾ Blended with HCC¹³CN $\nu_7 = 1$. ⁽⁸⁰⁾ Blended with HC₃CN $\nu_7 + \nu_6$. ⁽⁸¹⁾ Blended with HC¹⁸OCH₃. ⁽⁸²⁾ Blended with HC₃¹⁵N. ⁽⁸³⁾ Blended with O¹³CS. ⁽⁸⁴⁾ Blended with CO. ⁽⁸⁵⁾ Blended with OC³⁴S. ⁽⁸⁶⁾ Blended with c-C₃H₂. ⁽⁸⁷⁾ Blended with HCOOH. ⁽⁸⁸⁾ Blended with C₃S. ⁽⁸⁹⁾ Blended with g⁺–g[–]–CH₃CH₂OH. ⁽⁹⁰⁾ Blended with ¹³CH₃CCH. ⁽⁹¹⁾ Blended with HDCS.

Table A.9. continued.

Species/Transition $J_{K_a,K_c}-J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ 47 _{11,37} -48 _{10,38}	134 203.832	7.08	1333.6	134 205.2	5.9	0.06
SO ₂ 21 _{6,16} -22 _{5,17}	134 943.290	3.03	300.8	134 944.5	6.3	1.69
SO ₂ 5 _{1,5} -4 _{0,4}	135 696.017	3.13	15.7	135 696.5	7.9	17.3
SO ₂ 34 _{5,29} -33 _{6,28}	135 963.028	5.41	612.0	135 964.5	5.8	0.50
SO ₂ 5 _{3,3} -6 _{2,4}	139 355.030	0.50	35.9	139 356.4	6.1	5.14
SO ₂ 26 _{7,19} -27 _{6,22}	139 474.500	3.80	443.0	139 476.3	5.1	1.29
SO ₂ 6 _{2,4} -6 _{1,5}	140 306.166	3.83	29.2	140 307.0	7.2	14.4
SO ₂ 16 _{2,14} -16 _{1,15}	143 057.080	13.0	137.5	143 058.8	5.4	15.4
SO ₂ 31 _{8,24} -32 _{7,25}	143 357.818	4.57	613.1	143 358.9 ⁴	6.7	4.27
SO ₂ 51 _{8,44} -50 _{9,41}	145 970.266	8.08	1380.0	¹⁴	...	...
SO ₂ 40 _{6,34} -39 _{7,33}	146 393.711	6.35	846.1	146 396.4 ⁷	3.5	0.18
SO ₂ 10 _{4,6} -11 _{3,9}	146 550.044	1.27	89.8	146 551.3	6.4	4.02
SO ₂ 4 _{2,2} -4 _{1,3}	146 605.519	2.27	19.0	146 606.5	7.0	10.9
SO ₂ 36 _{9,27} -37 _{8,30}	147 239.288	5.34	811.1	147 240.2	7.1	0.14
SO ₂ 15 _{5,11} -16 _{4,12}	150 381.071	2.04	171.7	150 382.6	6.0	3.61
SO ₂ 41 _{6,36} -40 _{7,33}	150 486.942	6.45	883.4	¹⁵	...	...
SO ₂ 41 _{10,32} -42 _{9,33}	150 878.808	6.10	1036.8	¹⁶	...	...
SO ₂ 2 _{2,0} -2 _{1,1}	151 378.663	0.87	12.6	151 380.1	6.2	7.98
SO ₂ 43 _{4,40} -42 _{5,37}	153 677.158	2.50	909.7	⁵	...	...
SO ₂ 46 _{11,35} -47 _{10,38}	154 373.328	6.87	1290.3	154 367.6 ¹⁷	20.1	0.09
SO ₂ 20 _{6,14} -21 _{5,17}	155 389.625	2.81	281.4	155 391.4	5.6	3.29
SO ₂ 33 _{4,30} -32 _{5,27}	157 135.255	4.47	556.9	157 137.7	4.3	1.00
SO ₂ 3 _{2,2} -3 _{1,3}	158 199.781	1.44	15.3	158 201.4	5.9	13.4
SO ₂ 46 _{7,39} -45 _{8,38}	158 845.079	7.30	1118.3	158 846.5 ¹⁸	6.3	0.17
SO ₂ 25 _{7,19} -26 _{6,20}	159 447.934	3.58	419.1	159 450.1	4.9	1.56
SO ₂ 18 _{2,16} -18 _{1,17}	160 342.971	13.6	170.8	160 343.9	7.3	16.4
SO ₂ 4 _{3,1} -5 _{2,4}	160 543.024	0.30	31.3	160 543.6	7.9	3.96
SO ₂ 10 _{0,10} -9 _{1,9}	160 827.841	6.43	49.7	160 828.5	7.8	26.3
SO ₂ 18 _{2,16} -17 _{3,15}	163 119.379	3.72	170.8	163 121.4	5.3	11.1
SO ₂ 30 _{8,22} -31 _{7,25}	163 567.675	4.35	584.6	163 569.5	5.7	0.73
SO ₂ 14 _{1,13} -14 _{0,14}	163 605.533	6.41	101.8	163 606.5	7.2	18.5
SO ₂ 37 _{5,33} -36 _{6,30}	163 924.734	5.63	710.8	⁵	...	...
SO ₂ 9 _{4,6} -10 _{3,7}	165 123.634	1.05	80.6	165 125.2	6.2	7.24
SO ₂ 5 _{2,4} -5 _{1,5}	165 144.652	2.46	23.6	165 145.7	7.1	17.7
SO ₂ 7 _{1,7} -6 _{0,6}	165 225.452	4.43	27.1	165 226.4	7.3	25.3
SO ₂ 44 _{4,40} -45 _{3,43}	166 387.129	0.66	969.1	¹	...	...
SO ₂ 35 _{9,27} -36 _{8,28}	167 367.348	5.12	777.9	167 368.9	6.2	0.27
SO ₂ 24 _{2,22} -25 _{1,25}	168 790.063	0.18	292.8	^{1,5}	...	...
SO ₂ 34 _{3,31} -35 _{2,34}	170 293.819	0.41	581.9	⁴	...	...
SO ₂ 14 _{5,9} -15 _{4,12}	170 754.546	1.82	157.9	170 756.5	5.6	4.99
SO ₂ 40 _{10,30} -41 _{9,33}	171 018.058	5.89	999.0	⁴	...	...
SO ₂ 47 _{7,41} -46 _{8,38}	171 036.705	7.43	1161.5	171 038.9 ^{5,19}	5.2	0.29
SO ₂ 19 _{6,14} -20 _{5,15}	175 101.318	2.59	263.0	175 103.9	4.6	4.34
SO ₂ 7 _{2,6} -7 _{1,7}	175 275.722	3.30	35.5	175 277.6	5.8	18.2
SO ₂ 41 _{4,38} -40 _{5,35}	176 295.902	3.01	832.2	176 297.6 ⁵	6.1	0.43
SO ₂ 35 _{4,32} -34 _{5,29}	176 466.255	4.30	620.4	176 468.9	4.5	1.42
SO ₂ 20 _{3,17} -20 _{2,18}	197 142.060	15.4	217.2	197 144.9 ⁴	4.7	14.4
SO ₂ 39 _{5,35} -38 _{6,32}	197 585.319	5.74	782.1	⁴	...	...
SO ₂ 49 _{12,38} -50 _{11,39}	197 709.365	7.21	1478.6	197 711.0 ⁶	6.5	0.10
SO ₂ 42 _{6,36} -41 _{7,35}	198 847.847	6.67	923.6	⁶	...	...
SO ₂ 23 _{7,17} -24 _{6,18}	199 415.871	3.15	373.9	199 418.6	4.9	2.25
SO ₂ 24 _{3,21} -24 _{2,22}	200 287.422	19.4	302.4	200 289.9	5.3	8.35
SO ₂ 16 _{1,15} -16 _{0,16}	200 809.321	6.17	130.7	200 811.2	6.2	11.4
SO ₂ 12 _{0,12} -11 _{1,11}	203 391.484	8.43	70.1	203 391.9	8.4	17.5
SO ₂ 28 _{8,20} -29 _{7,23}	203 570.093	3.92	530.2	203 570.6 ⁷	8.3	2.02
SO ₂ 18 _{3,15} -18 _{2,16}	204 246.762	13.0	180.6	204 249.4	5.1	13.9
SO ₂ 7 _{4,4} -8 _{3,5}	204 384.191	0.63	65.0	204 387.0 ²¹	4.9	5.43
SO ₂ 11 _{2,10} -11 _{1,11}	205 300.539	4.55	70.2	205 302.3	6.4	17.7
SO ₂ 33 _{9,25} -34 _{8,26}	207 421.450	4.69	714.3	^{5,6}	...	...
SO ₂ 48 _{7,41} -47 _{8,40}	208 302.827	7.63	1206.7	²	...	...
SO ₂ 3 _{2,2} -2 _{1,1}	208 700.337	1.67	15.3	two peaks: 208 692.4 208 702.4	...	...
SO ₂ 53 _{5,49} -52 _{6,46}	209 874.382	2.96	1381.3	⁵	20.4 6.0	10.3 16.5

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ 12 _{5,7} –13 _{4,10}	209 936.041	1.39	133.0	209 938.7	5.2	5.51
SO ₂ 38 _{10,28} –39 _{9,31}	211 053.096	5.46	926.3	211 054.6	6.9	0.08
SO ₂ 26 _{3,23} –26 _{2,24}	213 068.427	20.4	350.8	213 071.1 ²²	5.2	11.0
SO ₂ 49 _{7,43} –48 _{8,40}	213 703.045	7.72	1251.5	⁵	...	...
SO ₂ 43 _{11,33} –44 _{10,34}	214 451.816	6.23	1166.0	214 454.9 ¹⁷	4.7	0.11
SO ₂ 16 _{3,13} –16 _{2,14}	214 689.395	10.6	147.8	214 692.3	4.9	13.6
SO ₂ 17 _{6,12} –18 _{5,13}	214 728.280	2.16	229.0	214 731.2	4.9	4.52
SO ₂ 26 _{2,24} –27 _{1,27}	215 094.516	0.15	340.6	⁴	...	...
SO ₂ 22 _{2,20} –22 _{1,21}	216 643.304	13.2	248.5	two peaks: 216 636.1	...	...
				216 646.1	19.0	4.49
				216 646.1	5.1	10.3
SO ₂ 22 _{7,15} –23 _{6,18}	219 275.970	2.93	352.8	219 278.6	5.4	3.05
SO ₂ 11 _{1,11} –10 _{0,10}	221 965.221	7.71	60.4	221 967.4	6.1	44.2
SO ₂ 36 _{3,33} –37 _{2,36}	222 869.135	0.36	648.6	222 871.2	6.2	0.09
SO ₂ 27 _{8,20} –28 _{7,21}	223 434.487	3.70	504.4	223 436.4	6.4	1.29
SO ₂ 6 _{4,2} –7 _{3,5}	223 883.568	0.43	58.6	223 886.2	5.5	5.57
SO ₂ 20 _{2,18} –19 _{3,17}	224 264.815	4.62	207.8	224 267.3	5.7	12.7
SO ₂ 46 _{4,42} –47 _{3,45}	224 473.442	0.59	1054.6	⁴	...	...
SO ₂ 13 _{2,12} –13 _{1,13}	225 153.705	4.97	93.0	two peaks: 225 146.2	...	...
				225 156.1	19.0	8.47
				225 156.1	5.8	16.2
SO ₂ 14 _{3,11} –14 _{2,12}	226 300.028	8.61	119.0	226 302.2	6.1	21.6
SO ₂ 41 _{5,37} –40 _{6,34}	226 508.309	5.72	857.0	226 509.9	6.9	0.36
SO ₂ 32 _{9,23} –33 _{8,26}	227 335.786	4.47	684.0	227 337.4	6.9	0.74
SO ₂ 11 _{5,7} –12 _{4,8}	229 347.627	1.17	122.0	229 349.9	6.0	3.10
SO ₂ 45 _{6,40} –44 _{7,37}	229 749.763	6.89	1044.8	¹⁶	...	...
SO ₂ 37 _{10,28} –38 _{9,29}	230 965.232	5.24	891.3	230 968.5	4.8	0.15
SO ₂ 28 _{3,25} –28 _{2,26}	234 187.057	20.7	403.1	two peaks: 234 185.5	...	...
				234 189.5	11.0	1.95
				234 189.5	5.9	2.33
SO ₂ 42 _{11,31} –43 _{10,34}	234 352.997	6.01	1126.4	234 357.6 ¹⁷	3.1	0.31
SO ₂ 16 _{6,10} –17 _{5,13}	234 421.582	1.94	213.3	234 426.3 ⁴	3.0	6.75
SO ₂ 4 _{2,2} –3 _{1,3}	235 151.721	1.71	19.0	two peaks: 235 144.5	...	...
				235 153.5	18.2	8.85
				235 153.5	6.7	15.4
SO ₂ 16 _{1,15} –15 _{2,14}	236 216.688	6.05	130.7	236 219.0 ²³	6.1	12.6
SO ₂ 12 _{3,9} –12 _{2,10}	237 068.834	6.90	94.0	two peaks: 237 061.0	...	...
				237 071.5	18.9	8.51
				237 071.5	5.6	14.1
SO ₂ 47 _{12,36} –48 _{11,37}	237 501.891	6.78	1389.2	⁶	...	...
SO ₂ 17 _{3,15} –18 _{0,18}	238 166.384	0.12	162.9	238 169.5	5.1	0.55
SO ₂ 21 _{7,15} –22 _{6,16}	238 992.525	2.71	332.5	two peaks: 238 989.5	...	...
				238 995.5	12.8	1.79
				238 995.5	5.3	3.53
SO ₂ 15 _{3,13} –16 _{0,16}	239 832.819	0.10	132.5	²⁴	...	...
SO ₂ 18 _{1,17} –18 _{0,18}	240 942.792	5.99	163.1	two peaks: 240 940.0	...	...
				240 946.1	12.5	10.3
				240 946.1	4.9	11.5
SO ₂ 51 _{5,47} –50 _{6,44}	241 044.688	3.54	1285.2	¹⁶	...	...
SO ₂ 5 _{2,4} –4 _{1,3}	241 615.798	2.12	23.6	two peaks: 241 608.0	...	...
				241 620.5 ^{3,4}	18.7	12.9
				241 620.5 ^{3,4}	3.2	20.3
SO ₂ 19 _{3,17} –20 _{0,20}	242 997.814	0.13	197.0	243 000.5	5.7	1.06
SO ₂ 5 _{4,2} –6 _{3,3}	243 087.646	0.25	53.1	243 090.2	5.9	2.91
SO ₂ 26 _{8,18} –27 _{7,21}	243 245.422	3.48	479.6	243 248.9	4.7	1.01
SO ₂ 14 _{0,14} –13 _{1,13}	244 254.220	10.5	93.9	two peaks: 244 245.2	...	...
				244 256.4	20.1	15.3
				244 256.4	6.3	24.6
SO ₂ 26 _{3,23} –25 _{4,22}	245 339.234	4.86	350.8	245 342.6	4.9	6.56
SO ₂ 10 _{3,7} –10 _{2,8}	245 563.423	5.44	72.7	245 565.5	6.5	18.6
SO ₂ 31 _{9,23} –32 _{8,24}	247 169.754	4.25	654.5	^{16,25}	...	...
SO ₂ 15 _{2,14} –15 _{1,15}	248 057.403	5.27	119.3	248 060.1	5.7	18.2
SO ₂ 13 _{3,11} –14 _{0,14}	248 436.938	0.74	105.8	248 440.2 ^{4,21}	5.1	2.44
SO ₂ 10 _{5,5} –11 _{4,8}	248 830.822	0.96	111.9	248 833.5	5.8	8.35

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ 43 _{5,39} –42 _{6,36}	248 995.137	5.54	935.6	248 997.5	6.2	0.45
SO ₂ 36 _{10,26} –37 _{9,29}	250 816.770	5.03	857.2	^{26,27}	...	...
SO ₂ 13 _{1,13} –12 _{0,12}	251 199.676	9.63	82.2	251 201.3	7.1	29.9
SO ₂ 8 _{3,5} –8 _{2,6}	251 210.586	4.14	55.2	⁸	...	...
SO ₂ 32 _{4,28} –31 _{5,27}	252 563.897	5.37	531.1	252 566.4	6.0	2.03
SO ₂ 21 _{3,19} –22 _{0,22}	253 753.446	0.14	234.7	253 757.4 ¹⁶	4.3	12.8
SO ₂ 38 _{5,33} –37 _{6,32}	253 935.893	6.11	749.1	253 940.0 ²³	4.2	3.63
SO ₂ 15 _{6,10} –16 _{5,11}	253 956.563	1.72	198.6	253 959.6	5.4	6.22
SO ₂ 41 _{11,31} –42 _{10,32}	254 194.858	5.80	1087.7	²⁸	...	...
SO ₂ 6 _{3,3} –6 _{2,4}	254 280.537	2.89	41.4	254 282.7 ²³	6.5	28.1
SO ₂ 24 _{2,22} –24 _{1,23}	254 283.322	12.7	292.8	⁸	...	...
SO ₂ 4 _{3,1} –4 _{2,2}	255 553.303	1.61	31.3	255 554.5	7.6	17.5
SO ₂ 51 _{7,45} –50 _{8,42}	255 595.369	7.97	1345.2	²⁹	...	...
SO ₂ 44 _{6,38} –43 _{7,37}	255 818.422	6.99	1005.1	255 819.5	7.7	0.21
SO ₂ 3 _{3,1} –3 _{2,2}	255 958.045	0.89	27.6	255 959.6	7.2	13.8
SO ₂ 5 _{3,3} –5 _{2,4}	256 246.946	2.26	35.9	256 248.3	7.4	19.6
SO ₂ 7 _{3,5} –7 _{2,6}	257 099.967	3.48	47.8	257 101.3	7.4	31.2
SO ₂ 46 _{12,34} –47 _{11,37}	257 318.855	6.57	1346.0	⁴	...	...
SO ₂ 32 _{4,28} –32 _{3,29}	258 388.714	25.5	531.1	258 391.4	5.9	2.08
SO ₂ 20 _{7,13} –21 _{6,16}	258 666.959	2.49	313.2	258 669.5	6.1	1.57
SO ₂ 9 _{3,7} –9 _{2,8}	258 942.200	4.65	63.5	258 943.4	7.6	9.56
SO ₂ 30 _{4,26} –30 _{3,27}	259 599.446	23.3	471.5	259 602.5	5.5	3.25
SO ₂ 49 _{5,45} –48 _{6,42}	260 269.339	4.15	1192.5	⁶	...	...
SO ₂ 50 _{7,43} –49 _{8,42}	261 062.785	7.93	1299.0	¹⁶	...	...
SO ₂ 27 _{4,24} –28 _{1,27}	261 091.176	0.31	388.0	261 096.4 ⁵	3.0	0.89
SO ₂ 11 _{3,9} –11 _{2,10}	262 256.907	5.78	82.8	262 258.9	6.7	26.1
SO ₂ 4 _{4,0} –5 _{3,3}	262 333.965	0.10	48.5	262 341.4	0.5	2.17
SO ₂ 28 _{2,26} –29 _{1,29}	262 524.931	0.13	391.8	262 528.8 ³⁰	4.6	0.27
SO ₂ 25 _{8,18} –26 _{7,19}	262 969.717	3.26	455.6	262 972.5	5.8	1.09
SO ₂ 45 _{5,41} –44 _{6,38}	263 216.484	5.21	1017.7	263 218.9	6.3	0.20
SO ₂ 30 _{3,27} –30 _{2,28}	263 543.954	20.3	459.1	263 546.4 ¹²	6.2	3.99
SO ₂ 25 _{4,22} –26 _{1,25}	263 897.868	0.28	339.0	263 900.5	6.0	0.35
SO ₂ 11 _{3,9} –12 _{0,12}	264 165.962	0.04	82.8	264 171.5	2.7	1.18
SO ₂ 29 _{4,26} –30 _{1,29}	265 461.469	0.33	440.7	265 465.1 ²⁵	4.9	0.54
SO ₂ 34 _{4,30} –34 _{3,31}	265 481.970	27.1	594.7	265 485.1 ^{4,23}	5.5	1.93
SO ₂ 47 _{6,42} –46 _{7,39}	265 608.359	6.99	1131.1	265 610.6	6.5	0.20
SO ₂ 30 _{9,21} –31 _{8,24}	266 943.308	4.04	625.9	266 944.5 ³²	7.7	1.05
SO ₂ 47 _{5,43} –46 _{6,40}	267 428.351	4.73	1103.4	267 433.8 ¹⁰	2.9	0.11
SO ₂ 13 _{3,11} –13 _{2,12}	267 537.453	6.87	105.8	267 538.5	7.8	13.1
SO ₂ 28 _{4,24} –28 _{3,25}	267 719.839	20.6	415.9	267 723.5	4.9	4.24
SO ₂ 9 _{5,5} –10 _{4,6}	268 168.331	0.76	102.7	two peaks: 268 165.1 268 171.4	12.6 5.6	2.75 4.36
SO ₂ 23 _{3,21} –24 _{0,24}	269 786.414	0.14	276.0	269 789.5	5.6	0.78
SO ₂ 35 _{10,26} –36 _{9,27}	270 605.490	4.81	824.1	270 608.5	5.7	0.24
SO ₂ 7 _{2,6} –6 _{1,5}	271 529.016	2.67	35.5	271 530.1	7.8	24.5
SO ₂ 37 _{5,33} –38 _{2,36}	271 726.167	0.53	710.8	³³	...	...
SO ₂ 14 _{6,8} –15 _{5,11}	273 462.663	1.51	184.8	273 466.4	4.9	3.12
SO ₂ 17 _{2,16} –17 _{1,17}	273 752.962	5.48	149.2	two peaks: 273 744.5 273 754.5	18.3 7.3	5.64 8.77
SO ₂ 40 _{11,29} –41 _{10,32}	273 982.611	5.58	1050.0	273 981.5 ⁴	10.2	0.51
SO ₂ 47 _{6,42} –48 _{3,45}	274 075.204	0.79	1131.1	³⁴	...	...
SO ₂ 35 _{5,31} –36 _{2,34}	274 521.579	0.49	643.1	274 522.6 ^{6,35}	7.9	3.12
SO ₂ 23 _{4,20} –24 _{1,23}	274 525.462	0.23	293.7	⁸	...	...
SO ₂ 15 _{3,13} –15 _{2,14}	275 240.185	7.88	132.5	275 242.6	6.4	21.6
SO ₂ 38 _{3,35} –39 _{2,38}	275 375.696	0.32	718.7	^{7,13}	...	...
SO ₂ 31 _{4,28} –32 _{1,31}	276 254.571	0.33	497.0	276 257.6	5.7	0.70
SO ₂ 45 _{6,40} –46 _{3,43}	276 301.223	0.74	1044.8	¹	...	...
SO ₂ 39 _{5,35} –40 _{2,38}	276 558.354	0.56	782.1	^{12,36}	...	...
SO ₂ 39 _{5,35} –40 _{2,38}	276 558.354	0.56	782.1	^{12,36}	...	...
SO ₂ 45 _{12,34} –46 _{11,35}	277 085.908	6.35	1303.6	^{9,37}	...	...
SO ₂ 19 _{7,13} –20 _{6,14}	278 250.961	2.27	294.8	278 255.1 ⁴	4.5	7.82

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ 49 _{6,44} –50 _{3,47}	279 766.567	0.81	1221.0	¹⁷	...	...
SO ₂ 26 _{4,22} –26 _{3,23}	280 807.245	18.0	364.3	280 810.5 ³⁸	5.5	4.56
³⁴ SO ₂ 10 _{1,9} –9 _{2,8}	82 124.347	2.45	54.6	82 125.5	4.8	0.32
³⁴ SO ₂ 8 _{1,7} –8 _{0,8}	83 043.821	6.26	36.6	83 044.5	6.6	0.90
³⁴ SO ₂ 33 _{3,31} –32 _{4,28}	85 972.412	1.74	533.7	85 973.3 ⁷	5.9	0.07
³⁴ SO ₂ 7 _{3,5} –8 _{2,6}	88 720.563	0.94	47.0	88 721.5	5.8	0.16
³⁴ SO ₂ 30 _{3,27} –31 _{2,30}	89 308.378	0.51	458.0	^{6,39}	...	...
³⁴ SO ₂ 26 _{4,22} –25 _{5,21}	92 428.871	4.10	362.6	92 427.5 ³²	13.4	0.33
³⁴ SO ₂ 17 _{5,18} –18 _{4,14}	93 852.067	2.47	199.7	93 854.5 ⁷	1.2	0.32
³⁴ SO ₂ 20 _{2,18} –21 _{1,21}	94 250.841	0.25	207.2	94 251.5 ^{40,41}	6.9	0.04
³⁴ SO ₂ 2 _{2,0} –3 _{1,3}	95 810.413	0.16	12.2	95 811.5	5.6	0.04
³⁴ SO ₂ 12 _{4,8} –13 _{3,11}	95 922.816	1.70	109.5	95 924.5	3.7	0.22
³⁴ SO ₂ 25 _{3,23} –24 _{4,20}	96 075.299	3.10	319.5	^{5,42}	...	...
³⁴ SO ₂ 22 _{6,16} –23 _{5,19}	96 193.856	3.24	317.6	96 195.5	3.9	0.05
³⁴ SO ₂ 27 _{7,21} –28 _{6,22}	96 204.065	4.01	463.1	96 205.5	4.5	0.02
³⁴ SO ₂ 3 _{1,3} –2 _{0,2}	102 031.880	2.02	7.6	102 032.5	7.2	0.70
³⁴ SO ₂ 10 _{1,9} –10 _{0,10}	104 391.706	6.52	54.6	104 392.5	6.7	1.38
³⁴ SO ₂ 31 _{3,29} –30 _{4,26}	104 914.698	2.14	475.0	104 915.5	6.7	0.04
³⁴ SO ₂ 33 _{5,29} –32 _{6,26}	106 374.262	5.10	576.3	^{4,36}	...	...
³⁴ SO ₂ 32 _{5,27} –31 _{6,26}	107 567.843	5.02	546.7	⁴³	...	...
³⁴ SO ₂ 27 _{3,25} –26 _{4,22}	109 260.509	2.89	367.9	⁴⁴	...	...
³⁴ SO ₂ 29 _{4,26} –28 _{5,23}	111 902.795	4.27	438.6	111 904.5	4.4	0.06
³⁴ SO ₂ 11 _{4,8} –12 _{3,9}	112 532.318	1.49	98.5	112 533.5	5.9	0.23
³⁴ SO ₂ 29 _{3,27} –28 _{4,24}	112 577.899	2.55	419.7	112 577.7 ¹⁷	9.5	0.02
³⁴ SO ₂ 6 _{3,3} –7 _{2,6}	114 574.435	0.71	40.6	114 576.5 ^{31,34}	3.6	0.29
³⁴ SO ₂ 16 _{2,14} –15 _{3,13}	115 291.389	3.04	137.1	⁷	...	...
³⁴ SO ₂ 21 _{6,16} –22 _{5,17}	115 722.150	3.03	297.4	115 724.5	2.9	0.09
³⁴ SO ₂ 16 _{5,11} –17 _{4,14}	115 744.668	2.26	184.1	115 746.5	4.3	0.14
³⁴ SO ₂ 5 _{3,3} –6 _{2,4}	130 584.304	0.50	35.1	130 585.5	6.3	0.27
³⁴ SO ₂ 12 _{1,11} –12 _{0,12}	132 114.053	6.41	76.2	132 115.1	6.6	1.32
³⁴ SO ₂ 5 _{1,5} –4 _{0,4}	133 471.429	3.14	15.5	133 472.6	6.4	1.53
³⁴ SO ₂ 22 _{2,20} –23 _{1,23}	134 417.591	0.19	247.8	⁴	...	...
³⁴ SO ₂ 10 _{4,6} –11 _{3,9}	134 535.253	1.27	88.4	134 538.5 ⁶	1.8	0.96
³⁴ SO ₂ 15 _{5,11} –16 _{4,12}	134 703.279	2.04	169.4	134 705.5 ⁶	4.1	0.57
³⁴ SO ₂ 6 _{2,4} –6 _{1,5}	134 826.248	3.88	28.8	134 827.5 ⁶	6.2	1.75
³⁴ SO ₂ 12 _{1,11} –11 _{2,10}	134 873.798	3.46	76.2	134 874.5	7.4	0.78
³⁴ SO ₂ 22 _{3,19} –21 _{4,18}	135 566.286	3.71	256.9	135 567.5	6.3	0.23
³⁴ SO ₂ 20 _{6,14} –21 _{5,17}	136 343.660	2.81	278.0	136 346.3	3.2	0.10
³⁴ SO ₂ 25 _{7,19} –26 _{6,20}	136 847.952	3.58	414.4	136 849.5	5.6	0.13
³⁴ SO ₂ 30 _{8,22} –31 _{7,25}	137 520.630	4.35	578.4	¹⁷	...	...
³⁴ SO ₂ 4 _{2,2} –4 _{1,3}	141 158.940	2.29	18.7	141 160.2	6.3	1.31
³⁴ SO ₂ 31 _{4,28} –30 _{5,25}	141 195.794	4.34	494.8	141 198.7	2.8	0.08
³⁴ SO ₂ 16 _{2,14} –16 _{1,15}	141 653.405	12.8	137.1	141 653.5 ⁵	8.8	4.34
³⁴ SO ₂ 35 _{5,31} –34 _{6,28}	144 436.662	5.34	640.1	144 438.8	4.6	0.11
³⁴ SO ₂ 2 _{2,0} –2 _{1,1}	146 020.420	0.87	12.2	146 023.5 ^{5,36}	2.7	1.12
³⁴ SO ₂ 28 _{4,24} –27 _{5,23}	149 209.906	4.50	414.3	149 212.6 ¹	3.6	0.16
³⁴ SO ₂ 4 _{3,1} –5 _{2,4}	151 917.559	0.30	30.5	151 917.5 ³²	9.1	1.01
³⁴ SO ₂ 9 _{4,6} –10 _{3,7}	152 953.645	1.05	79.2	152 955.5 ⁶	5.4	0.93
³⁴ SO ₂ 3 _{2,2} –3 _{1,3}	153 015.053	1.44	15.0	153 016.4	6.4	0.94
³⁴ SO ₂ 14 _{5,9} –15 _{4,12}	155 232.875	1.82	155.6	155 235.0	4.9	0.39
³⁴ SO ₂ 19 _{6,14} –20 _{5,15}	156 033.446	2.59	259.7	156 035.2	5.6	0.55
³⁴ SO ₂ 24 _{7,17} –25 _{6,20}	157 058.684	3.36	391.4	¹⁶	...	...
³⁴ SO ₂ 29 _{8,22} –30 _{7,23}	157 588.146	4.13	550.8	157 590.5	4.5	0.11
³⁴ SO ₂ 5 _{2,4} –5 _{1,5}	160 143.612	2.45	23.2	160 142.6 ⁴⁵	10.9	2.60
³⁴ SO ₂ 18 _{2,16} –18 _{1,17}	160 802.573	13.2	170.3	160 804.5	5.4	2.13
³⁴ SO ₂ 34 _{5,29} –33 _{6,28}	161 392.836	5.37	609.3	⁴	...	...
³⁴ SO ₂ 10 _{0,10} –9 _{1,9}	162 020.378	6.52	49.5	162 021.3	7.3	2.77
³⁴ SO ₂ 7 _{1,7} –6 _{0,6}	162 775.882	4.45	26.9	162 775.5 ⁵	9.7	5.90
³⁴ SO ₂ 33 _{4,30} –32 _{5,27}	164 323.365	4.25	554.6	164 324.0	7.8	0.09
³⁴ SO ₂ 14 _{1,13} –14 _{0,14}	165 620.729	6.17	101.5	165 622.5	5.8	1.88
³⁴ SO ₂ 3 _{3,1} –4 _{2,2}	170 284.815	0.13	26.8	⁴	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
³⁴ SO ₂ 7 _{2,6} –7 _{1,7}	170 546.952	3.29	35.1	170 548.9 ⁶	5.6	2.29
³⁴ SO ₂ 8 _{4,4} –9 _{3,7}	173 207.298	0.84	70.9	173 210.2	4.0	0.63
³⁴ SO ₂ 13 _{5,9} –14 _{4,10}	174 576.459	1.60	142.7	⁵	...	...
³⁴ SO ₂ 18 _{2,16} –17 _{3,15}	174 850.251	3.81	170.3	174 851.5 ^{5,46}	6.9	1.45
³⁴ SO ₂ 18 _{6,12} –19 _{5,15}	176 093.351	2.37	242.2	176 096.4	3.8	0.74
³⁴ SO ₂ 23 _{7,17} –24 _{6,18}	176 940.267	3.15	369.3	176 944.5	1.8	0.54
³⁴ SO ₂ 28 _{8,20} –29 _{7,23}	177 647.037	3.92	524.1	177 648.5	6.5	0.45
³⁴ SO ₂ 22 _{7,15} –23 _{6,18}	196 854.461	2.93	348.2	196 856.1	6.5	0.22
³⁴ SO ₂ 24 _{3,21} –24 _{2,22}	197 044.107	19.3	301.5	197 046.1 ^{4,6}	6.0	1.20
³⁴ SO ₂ 27 _{8,20} –28 _{7,21}	197 555.307	3.70	498.4	⁴	...	...
³⁴ SO ₂ 32 _{9,23} –33 _{8,26}	198 018.213	4.47	676.2	⁵	...	...
³⁴ SO ₂ 24 _{3,21} –23 _{4,20}	198 348.517	4.28	301.5	198 351.1	5.1	0.29
³⁴ SO ₂ 11 _{2,11} –11 _{1,11}	201 376.485	4.50	69.7	201 379.9	3.9	2.14
³⁴ SO ₂ 3 _{2,3} –3 _{1,1}	203 225.060	1.67	15.0	203 226.9	6.3	1.01
³⁴ SO ₂ 16 _{1,15} –16 _{0,16}	203 504.216	5.93	130.3	203 506.9	5.0	1.22
³⁴ SO ₂ 12 _{0,12} –11 _{1,11}	204 136.230	8.54	69.9	204 138.2	6.1	4.03
³⁴ SO ₂ 16 _{3,13} –16 _{2,14}	204 525.183	10.9	146.9	204 525.6 ⁷	8.4	2.71
³⁴ SO ₂ 39 _{5,35} –38 _{6,32}	210 817.577	5.53	778.8	⁵	...	...
³⁴ SO ₂ 30 _{4,26} –29 _{5,25}	211 418.824	4.92	469.9	211 419.9 ¹	7.5	0.13
³⁴ SO ₂ 6 _{4,2} –7 _{3,5}	211 762.760	0.43	57.2	211 764.8	6.1	0.20
³⁴ SO ₂ 26 _{3,23} –26 _{2,24}	212 981.206	20.0	349.9	212 983.7	5.5	1.19
³⁴ SO ₂ 11 _{5,7} –12 _{4,8}	213 807.332	1.17	119.8	213 811.1	3.7	0.45
³⁴ SO ₂ 16 _{6,10} –17 _{5,13}	215 468.142	1.94	210.0	215 471.2	4.7	0.35
³⁴ SO ₂ 14 _{3,11} –14 _{2,12}	215 999.732	8.75	118.1	216 002.4 ³⁴	5.3	3.59
³⁴ SO ₂ 21 _{7,15} –22 _{6,16}	216 593.474	2.71	328.0	216 596.1	5.4	0.30
³⁴ SO ₂ 26 _{8,18} –27 _{7,21}	217 412.916	3.48	473.6	³⁸	...	...
³⁴ SO ₂ 31 _{9,23} –32 _{8,24}	217 902.356	4.25	646.8	217 903.6	7.3	0.11
³⁴ SO ₂ 11 _{1,11} –10 _{0,10}	219 355.012	7.79	60.1	two peaks: 219 347.5 219 357.3	...	1.83 4.49
³⁴ SO ₂ 36 _{5,31} –35 _{6,30}	220 451.861	5.72	676.0	220 453.7	6.5	0.12
³⁴ SO ₂ 22 _{2,20} –22 _{1,21}	221 114.901	12.7	247.8	221 117.4	5.6	1.40
³⁴ SO ₂ 13 _{2,12} –13 _{1,13}	221 735.717	4.89	92.5	221 738.7 ³⁴	5.0	2.36
³⁴ SO ₂ 26 _{2,24} –27 _{1,27}	225 583.126	0.14	339.6	225 587.4 ⁶	3.3	1.03
³⁴ SO ₂ 12 _{3,9} –12 _{2,10}	227 031.884	6.98	93.1	227 034.9	5.0	3.61
³⁴ SO ₂ 4 _{2,2} –3 _{1,3}	229 857.629	1.70	18.7	229 859.9 ^{4,20}	6.0	2.63
³⁴ SO ₂ 15 _{3,13} –16 _{0,16}	229 866.232	0.10	131.6	¹⁶	...	...
³⁴ SO ₂ 17 _{3,15} –18 _{0,18}	229 888.286	0.12	161.9	229 889.9	6.9	0.12
³⁴ SO ₂ 5 _{4,2} –6 _{3,3}	230 933.358	0.25	51.7	230 934.9	7.0	0.22
³⁴ SO ₂ 10 _{5,5} –11 _{4,8}	233 296.401	0.96	109.7	233 301.3 ⁴⁸	2.7	0.19
³⁴ SO ₂ 15 _{6,10} –16 _{5,11}	235 004.013	1.72	195.4	235 006.5	5.8	0.40
³⁴ SO ₂ 5 _{2,4} –4 _{1,3}	235 927.500	2.13	23.2	235 933.5 ⁵	1.4	1.91
³⁴ SO ₂ 10 _{3,7} –10 _{2,8}	235 951.921	5.48	71.9	235 954.6	5.6	2.54
³⁴ SO ₂ 20 _{2,18} –19 _{3,17}	236 225.098	4.77	207.2	⁴⁹	...	...
³⁴ SO ₂ 20 _{7,13} –21 _{6,16}	236 295.678	2.49	308.7	236 300.1 ^{36,50}	3.4	0.29
³⁴ SO ₂ 19 _{3,17} –20 _{0,20}	236 428.774	0.13	195.9	236 432.6	4.2	0.24
³⁴ SO ₂ 13 _{3,11} –14 _{0,14}	236 871.403	0.08	104.9	236 874.5	5.1	0.19
³⁴ SO ₂ 25 _{8,18} –26 _{7,19}	237 169.109	3.26	449.7	⁴	...	...
³⁴ SO ₂ 28 _{3,25} –28 _{2,26}	237 521.028	20.0	402.1	237 523.9	5.4	1.06
³⁴ SO ₂ 30 _{9,21} –31 _{8,24}	237 721.815	4.03	618.3	³²	...	...
³⁴ SO ₂ 16 _{1,15} –15 _{2,14}	241 509.049	6.25	130.3	241 512.6	4.6	2.71
³⁴ SO ₂ 8 _{3,5} –8 _{2,6}	241 985.451	4.15	54.4	^{4,6}	...	...
³⁴ SO ₂ 18 _{1,17} –18 _{0,18}	243 935.963	5.77	162.6	243 938.5	5.9	1.38
³⁴ SO ₂ 14 _{0,14} –13 _{0,13}	244 481.520	10.6	93.5	244 484.5	5.3	4.51
³⁴ SO ₂ 15 _{2,14} –15 _{1,15}	245 178.728	5.17	118.7	245 181.4	5.7	1.96
³⁴ SO ₂ 6 _{3,3} –6 _{2,4}	245 302.240	2.90	40.6	245 305.1	5.5	2.06
³⁴ SO ₂ 4 _{3,1} –4 _{2,2}	246 686.119	1.62	30.5	246 687.5	7.3	1.63
³⁴ SO ₂ 3 _{3,1} –3 _{2,2}	247 127.390	0.89	26.8	two peaks: 247 128.9 ¹⁸ 247 133.9	...	0.67 0.49
³⁴ SO ₂ 5 _{3,3} –5 _{2,4}	247 440.298	2.26	35.1	247 442.7	6.1	1.33
³⁴ SO ₂ 7 _{3,5} –7 _{2,6}	248 364.769	3.48	47.0	248 367.7	5.5	3.07

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
³⁴ SO ₂ 13 _{1,13} –12 _{0,12}	248 698.698	9.73	81.8	248 702.5	4.4	5.83
³⁴ SO ₂ 21 _{3,19} –22 _{0,22}	248 855.716	0.13	233.5	248 856.5 ¹⁶	8.1	1.04
³⁴ SO ₂ 30 _{4,26} –30 _{3,27}	249 099.208	23.7	469.9	249 101.3 ³²	6.5	0.80
³⁴ SO ₂ 4 _{4,0} –5 _{3,3}	250 156.048	0.10	47.1	250 163.9	-0.4	0.75
³⁴ SO ₂ 9 _{3,7} –9 _{2,8}	250 358.384	4.66	62.6	two peaks: 250 351.4 250 362.0 ⁴	... 17.4 4.7	... 1.19 2.57
³⁴ SO ₂ 11 _{3,9} –12 _{0,12}	251 176.574	0.05	81.9	⁴⁹	...	...
³⁴ SO ₂ 25 _{4,22} –26 _{1,25}	251 438.065	0.28	337.2	⁶	...	...
³⁴ SO ₂ 27 _{4,24} –28 _{1,27}	251 639.934	0.31	386.1	¹⁶	...	...
³⁴ SO ₂ 32 _{4,28} –32 _{3,29}	251 758.330	25.6	529.6	251 760.5	6.4	0.31
³⁴ SO ₂ 9 _{5,5} –10 _{4,6}	252 615.371	0.76	100.5	252 618.4	5.4	0.47
³⁴ SO ₂ 11 _{3,9} –11 _{2,10}	253 936.319	5.79	81.9	253 940.0 ⁴⁹	4.7	3.63
³⁴ SO ₂ 28 _{4,24} –28 _{3,25}	254 277.643	21.2	414.3	⁴⁹	...	...
³⁴ SO ₂ 14 _{6,8} –15 _{5,11}	254 516.775	1.51	181.6	254 519.5 ¹⁸	5.8	0.38
³⁴ SO ₂ 19 _{7,13} –20 _{6,14}	255 892.295	2.27	290.3	255 896.5	4.1	0.18
³⁴ SO ₂ 24 _{8,16} –25 _{7,19}	256 864.330	3.04	426.7	⁵¹	...	...
³⁴ SO ₂ 29 _{9,21} –30 _{8,22}	257 466.731	3.81	590.8	¹³	...	...
³⁴ SO ₂ 29 _{4,26} –30 _{1,29}	258 889.599	0.32	438.6	258 893.6	4.4	0.08
³⁴ SO ₂ 23 _{4,20} –24 _{1,23}	259 022.539	0.24	291.9	⁵²	...	...
³⁴ SO ₂ 13 _{3,11} –13 _{2,12}	259 617.206	6.87	104.9	259 618.5 ^{5,7,34}	7.5	2.28
³⁴ SO ₂ 24 _{2,22} –24 _{1,23}	260 326.950	12.2	292.0	260 331.4 ^{4,7}	3.9	3.34
³⁴ SO ₂ 23 _{4,20} –24 _{1,23}	259 022.539	0.24	291.9	⁵²	...	...
³⁴ SO ₂ 34 _{4,30} –34 _{3,31}	263 436.078	26.7	593.1	263 441.4 ¹⁸	2.9	0.46
³⁴ SO ₂ 26 _{3,23} –25 _{4,22}	264 682.899	4.98	349.9	³	...	...
³⁴ SO ₂ 26 _{4,22} –26 _{3,23}	265 488.694	18.5	362.6	265 485.1 ^{4,49}	13.1	1.93
³⁴ SO ₂ 7 _{2,6} –6 _{1,25}	265 554.053	2.68	35.1	265 555.2	7.7	1.06
³⁴ SO ₂ 23 _{3,21} –24 _{0,24}	266 469.801	0.13	274.7	266 470.1	8.7	0.24
³⁴ SO ₂ 33 _{5,29} –34 _{2,32}	267 094.152	0.45	576.3	267 097.6	5.1	0.26
³⁴ SO ₂ 15 _{3,13} –15 _{2,14}	267 871.064	7.85	131.6	267 872.5 ³⁹	7.4	1.74
³⁴ SO ₂ 30 _{3,27} –30 _{2,28}	270 229.677	19.5	458.0	270 231.4 ⁷	7.1	0.52
³⁴ SO ₂ 17 _{2,16} –17 _{1,17}	271 410.227	5.36	148.5	271 413.9 ¹⁸	4.9	1.19
³⁴ SO ₂ 8 _{5,3} –9 _{4,6}	271 916.826	0.56	92.3	271 928.5 ⁴⁷	-3.9	0.72
³⁴ SO ₂ 31 _{4,28} –32 _{1,31}	272 363.869	0.32	494.8	¹⁶	...	...
³⁴ SO ₂ 9 _{3,7} –10 _{0,10}	272 625.742	0.02	62.6	³⁴	...	...
³⁴ SO ₂ 28 _{2,26} –29 _{1,29}	272 789.518	0.12	390.7	272 794.5	3.5	0.13
³⁴ SO ₂ 13 _{6,8} –14 _{5,9}	273 929.985	1.29	168.7	273 931.5	7.3	0.43
³⁴ SO ₂ 21 _{4,18} –22 _{1,21}	274 940.961	0.18	250.4	274 942.6	7.2	0.72
³⁴ SO ₂ 18 _{7,11} –19 _{6,14}	275 434.219	2.06	272.9	275 441.4 ³²	1.2	0.89
³⁴ SO ₂ 23 _{8,16} –24 _{7,17}	276 484.001	2.82	404.7	²⁴	...	...
³⁴ SO ₂ 6 _{2,4} –5 _{1,5}	276 999.606	1.85	28.8	277 001.3	7.2	1.61
³⁴ SO ₂ 28 _{9,19} –29 _{8,22}	277 150.593	3.60	564.1	277 154.0	5.3	0.14
³⁴ SO ₂ 33 _{10,24} –34 _{9,25}	277 470.086	4.37	751.2	277 471.3 ^{53,54}	7.7	0.57
³⁴ SO ₂ 32 _{4,28} –31 _{5,27}	278 835.214	5.43	529.6	278 834.5 ⁴³	9.8	0.56
³⁴ SO ₂ 17 _{3,15} –17 _{2,16}	279 075.261	8.72	161.9	279 076.3 ⁵	7.9	3.39
³⁴ SO ₂ 15 _{1,15} –14 _{0,14}	279 429.979	11.8	107.0	279 433.8 ^{6,18}	4.9	5.67
³⁴ SO ₂ 24 _{4,20} –24 _{3,21}	280 407.893	15.9	314.9	280 412.6 ⁶	4.0	2.09
³³ SO ₂ 8 _{3,5} –9 _{2,8}	82 380.654	1.13	54.8	82 380.5	9.6	0.03
³³ SO ₂ 26 _{4,22} –25 _{5,21}	82 777.117	4.11	363.4	⁴	...	...
³³ SO ₂ 8 _{1,7} –8 _{0,8}	83 345.818	6.32	36.7	83 347.5	3.0	0.06
³³ SO ₂ 18 _{5,13} –19 _{4,16}	83 540.669	2.68	217.4	83 541.5	6.0	0.01
³³ SO ₂ 23 _{6,18} –24 _{5,19}	84 025.261	3.46	340.4	¹⁷	...	...
³³ SO ₂ 28 _{7,21} –29 _{6,24}	87 241.461	4.22	491.2	⁵	...	...
³³ SO ₂ 33 _{8,26} –34 _{7,27}	89 094.697	4.99	669.8	89 096.4	3.3	0.01
³³ SO ₂ 20 _{2,18} –21 _{1,21}	90 595.537	0.26	207.5	³³	...	...
³³ SO ₂ 33 _{3,31} –32 _{4,28}	92 105.596	1.87	534.7	noise level	...	...
³³ SO ₂ 7 _{3,5} –8 _{2,6}	93 072.174	0.94	47.4	93 073.5	4.7	0.04
³³ SO ₂ 25 _{3,23} –24 _{4,20}	93 533.322	3.18	320.2	93 535.5	2.0	0.03
³³ SO ₂ 32 _{5,27} –31 _{6,26}	96 205.274	5.03	548.0	96 208.5 ³⁴	...	0.05
³³ SO ₂ 33 _{5,29} –32 _{6,26}	97 491.820	5.13	577.7	97 493.7	3.2	0.02
³³ SO ₂ 2 _{2,0} –3 _{1,3}	98 261.870	0.16	12.4	^{34,43}	...	...
³³ SO ₂ 17 _{5,13} –18 _{4,14}	101 560.254	2.48	200.9	⁷	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
³³ SO ₂ 12 _{4,8} –13 _{3,11}	101 688.876	1.70	110.2	⁴	...	...
³³ SO ₂ 3 _{1,3} –2 _{0,2}	103 000.258	2.02	7.7	103 003.4	-0.1	0.11
³³ SO ₂ 10 _{1,9} –10 _{0,10}	104 301.966	6.61	54.6	¹⁶	...	...
³³ SO ₂ 22 _{6,16} –23 _{5,19}	105 452.527	3.24	319.3	105 456.4 ⁶	-2.0	0.13
³³ SO ₂ 29 _{4,26} –28 _{5,23}	105 943.555	4.32	439.6	105 944.5	6.3	0.02
³³ SO ₂ 27 _{7,21} –28 _{6,22}	107 245.759	4.01	465.5	107 246.5	6.9	0.02
³³ SO ₂ 27 _{3,25} –26 _{4,22}	108 383.700	2.99	368.6	³⁰	...	...
³³ SO ₂ 31 _{3,29} –30 _{4,26}	108 514.453	2.28	475.9	¹⁹	...	...
³³ SO ₂ 32 _{8,24} –33 _{7,27}	109 681.906	4.78	639.4	⁶	...	...
³³ SO ₂ 16 _{2,14} –15 _{3,13}	109 828.514	3.02	137.3	109 829.5	6.3	0.11
³³ SO ₂ 29 _{3,27} –28 _{4,24}	113 783.648	2.67	420.5	¹⁷	...	...
³³ SO ₂ 14 _{2,12} –14 _{1,13}	131 191.102	11.7	107.9	131 192.7	5.4	0.36
³³ SO ₂ 8 _{2,6} –8 _{1,7}	131 247.049	5.73	43.0	131 249.5	3.4	0.32
³³ SO ₂ 12 _{1,11} –12 _{0,12}	131 561.786	6.53	76.3	131 562.6 ⁴⁷	7.1	0.29
³³ SO ₂ 12 _{1,11} –11 _{2,10}	132 084.974	3.42	76.3	132 086.4 ^{5,55}	5.8	0.22
³³ SO ₂ 5 _{1,5} –4 _{0,4}	134 550.979	3.14	15.6	134 550.1 ⁴	11.0	2.72
³³ SO ₂ 5 _{3,3} –6 _{2,4}	134 830.627	0.50	35.5	^{6,23}	...	...
³³ SO ₂ 35 _{5,31} –34 _{6,28}	136 073.824	5.39	641.6	136 075.1	6.2	0.02
³³ SO ₂ 31 _{2,28} –30 _{5,25}	136 345.497	4.41	495.9	²³	...	...
³³ SO ₂ 6 _{2,4} –6 _{1,5}	137 478.134	3.85	29.0	137 481.4	1.9	0.43
³³ SO ₂ 10 _{4,6} –11 _{3,9}	140 348.741	1.27	89.1	140 350.1	6.1	0.11
³³ SO ₂ 16 _{2,14} –16 _{1,15}	142 281.376	12.9	137.3	142 281.4	8.9	0.40
³³ SO ₂ 15 _{5,11} –16 _{4,12}	142 295.587	2.04	170.5	¹⁷	...	...
³³ SO ₂ 4 _{2,2} –4 _{1,3}	143 795.870	2.28	18.8	two peaks: 143 795.5 143 799.5	9.8 1.4	0.27 0.48
³³ SO ₂ 20 _{6,14} –21 _{5,17}	145 564.070	2.81	279.7	⁵⁶	...	...
³³ SO ₂ 25 _{7,19} –26 _{6,20}	147 793.083	3.58	416.7	147 795.5	4.1	0.11
³³ SO ₂ 2 _{2,0} –2 _{1,1}	148 614.406	0.87	12.4	⁵	...	...
³³ SO ₂ 34 _{5,29} –33 _{6,28}	148 926.741	5.39	610.6	¹⁷	...	...
³³ SO ₂ 30 _{8,22} –31 _{7,25}	150 134.771	4.35	581.4	¹⁶	...	...
³³ SO ₂ 3 _{2,2} –3 _{1,3}	155 523.945	1.44	15.2	two peaks: 155 523.5 155 526.4	9.9 4.3	0.27 0.24
³³ SO ₂ 4 _{3,1} –5 _{2,4}	156 091.249	0.30	30.9	⁹	...	...
³³ SO ₂ 9 _{4,6} –10 _{3,7}	158 845.420	1.05	79.9	158 846.5 ⁴⁹	7.0	0.17
³³ SO ₂ 18 _{2,16} –18 _{1,17}	160 513.715	13.4	170.5	³¹	...	...
³³ SO ₂ 33 _{4,30} –32 _{5,27}	161 071.892	4.36	555.7	⁴	...	...
³³ SO ₂ 10 _{0,10} –9 _{1,9}	161 452.956	6.48	49.6	161 452.6 ^{4,32}	9.7	2.53
³³ SO ₂ 5 _{2,4} –5 _{1,5}	162 562.342	2.45	23.4	162 564.5	5.0	0.51
³³ SO ₂ 14 _{5,9} –15 _{4,12}	162 745.229	1.82	156.7	162 748.5 ⁵	3.0	0.48
³³ SO ₂ 7 _{1,7} –6 _{0,6}	163 964.985	4.44	27.0	⁵	...	...
³³ SO ₂ 14 _{1,13} –14 _{0,14}	164 626.053	6.29	101.6	164 626.5	8.2	0.37
³³ SO ₂ 19 _{6,14} –20 _{5,15}	165 265.989	2.59	261.3	⁴	...	...
³³ SO ₂ 24 _{7,17} –25 _{6,20}	167 953.648	3.36	393.7	167 954.6 ³⁴	7.3	0.14
³³ SO ₂ 18 _{2,16} –17 _{3,15}	169 164.044	3.76	170.5	169 167.6	2.7	0.23
³³ SO ₂ 29 _{8,22} –30 _{7,23}	170 176.428	4.13	553.8	¹⁷	...	...
³³ SO ₂ 7 _{2,6} –7 _{1,7}	172 832.024	3.29	35.3	172 831.5	9.9	0.57
³³ SO ₂ 24 _{2,22} –25 _{1,25}	173 951.097	0.17	292.4	²⁵	...	...
³³ SO ₂ 3 _{3,1} –4 _{2,2}	174 505.972	0.13	27.2	174 506.5	8.1	0.37
³³ SO ₂ 7 _{4,4} –8 _{3,5}	198 125.389	0.63	64.3	198 127.4 ⁵⁵	6.0	0.22
³³ SO ₂ 24 _{3,21} –24 _{2,22}	198 479.747	19.3	301.9	198 482.4	5.0	0.52
³³ SO ₂ 18 _{3,15} –18 _{2,16}	199 340.675	13.1	180.1	199 343.6	4.6	0.54
³³ SO ₂ 30 _{4,26} –29 _{5,25}	199 653.586	4.92	470.7	⁴	...	...
³³ SO ₂ 12 _{5,7} –13 _{4,10}	201 927.690	1.39	131.9	201 929.4	6.5	0.19
³³ SO ₂ 16 _{1,15} –16 _{0,16}	202 188.357	6.04	130.5	202 194.4 ^{5,57}	0.0	0.89
³³ SO ₂ 11 _{2,10} –11 _{1,11}	203 266.908	4.53	70.0	203 268.2	7.1	0.47
³³ SO ₂ 12 _{0,12} –11 _{1,11}	203 790.096	8.49	70.0	203 793.3	4.3	0.83
³³ SO ₂ 17 _{6,12} –18 _{5,13}	204 932.906	2.16	227.3	⁷	...	...
³³ SO ₂ 3 _{2,2} –2 _{1,1}	205 876.481	1.67	15.2	205 876.1 ^{4,58}	9.6	1.06
³³ SO ₂ 36 _{5,31} –35 _{6,30}	206 591.663	5.74	677.2	⁶	...	...
³³ SO ₂ 22 _{7,15} –23 _{6,18}	207 708.782	2.93	350.4	⁷	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
³³ SO ₂ 16 _{3,13} –16 _{2,14}	209 431.260	10.8	147.4	209 434.9 ⁵⁹	3.8	1.15
³³ SO ₂ 27 _{8,20} –28 _{7,21}	210 085.250	3.70	501.3	210 088.7	4.1	0.16
³³ SO ₂ 32 _{9,23} –33 _{8,26}	212 214.107	4.47	680.0	noisy spectrum	...	...
³³ SO ₂ 26 _{3,23} –26 _{2,24}	212 860.266	20.2	350.3	212 862.3 ⁷	6.1	0.18
³³ SO ₂ 6 _{4,2} –7 _{3,5}	217 628.603	0.43	57.9	217 629.8	7.4	0.18
³³ SO ₂ 22 _{2,20} –22 _{1,21}	218 878.861	12.9	248.1	218 879.9 ⁶⁰	7.6	0.43
³³ SO ₂ 11 _{1,11} –10 _{0,10}	220 619.071	7.75	60.2	⁵⁷	...	...
³³ SO ₂ 14 _{3,11} –14 _{2,12}	220 987.225	8.68	118.5	220 986.2 ^{5,24,60}	10.4	0.92
³³ SO ₂ 11 _{5,7} –12 _{4,8}	221 328.839	1.17	120.9	221 332.4	4.2	0.14
³³ SO ₂ 13 _{2,12} –13 _{1,13}	223 378.596	4.93	92.7	⁴	...	...
³³ SO ₂ 16 _{6,10} –17 _{5,13}	224 641.972	1.94	211.6	⁴	...	...
³³ SO ₂ 21 _{7,15} –22 _{6,16}	227 436.553	2.71	330.2	⁵⁶	...	...
³³ SO ₂ 26 _{8,18} –27 _{7,21}	229 919.132	3.48	476.5	229 919.9 ¹⁷	8.0	0.11
³³ SO ₂ 20 _{2,18} –19 _{3,17}	230 438.867	4.69	207.5	230 442.4 ⁵	4.4	0.24
³³ SO ₂ 12 _{3,9} –12 _{2,10}	231 898.417	6.94	93.5	231 904.9 ^{7,10,61}	0.6	0.41
³³ SO ₂ 31 _{9,23} –32 _{8,24}	232 073.029	4.25	650.5	^{36,39}	...	...
³³ SO ₂ 4 _{2,2} –3 _{1,3}	232 419.835	1.71	18.8	¹⁶	...	...
³³ SO ₂ 17 _{3,15} –18 _{0,18}	233 838.726	0.12	162.4	233 840.5	6.7	0.12
³³ SO ₂ 15 _{3,13} –16 _{0,16}	234 641.219	0.10	132.0	234 647.7	0.7	0.09
³³ SO ₂ 28 _{3,25} –28 _{2,26}	235 726.867	20.3	402.5	¹⁷	...	...
³³ SO ₂ 5 _{4,2} –6 _{3,3}	236 815.676	0.25	52.4	^{5,6}	...	...
³³ SO ₂ 5 _{2,4} –4 _{1,3}	238 683.410	2.12	23.4	¹³	...	...
³³ SO ₂ 16 _{1,15} –15 _{2,14}	238 967.956	6.15	130.5	¹³	...	...
³³ SO ₂ 19 _{3,17} –20 _{0,20}	239 546.722	0.13	196.4	¹⁷	...	...
³³ SO ₂ 10 _{3,7} –10 _{2,8}	240 612.356	5.46	72.3	240 614.9	5.8	0.77
³³ SO ₂ 10 _{5,5} –11 _{4,8}	240 814.508	0.96	110.8	240 819.9 ¹⁷	2.3	0.43
³³ SO ₂ 13 _{3,11} –14 _{0,14}	242 429.337	0.76	105.4	⁹	...	...
³³ SO ₂ 18 _{1,17} –18 _{0,18}	242 489.055	5.88	162.8	^{4,16}	...	...
³³ SO ₂ 15 _{6,10} –16 _{5,11}	244 177.299	1.72	196.9	244 178.9	7.0	0.10
³³ SO ₂ 14 _{0,14} –13 _{1,13}	244 388.890	1.06	93.7	244 392.0 ⁵⁹	5.2	1.53
³³ SO ₂ 8 _{3,5} –8 _{2,6}	246 455.769	4.15	54.8	246 457.6 ⁵	6.8	1.00
³³ SO ₂ 15 _{2,14} –15 _{1,15}	246 558.644	5.22	119.0	⁶²	...	...
³³ SO ₂ 20 _{7,13} –21 _{6,16}	247 124.476	2.49	310.9	247 128.9 ¹⁷	3.6	0.67
³³ SO ₂ 6 _{3,3} –6 _{2,4}	249 650.188	2.90	41.0	249 652.5	6.2	0.99
³³ SO ₂ 25 _{8,18} –26 _{7,19}	249 659.233	3.26	452.6	249 660.5 ¹⁰	7.5	0.89
³³ SO ₂ 25 _{8,17} –26 _{7,20}	249 664.196	3.26	452.6	249 668.5	3.8	0.41
³³ SO ₂ 13 _{1,13} –12 _{0,12}	249 907.904	9.68	82.0	249 909.4	7.2	1.33
³³ SO ₂ 4 _{3,1} –4 _{2,2}	250 978.790	1.61	30.9	250 981.5 ⁶	5.8	0.80
³³ SO ₂ 21 _{3,19} –22 _{0,22}	251 161.805	0.13	234.1	¹⁶	...	...
³³ SO ₂ 3 _{3,1} –3 _{2,2}	251 401.862	0.89	27.2	251 408.9 ⁴³	0.6	0.48
³³ SO ₂ 5 _{3,3} –5 _{2,4}	251 702.803	2.26	35.5	251 706.5 ⁵	4.6	0.72
³³ SO ₂ 30 _{9,21} –31 _{8,24}	251 869.264	4.03	622.0	¹⁶	...	...
³³ SO ₂ 7 _{3,5} –7 _{2,6}	252 591.694	3.48	47.4	252 594.5	5.7	0.64
³³ SO ₂ 30 _{4,26} –30 _{3,27}	253 982.798	23.5	470.7	²⁹	...	...
³³ SO ₂ 9 _{3,7} –9 _{2,8}	254 510.018	4.65	63.0	254 518.8 ²³	-1.3	0.38
³³ SO ₂ 32 _{4,28} –32 _{3,29}	254 706.303	25.6	530.3	⁵⁶	...	...
³³ SO ₂ 26 _{3,23} –25 _{4,22}	255 285.450	4.92	350.3	255 288.8	5.1	0.04
³³ SO ₂ 4 _{4,0} –5 _{3,3}	256 049.817	0.10	47.8	^{5,53}	...	...
³³ SO ₂ 24 _{2,22} –24 _{1,23}	257 349.346	12.5	292.4	¹³	...	...
³³ SO ₂ 11 _{3,9} –11 _{2,10}	257 957.223	5.79	82.4	257 959.0	6.9	0.32
³³ SO ₂ 9 _{5,5} –10 _{4,6}	260 142.516	0.76	101.6	260 141.4 ^{5,9}	10.3	0.71
³³ SO ₂ 28 _{4,24} –28 _{3,25}	260 651.733	20.9	415.1	⁵	...	...
³³ SO ₂ 13 _{3,11} –13 _{2,12}	263 439.631	6.87	105.4	263 441.4 ²³	7.0	0.46
³³ SO ₂ 14 _{6,8} –15 _{5,11}	263 686.350	1.51	183.1	263 688.5 ⁶³	6.6	0.36
³³ SO ₂ 34 _{4,30} –31 _{3,31}	264 112.472	26.9	593.9	264 115.1	6.0	0.33
³³ SO ₂ 32 _{4,28} –31 _{5,27}	265 999.703	5.40	530.3	³²	...	...
³³ SO ₂ 23 _{4,20} –24 _{1,23}	266 389.236	0.23	292.8	³²	...	...
³³ SO ₂ 19 _{7,13} –20 _{6,14}	266 714.606	2.27	292.5	266 720.5 ⁴⁷	2.4	0.77
³³ SO ₂ 30 _{3,27} –30 _{2,28}	266 817.889	19.9	458.5	⁵	...	...
³³ SO ₂ 23 _{3,21} –24 _{0,24}	268 010.417	0.13	275.4	⁴	...	...
³³ SO ₂ 7 _{2,6} –6 _{1,5}	268 450.516	2.68	35.3	268 455.1	3.9	0.35
³³ SO ₂ 24 _{8,17} –25 _{7,18}	269 336.898	3.04	429.6	269 338.8	6.9	0.32

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
³³ SO ₂ 24 _{8,16} –25 _{7,19}	269 339.793	3.04	429.6	⁸	...	...
³³ SO ₂ 38 _{5,33} –37 _{6,32}	269 919.292	6.10	747.8	269 922.5 ⁴¹	5.4	0.09
³³ SO ₂ 15 _{3,13} –15 _{2,14}	271 420.818	7.87	132.0	271 413.9 ²³	16.6	1.19
³³ SO ₂ 29 _{9,21} –30 _{8,22}	271 595.561	3.82	594.4	271 599.4	4.8	0.16
³³ SO ₂ 17 _{2,16} –17 _{1,17}	272 529.988	5.42	148.9	272 532.5	6.2	0.35
³³ SO ₂ 26 _{4,22} –26 _{3,23}	272 834.379	18.3	363.4	272 836.5	6.7	0.36
³³ SO ₂ 34 _{10,24} –35 _{9,27}	273 528.762	4.59	787.0	273 531.5	6.0	0.14
³³ SO ₂ 6 _{2,4} –5 _{1,5}	279 434.518	1.86	29.0	^{7,23}	...	...
³³ SO ₂ 8 _{5,3} –9 _{4,6}	279 451.477	0.56	93.3	279 456.5	3.6	0.47
³³ SO ₂ 15 _{1,15} –14 _{0,14}	280 557.119	11.7	107.2	⁴	...	...
SO ¹⁸ O 19 _{5,15} –20 _{4,16}	80 417.639	2.91	225.1	noise level	...	...
SO ¹⁸ O 8 _{3,6} –9 _{2,7}	80 709.124	1.17	52.9	⁷	...	...
SO ¹⁸ O 19 _{5,14} –20 _{4,17}	83 312.870	2.91	225.1	³¹	...	...
SO ¹⁸ O 2 _{1,2} –1 _{0,1}	84 094.060	1.50	4.9	84 094.5	7.4	0.02
SO ¹⁸ O 16 _{2,14} –15 _{3,13}	86 720.509	2.95	130.1	86 722.3	2.8	0.03
SO ¹⁸ O 7 _{0,7} –6 _{1,6}	87 752.674	3.73	24.1	⁶⁴	...	...
SO ¹⁸ O 9 _{1,8} –9 _{0,9}	88 201.737	6.75	42.8	88 202.5 ⁴	...	0.06
SO ¹⁸ O 26 _{3,24} –25 _{4,21}	88 869.508	3.38	326.4	88 870.4	6.0	0.02
SO ¹⁸ O 26 _{6,19} –25 _{5,20}	88 950.657	3.68	347.0	noise level	...	...
SO ¹⁸ O 8 _{3,5} –9 _{2,8}	90 082.440	1.13	52.9	90 082.6	8.5	0.02
SO ¹⁸ O 24 _{6,18} –25 _{5,21}	90 093.680	3.68	347.0	noise level	...	...
SO ¹⁸ O 11 _{1,10} –10 _{2,9}	90 833.653	2.81	61.5	90 835.5	2.9	0.02
SO ¹⁸ O 13 _{4,10} –14 _{3,11}	91 008.626	1.93	117.4	³⁶	...	...
SO ¹⁸ O 22 _{3,19} –21 _{4,18}	94 940.503	3.67	243.9	³²	...	...
SO ¹⁸ O 13 _{4,9} –14 _{3,12}	95 583.519	1.92	117.4	noise level	...	...
SO ¹⁸ O 27 _{3,25} –26 _{4,22}	97 271.829	3.31	349.7	97 273.5 ⁶⁵	...	0.02
SO ¹⁸ O 10 _{1,9} –10 _{0,10}	98 201.071	6.89	51.7	98 201.5	7.7	0.07
SO ¹⁸ O 28 _{4,24} –27 _{5,23}	98 879.028	4.52	393.7	98 881.4	1.8	0.02
SO ¹⁸ O 3 _{1,3} –2 _{0,2}	100 072.226	2.01	7.4	⁵⁶	...	...
SO ¹⁸ O 18 _{5,14} –19 _{4,15}	100 152.038	2.70	208.5	100 152.6 ^{1,34}	7.3	0.07
SO ¹⁸ O 2 _{2,0} –3 _{1,3}	100 241.696	0.16	12.2	⁶⁶	...	...
SO ¹⁸ O 7 _{3,5} –8 _{2,6}	101 189.989	0.94	45.9	¹⁶	...	...
SO ¹⁸ O 18 _{5,13} –19 _{4,16}	102 098.856	2.69	208.5	102 099.5	7.1	0.01
SO ¹⁸ O 28 _{3,26} –27 _{4,23}	103 761.584	3.21	373.9	103 761.5 ¹⁷	9.2	0.04
SO ¹⁸ O 7 _{3,4} –8 _{2,7}	107 207.806	0.92	45.9	107 210.5 ⁶⁷	1.5	0.06
SO ¹⁸ O 29 _{3,27} –28 _{4,24}	108 156.775	3.07	398.9	108 158.5	4.2	0.03
SO ¹⁸ O 23 _{6,18} –24 _{5,19}	108 397.195	3.47	326.1	108 398.5	5.4	0.02
SO ¹⁸ O 8 _{0,8} –7 _{1,7}	108 695.341	4.54	30.9	108 697.5 ¹⁶	3.0	0.05
SO ¹⁸ O 23 _{6,17} –24 _{5,20}	109 165.615	3.46	326.1	³¹	...	...
SO ¹⁸ O 11 _{1,11} –11 _{0,11}	109 636.196	6.93	61.5	109 637.5	5.4	0.07
SO ¹⁸ O 12 _{4,9} –13 _{3,10}	110 819.438	1.71	106.1	110 820.5 ⁵³	6.1	0.06
SO ¹⁸ O 12 _{4,8} –13 _{3,11}	113 802.293	1.70	106.1	⁷	...	...
SO ¹⁸ O 17 _{2,15} –16 _{3,14}	113 985.361	3.28	145.3	⁴	...	...
SO ¹⁸ O 4 _{1,4} –3 _{0,3}	115 401.986	2.55	10.7	115 404.5	2.5	0.08
SO ¹⁸ O 5 _{1,5} –4 _{0,4}	130 142.719	3.12	14.9	130 146.4	0.5	0.13
SO ¹⁸ O 11 _{4,8} –12 _{3,9}	130 201.251	1.49	95.7	⁶	...	...
SO ¹⁸ O 8 _{2,6} –8 _{1,7}	131 766.987	5.61	41.1	131 767.6	7.6	0.13
SO ¹⁸ O 15 _{2,13} –15 _{1,14}	131 783.379	12.5	115.7	131 785.5 ⁶⁸	4.2	0.14
SO ¹⁸ O 11 _{4,7} –12 _{3,10}	132 076.129	1.49	95.7	132 076.4 ¹⁷	8.4	0.09
SO ¹⁸ O 7 _{2,5} –7 _{1,6}	134 717.922	4.66	34.0	134 719.6	5.3	0.14
SO ¹⁸ O 16 _{2,14} –16 _{1,15}	136 657.242	13.1	130.1	⁵	...	...
SO ¹⁸ O 13 _{1,12} –13 _{0,13}	136 749.392	6.80	83.8	136 751.1	5.3	0.21
SO ¹⁸ O 6 _{2,4} –6 _{1,5}	137 821.359	3.79	27.9	137 824.5	2.2	0.20
SO ¹⁸ O 16 _{5,12} –17 _{4,13}	138 730.445	2.26	178.1	138 730.5 ¹⁷	8.9	0.12
SO ¹⁸ O 16 _{5,11} –17 _{4,14}	139 548.900	2.26	178.1	139 551.4	3.6	0.11
SO ¹⁸ O 5 _{3,3} –6 _{2,4}	140 259.456	0.50	34.6	⁵³	...	...
SO ¹⁸ O 5 _{2,3} –5 _{1,4}	140 879.971	2.99	22.7	140 880.5	7.9	0.11
SO ¹⁸ O 13 _{1,12} –12 _{2,11}	141 009.800	3.85	83.8	141 012.7	2.8	0.12
SO ¹⁸ O 18 _{2,16} –17 _{3,15}	141 890.087	3.64	161.4	141 891.6	5.8	0.08
SO ¹⁸ O 17 _{2,15} –17 _{1,16}	143 096.211	13.6	145.3	¹⁶	...	...
SO ¹⁸ O 4 _{2,2} –4 _{1,3}	143 714.712	2.26	18.3	143 715.5	7.4	0.10
SO ¹⁸ O 6 _{1,6} –5 _{0,5}	144 375.674	3.74	19.9	144 377.6	5.0	0.14

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ¹⁸ O 3 _{2,1} –3 _{1,2}	146 171.277	1.57	14.8	¹	...	...
SO ¹⁸ O 21 _{6,16} –22 _{5,17}	146 720.814	3.03	287.0	146 725.4 ¹⁷	-0.4	0.03
SO ¹⁸ O 21 _{6,15} –22 _{5,18}	147 048.896	3.03	287.0	³⁴	...	...
SO ¹⁸ O 2 _{2,0} –2 _{1,1}	148 124.155	0.87	12.2	148 125.1 ¹⁷	7.1	0.24
SO ¹⁸ O 10 _{4,7} –11 _{3,8}	149 240.910	1.27	86.1	149 241.3	8.2	0.08
SO ¹⁸ O 10 _{0,10} –9 _{1,9}	150 298.672	6.34	47.0	150 301.4	3.6	0.18
SO ¹⁸ O 10 _{4,6} –11 _{3,9}	150 370.440	1.27	86.1	⁴⁹	...	...
SO ¹⁸ O 18 _{2,16} –18 _{1,17}	151 170.878	13.9	161.4	151 172.6 ⁴¹	5.6	0.13
SO ¹⁸ O 24 _{3,21} –23 _{4,20}	151 524.215	4.17	285.9	151 525.1	7.3	0.05
SO ¹⁸ O 2 _{2,1} –2 _{1,2}	152 273.960	0.83	12.2	⁶⁹	...	...
SO ¹⁸ O 14 _{1,13} –14 _{0,14}	152 276.995	6.68	96.2	152 278.9	5.3	0.22
SO ¹⁸ O 3 _{2,2} –3 _{1,3}	154 383.207	1.44	14.8	154 385.1	5.3	0.11
SO ¹⁸ O 4 _{2,3} –4 _{1,4}	157 205.792	1.98	18.3	157 206.4	7.8	0.17
SO ¹⁸ O 15 _{5,11} –16 _{4,12}	157 677.252	2.04	164.2	157 679.5 ⁴⁰	4.7	0.11
SO ¹⁸ O 15 _{5,10} –16 _{4,13}	158 186.297	2.04	164.2	⁴⁹	...	...
SO ¹⁸ O 7 _{1,7} –6 _{0,6}	158 202.045	4.40	25.7	⁴⁹	...	...
SO ¹⁸ O 4 _{3,2} –5 _{2,3}	159 085.121	0.30	30.3	¹⁷	...	...
SO ¹⁸ O 4 _{3,1} –5 _{2,4}	160 099.923	0.30	30.3	160 102.7 ¹⁷	3.8	0.19
SO ¹⁸ O 5 _{2,4} –5 _{1,5}	160 749.394	2.46	22.6	160 750.5	6.9	0.19
SO ¹⁸ O 19 _{2,17} –19 _{1,18}	160 926.624	14.0	178.4	160 927.5	7.4	0.15
SO ¹⁸ O 6 _{2,5} –6 _{1,6}	165 022.264	2.91	27.8	165 023.9	6.0	0.14
SO ¹⁸ O 9 _{2,7} –8 _{2,6}	165 236.094	8.55	49.0	⁴⁹	...	...
SO ¹⁸ O 20 _{6,15} –21 _{5,16}	165 650.855	2.82	268.7	⁵	...	...
SO ¹⁸ O 20 _{6,14} –21 _{5,17}	165 858.555	2.82	268.7	^{1,24}	...	...
SO ¹⁸ O 14 _{1,13} –13 _{2,12}	166 375.483	4.45	96.2	166 377.6 ^{70,71}	5.2	0.15
SO ¹⁸ O 9 _{4,6} –10 _{3,7}	168 012.811	1.05	77.5	168 014.5 ¹⁷	6.0	0.15
SO ¹⁸ O 9 _{4,5} –10 _{3,8}	168 660.086	1.05	77.5	¹⁷	...	...
SO ¹⁸ O 15 _{1,14} –15 _{0,15}	168 946.152	6.55	109.4	168 947.5 ⁵³	6.6	0.21
SO ¹⁸ O 7 _{2,6} –7 _{1,7}	170 032.391	3.32	33.9	⁵	...	...
SO ¹⁸ O 19 _{2,17} –18 _{3,16}	170 334.178	4.04	178.4	⁴	...	...
SO ¹⁸ O 11 _{0,11} –10 _{1,10}	170 740.229	7.31	56.3	⁴⁹	...	...
SO ¹⁸ O 8 _{1,8} –7 _{0,7}	171 738.990	5.13	32.3	⁴	...	...
SO ¹⁸ O 20 _{2,18} –20 _{1,19}	172 376.560	14.1	196.3	⁵	...	...
SO ¹⁸ O 25 _{7,19} –26 _{6,20}	173 292.221	3.59	399.7	⁷	...	...
SO ¹⁸ O 25 _{7,18} –26 _{6,21}	173 372.106	3.59	399.7	⁹	...	...
SO ¹⁸ O 8 _{2,7} –8 _{1,8}	175 786.587	3.70	40.8	³	...	...
SO ¹⁸ O 14 _{5,10} –15 _{4,11}	176 449.762	1.82	151.1	¹⁷	...	...
SO ¹⁸ O 14 _{5,9} –15 _{4,12}	176 756.335	1.82	151.1	³⁴	...	...
SO ¹⁸ O 3 _{3,1} –4 _{2,2}	177 592.074	0.13	26.8	177 593.6 ⁷²	6.4	0.33
SO ¹⁸ O 3 _{3,0} –4 _{2,3}	178 027.433	0.13	26.8	¹⁷	...	...
SO ¹⁸ O 25 _{3,22} –25 _{2,23}	196 757.077	20.2	308.3	⁶	...	...
SO ¹⁸ O 11 _{2,10} –11 _{1,11}	197 543.946	4.61	66.7	⁴	...	...
SO ¹⁸ O 19 _{3,16} –19 _{2,17}	198 011.793	13.9	187.9	⁵	...	...
SO ¹⁸ O 10 _{1,10} –9 _{0,9}	198 451.881	6.74	48.1	198 454.9	4.4	0.23
SO ¹⁸ O 20 _{2,18} –19 _{3,17}	199 209.147	4.48	196.3	¹⁷	...	...
SO ¹⁸ O 22 _{2,20} –22 _{1,21}	200 212.306	13.8	234.8	200 213.6	7.1	0.09
SO ¹⁸ O 26 _{3,23} –26 _{2,24}	202 204.122	20.7	331.6	¹³	...	...
SO ¹⁸ O 3 _{2,2} –2 _{1,1}	202 265.667	1.67	14.8	¹³	...	...
SO ¹⁸ O 18 _{3,15} –18 _{2,16}	202 393.329	12.7	171.1	202 393.2	9.2	0.11
SO ¹⁸ O 18 _{6,13} –19 _{5,14}	203 148.227	2.38	234.8	203 150.9	5.1	0.13
SO ¹⁸ O 18 _{6,12} –19 _{5,15}	203 225.585	2.38	234.8	²³	...	...
SO ¹⁸ O 7 _{4,4} –8 _{3,5}	204 989.937	0.63	62.7	204 993.6	3.6	0.10
SO ¹⁸ O 17 _{1,16} –17 _{0,17}	205 002.547	6.31	138.4	^{5,7}	...	...
SO ¹⁸ O 7 _{4,3} –8 _{3,6}	205 164.732	0.63	62.7	205 167.4 ²⁶	5.1	0.42
SO ¹⁸ O 12 _{2,11} –12 _{1,12}	206 285.933	4.85	77.0	206 286.2	8.6	0.28
SO ¹⁸ O 3 _{2,1} –2 _{1,2}	206 589.735	1.60	14.8	⁷	...	...
SO ¹⁸ O 17 _{3,14} –17 _{2,15}	207 401.220	11.5	155.2	^{4,7,73}	...	...
SO ¹⁸ O 27 _{3,24} –27 _{2,25}	209 536.690	21.1	355.8	¹⁶	...	...
SO ¹⁸ O 13 _{0,13} –12 _{1,12}	210 546.341	9.34	77.2	210 548.7 ³⁴	5.6	1.23
SO ¹⁸ O 11 _{1,11} –10 _{0,10}	211 873.232	7.63	57.2	211 873.6 ⁶⁰	8.5	0.82
SO ¹⁸ O 26 _{3,23} –25 _{4,22}	211 913.681	4.76	331.6	noisy spectrum	...	...
SO ¹⁸ O 16 _{3,13} –16 _{2,14}	212 789.912	10.4	140.3	³²	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ¹⁸ O 12 _{5,8} –13 _{4,9}	213 591.909	1.39	127.7	213 593.6	6.6	0.11
SO ¹⁸ O 12 _{5,7} –13 _{4,10}	213 691.030	1.39	127.7	213 694.9	3.6	0.09
SO ¹⁸ O 13 _{2,12} –13 _{1,13}	215 756.356	5.05	88.2	215 757.4 ⁴	7.6	0.51
SO ¹⁸ O 23 _{2,21} –23 _{1,22}	216 415.486	13.6	255.3	216 416.1 ⁹	8.1	0.16
SO ¹⁸ O 16 _{1,15} –15 _{2,14}	217 102.694	5.86	123.5	74	...	...
SO ¹⁸ O 4 _{2,3} –3 _{1,2}	218 230.244	1.88	18.3	15	...	...
SO ¹⁸ O 15 _{3,12} –15 _{2,13}	218 316.801	9.40	126.2	56	...	...
SO ¹⁸ O 28 _{3,25} –28 _{2,26}	218 793.885	21.3	380.9	218 796.1	6.0	0.09
SO ¹⁸ O 17 _{6,12} –18 _{5,13}	221 746.496	2.16	219.2	23	...	...
SO ¹⁸ O 17 _{6,11} –18 _{5,14}	221 791.775	2.16	219.2	221 794.9 ¹⁷	4.8	0.57
SO ¹⁸ O 6 _{4,3} –7 _{3,4}	223 286.066	0.43	56.6	223 287.4	7.2	0.09
SO ¹⁸ O 6 _{4,2} –7 _{3,5}	223 365.572	0.43	56.6	223 367.4 ⁴	6.5	0.15
SO ¹⁸ O 14 _{3,11} –14 _{2,12}	223 753.919	8.47	113.1	223 757.4	4.3	0.33
SO ¹⁸ O 18 _{1,17} –18 _{0,18}	223 997.568	6.22	154.2	4	...	...
SO ¹⁸ O 12 _{1,12} –11 _{0,11}	225 476.608	8.56	67.1	225 479.8	4.8	0.33
SO ¹⁸ O 14 _{2,13} –14 _{1,14}	225 937.235	5.23	100.2	225 939.9	5.5	0.16
SO ¹⁸ O 4 _{2,2} –3 _{1,3}	227 022.358	1.72	18.3	5	...	...
SO ¹⁸ O 21 _{2,19} –20 _{3,18}	228 399.026	4.97	215.1	228 403.5	3.1	0.06
SO ¹⁸ O 13 _{3,10} –13 _{2,11}	228 899.481	7.61	100.8	228 901.1 ²⁵	6.9	1.25
SO ¹⁸ O 22 _{7,16} –23 _{6,17}	229 536.105	2.93	337.1	229 541.1 ⁵	2.5	0.27
SO ¹⁸ O 22 _{7,15} –23 _{6,18}	229 554.746	2.93	337.1	229 557.4	5.5	0.12
SO ¹⁸ O 14 _{0,14} –13 _{1,13}	229 854.843	10.4	88.9	23	...	...
SO ¹⁸ O 29 _{3,26} –29 _{2,27}	229 980.850	21.3	406.9	229 984.9	3.7	0.15
SO ¹⁸ O 11 _{5,7} –12 _{4,8}	232 008.234	1.17	117.3	4	...	...
SO ¹⁸ O 11 _{5,6} –12 _{4,9}	232 060.800	1.17	117.3	232 064.9	3.7	0.16
SO ¹⁸ O 17 _{3,15} –18 _{0,18}	233 278.358	0.12	154.6	4	...	...
SO ¹⁸ O 5 _{2,4} –4 _{1,3}	233 497.590	2.12	22.6	4	...	...
SO ¹⁸ O 12 _{3,9} –12 _{2,10}	233 588.336	6.82	89.5	6	...	...
SO ¹⁸ O 24 _{2,22} –24 _{1,23}	233 949.989	13.3	276.6	233 950.5 ^{6,36}	8.3	0.27
SO ¹⁸ O 18 _{3,16} –19 _{0,19}	233 967.257	0.13	170.3	6	...	...
SO ¹⁸ O 16 _{3,14} –17 _{0,17}	234 113.397	0.11	139.8	5	...	...
SO ¹⁸ O 19 _{3,17} –20 _{0,20}	236 122.215	0.14	186.8	17	...	...
SO ¹⁸ O 15 _{3,13} –16 _{0,16}	236 522.092	0.10	125.9	56	...	...
SO ¹⁸ O 15 _{2,14} –15 _{1,15}	236 804.935	5.38	113.1	5,6	...	...
SO ¹⁸ O 27 _{8,20} –28 _{7,21}	237 018.562	3.70	481.6	237 021.5	5.3	0.14
SO ¹⁸ O 27 _{8,19} –28 _{7,22}	237 025.774	3.70	481.6	237 026.5	8.1	0.17
SO ¹⁸ O 11 _{3,8} –11 _{2,9}	237 700.285	6.09	79.0	237 706.3	1.4	0.18
SO ¹⁸ O 13 _{1,13} –12 _{0,12}	239 336.024	9.53	77.8	239 340.2	3.8	0.45
SO ¹⁸ O 16 _{6,11} –17 _{5,12}	240 261.313	1.94	204.4	35	...	...
SO ¹⁸ O 16 _{6,10} –17 _{5,13}	240 286.978	1.94	204.4	5	...	...
SO ¹⁸ O 10 _{3,7} –10 _{2,8}	241 165.049	5.40	69.4	16	...	...
SO ¹⁸ O 5 _{4,2} –6 _{3,3}	241 499.067	0.25	51.4	7,23	...	...
SO ¹⁸ O 5 _{4,1} –6 _{3,4}	241 530.882	0.25	51.4	7	...	...
SO ¹⁸ O 17 _{1,16} –16 _{2,15}	242 215.554	6.66	138.4	4	...	...
SO ¹⁸ O 30 _{3,27} –30 _{2,28}	243 063.849	21.2	433.8	243 066.3	6.0	0.43
SO ¹⁸ O 27 _{3,24} –26 _{4,23}	243 287.035	5.11	355.8	34	...	...
SO ¹⁸ O 19 _{1,18} –19 _{0,19}	243 374.811	6.15	170.7	243 377.6	5.6	0.17
SO ¹⁸ O 33 _{4,29} –32 _{5,28}	243 806.001	5.57	531.7	243 810.5 ¹⁷	3.5	0.33
SO ¹⁸ O 9 _{3,6} –9 _{2,7}	243 962.753	4.75	60.7	243 965.5	5.6	0.41
SO ¹⁸ O 21 _{3,19} –22 _{0,22}	244 570.319	0.14	222.4	33	...	...
SO ¹⁸ O 8 _{3,5} –8 _{2,6}	246 119.337	4.12	52.9	246 122.6	5.0	0.32
SO ¹⁸ O 13 _{3,11} –14 _{0,14}	246 199.086	0.07	100.7	56	...	...
SO ¹⁸ O 7 _{3,4} –7 _{2,5}	247 697.435	3.50	45.9	5	...	...
SO ¹⁸ O 6 _{2,5} –5 _{1,4}	248 074.508	2.38	27.8	49	...	...
SO ¹⁸ O 21 _{7,15} –22 _{6,16}	248 124.713	2.71	318.0	248 128.9 ¹⁷	3.9	0.35
SO ¹⁸ O 21 _{7,14} –22 _{6,17}	248 135.684	2.71	318.0	no spectrum	...	...
SO ¹⁸ O 16 _{2,15} –16 _{1,16}	248 330.358	5.50	126.8	248 332.6	6.3	0.30
SO ¹⁸ O 5 _{2,3} –4 _{1,4}	248 435.799	1.83	22.7	4	...	...
SO ¹⁸ O 15 _{0,15} –14 _{1,14}	248 771.504	11.4	101.3	248 772.5	7.8	0.75
SO ¹⁸ O 6 _{3,3} –6 _{2,4}	248 784.360	2.89	39.8	5	...	...
SO ¹⁸ O 5 _{3,2} –5 _{2,3}	249 479.459	2.26	34.6	249 483.9 ^{7,71}	3.7	0.36
SO ¹⁸ O 4 _{3,1} –4 _{2,2}	249 882.801	1.61	30.3	16	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ¹⁸ O 3 _{3,0} –3 _{2,1}	250 086.400	0.89	26.8	³⁹	...	...
SO ¹⁸ O 3 _{3,1} –3 _{2,2}	250 231.226	0.89	26.8	250 236.3	2.9	0.15
SO ¹⁸ O 4 _{3,2} –4 _{2,3}	250 315.128	1.61	30.3	⁶	...	...
SO ¹⁸ O 10 _{5,6} –11 _{4,7}	250 345.658	0.96	107.7	²³	...	...
SO ¹⁸ O 10 _{5,5} –11 _{4,8}	250 371.975	0.96	107.7	²³	...	...
SO ¹⁸ O 5 _{3,3} –5 _{2,4}	250 481.005	2.26	34.6	250 482.6 ^{19,26,27}	7.1	0.58
SO ¹⁸ O 22 _{3,20} –23 _{0,23}	250 723.320	0.14	241.5	250 726.5 ⁷²	5.2	0.08
SO ¹⁸ O 6 _{3,4} –6 _{2,5}	250 767.445	2.87	39.8	no spectrum	...	...
SO ¹⁸ O 7 _{3,5} –7 _{2,6}	251 218.717	3.47	45.9	⁴⁹	...	...
SO ¹⁸ O 8 _{3,6} –8 _{2,7}	251 883.714	4.06	52.9	¹⁶	...	...
SO ¹⁸ O 32 _{4,28} –32 _{3,29}	252 312.209	25.2	502.2	252 316.4	4.0	0.11
SO ¹⁸ O 33 _{4,29} –33 _{3,30}	252 599.016	26.3	531.7	252 601.5 ⁴¹	6.1	0.38
SO ¹⁸ O 25 _{2,23} –25 _{1,24}	252 627.480	13.1	298.8	252 633.5 ⁴	1.9	0.55
SO ¹⁸ O 9 _{3,7} –9 _{2,8}	252 814.791	4.64	60.7	¹⁶	...	...
SO ¹⁸ O 12 _{3,10} –13 _{0,13}	253 493.155	0.06	89.4	⁶⁹	...	...
SO ¹⁸ O 14 _{1,14} –13 _{0,13}	253 497.373	10.5	89.4	253 501.3	4.4	0.28
SO ¹⁸ O 31 _{4,27} –31 _{3,28}	253 792.638	24.1	473.7	253 793.5 ¹⁷	8.0	0.21
SO ¹⁸ O 10 _{3,8} –10 _{2,9}	254 066.518	5.21	69.4	254 068.9 ⁴	6.2	0.93
SO ¹⁸ O 34 _{4,30} –34 _{3,31}	254 792.758	27.2	562.1	¹²	...	...
SO ¹⁸ O 26 _{8,19} –27 _{7,20}	255 656.625	3.48	458.1	^{22,75}	...	...
SO ¹⁸ O 26 _{8,18} –27 _{7,21}	255 660.974	3.48	458.1	^{22,75}	...	...
SO ¹⁸ O 11 _{3,9} –11 _{2,10}	255 694.394	5.78	78.9	⁶²	...	...
SO ¹⁸ O 28 _{4,25} –29 _{1,28}	256 635.956	0.32	392.1	256 640.4	3.8	0.07
SO ¹⁸ O 27 _{4,24} –28 _{1,27}	256 860.014	0.31	367.7	⁵¹	...	...
SO ¹⁸ O 30 _{4,26} –30 _{3,27}	256 869.345	22.8	446.1	⁵¹	...	...
SO ¹⁸ O 12 _{3,10} –12 _{2,11}	257 753.563	6.33	89.4	257 754.5 ^{5,23}	7.9	0.28
SO ¹⁸ O 22 _{2,20} –21 _{3,19}	257 780.402	5.51	234.8	257 783.5 ²⁷	5.4	0.12
SO ¹⁸ O 31 _{3,28} –31 _{2,29}	257 966.427	21.0	461.5	257 968.5	6.6	0.19
SO ¹⁸ O 29 _{4,26} –30 _{1,29}	258 050.529	0.34	417.4	⁵	...	...
SO ¹⁸ O 23 _{3,21} –24 _{0,24}	258 063.984	0.14	261.4	⁵	...	...
SO ¹⁸ O 15 _{6,10} –16 _{5,11}	258 703.135	1.72	190.5	⁵	...	...
SO ¹⁸ O 15 _{6,9} –16 _{5,12}	258 717.168	1.72	190.5	258 720.5	5.1	0.12
SO ¹⁸ O 26 _{4,23} –27 _{1,26}	258 800.211	0.29	344.1	258 802.5 ¹⁷	6.4	0.16
SO ¹⁸ O 35 _{4,31} –35 _{3,32}	259 001.896	27.9	593.5	⁵²	...	...
SO ¹⁸ O 29 _{2,27} –30 _{1,30}	259 066.034	0.14	395.8	259 070.1 ¹⁷	4.3	0.19
SO ¹⁸ O 4 _{4,1} –5 _{3,2}	259 653.472	0.10	47.1	⁵	...	...
SO ¹⁸ O 4 _{4,0} –5 _{3,3}	259 664.080	0.10	47.1	⁵	...	...
SO ¹⁸ O 13 _{3,11} –13 _{2,12}	260 297.574	6.87	100.7	⁶	...	...
SO ¹⁸ O 17 _{2,16} –17 _{1,17}	260 479.408	5.60	141.3	⁷⁴	...	...
SO ¹⁸ O 30 _{4,27} –31 _{1,30}	261 020.897	0.34	443.6	¹⁷	...	...
SO ¹⁸ O 29 _{4,25} –29 _{3,26}	261 340.830	21.4	419.4	261 341.4	8.3	0.48
SO ¹⁸ O 7 _{2,6} –6 _{1,5}	261 972.250	2.67	33.9	261 971.5 ^{17,41}	9.9	0.39
SO ¹⁸ O 11 _{3,9} –12 _{0,12}	262 401.534	0.04	78.9	⁷	...	...
SO ¹⁸ O 25 _{4,22} –26 _{1,25}	262 526.174	0.27	321.4	^{30,49}	...	...
SO ¹⁸ O 31 _{9,23} –32 _{8,24}	262 894.205	4.26	624.7	⁷	...	...
SO ¹⁸ O 31 _{9,22} –32 _{8,25}	262 895.846	4.26	624.7	⁷	...	...
SO ¹⁸ O 20 _{1,19} –20 _{0,20}	262 954.802	6.10	188.1	²⁶	...	...
SO ¹⁸ O 14 _{3,12} –14 _{2,13}	263 377.210	7.39	112.8	263 377.6 ⁵	8.6	0.19
SO ¹⁸ O 36 _{4,32} –36 _{3,33}	265 303.263	28.3	625.7	265 302.7 ⁶⁸	9.6	0.17
SO ¹⁸ O 31 _{4,28} –32 _{1,31}	265 460.709	0.35	470.6	²⁵	...	...
SO ¹⁸ O 20 _{7,14} –21 _{6,15}	266 646.030	2.49	299.8	266 648.5	6.2	0.19
SO ¹⁸ O 20 _{7,13} –21 _{6,16}	266 652.322	2.49	299.8	266 653.5 ⁷⁷	7.7	0.24
SO ¹⁸ O 28 _{4,24} –28 _{3,25}	266 977.664	20.1	393.7	266 980.5	5.8	0.32
SO ¹⁸ O 18 _{1,17} –17 _{2,16}	266 993.928	7.52	154.2	⁶	...	...
SO ¹⁸ O 15 _{3,13} –15 _{2,14}	267 039.427	7.90	125.9	267 043.9	4.0	0.17
SO ¹⁸ O 16 _{0,16} –15 _{1,15}	267 322.270	12.5	114.5	no spectrum	...	...
SO ¹⁸ O 15 _{1,15} –14 _{0,14}	267 979.833	11.5	101.7	267 985.5	2.7	0.41
SO ¹⁸ O 24 _{4,21} –25 _{1,24}	268 096.198	0.24	299.6	268 096.4 ¹⁷	8.8	0.31
SO ¹⁸ O 9 _{5,5} –10 _{4,6}	268 618.479	0.76	99.0	268 620.5	6.7	0.19
SO ¹⁸ O 9 _{5,4} –10 _{4,7}	268 630.772	0.76	99.0	³¹	...	...
SO ¹⁸ O 6 _{2,4} –5 _{1,5}	270 970.943	1.90	27.9	270 974.5 ³⁴	5.1	0.39
SO ¹⁸ O 32 _{4,29} –33 _{1,32}	271 281.411	0.35	498.5	⁷	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c} - J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ¹⁸ O 16 _{3,14} –16 _{2,15}	271 326.403	8.37	139.8	271 328.9 ³⁶	6.2	0.18
SO ¹⁸ O 26 _{2,24} –26 _{1,25}	272 235.733	12.9	321.9	³¹	...	...
SO ¹⁸ O 10 _{3,8} –11 _{0,11}	272 869.061	0.03	69.4	⁵⁶	...	...
SO ¹⁸ O 18 _{2,17} –18 _{1,18}	273 213.674	5.69	156.7	273 216.5	5.9	0.14
SO ¹⁸ O 27 _{4,23} –27 _{3,24}	273 527.753	18.7	368.9	273 528.6	8.1	0.24
SO ¹⁸ O 37 _{4,33} –37 _{3,34}	273 740.474	28.6	658.9	⁴⁸	...	...
SO ¹⁸ O 25 _{8,18} –26 _{7,19}	274 232.871	3.26	435.5	⁶⁹	...	...
SO ¹⁸ O 25 _{8,17} –26 _{7,20}	274 235.442	3.26	435.5	274 236.3	8.1	0.08
SO ¹⁸ O 32 _{3,29} –32 _{2,30}	274 568.048	20.7	490.1	274 568.5 ⁵	8.5	0.33
SO ¹⁸ O 8 _{2,7} –7 _{1,6}	275 207.551	2.97	40.8	⁴⁹	...	...
SO ¹⁸ O 28 _{3,25} –27 _{4,24}	275 282.312	5.49	380.9	275 283.9	7.3	0.17
SO ¹⁸ O 23 _{4,20} –24 _{1,23}	275 552.789	0.22	278.6	no spectrum	...	...
SO ¹⁸ O 25 _{3,23} –26 _{0,26}	276 001.955	0.14	303.9	³²	...	...
SO ¹⁸ O 17 _{3,15} –17 _{2,16}	276 274.719	8.82	154.6	276 277.6	5.9	0.21
SO ¹⁸ O 34 _{4,30} –33 _{5,29}	276 277.576	5.84	562.1	⁸	...	...
SO ¹⁸ O 14 _{6,9} –15 _{5,10}	277 081.114	1.51	177.5	277 086.3 ^{9,37}	3.4	0.36
SO ¹⁸ O 14 _{6,8} –15 _{5,11}	277 088.479	1.51	177.5	277 092.6	4.5	0.22
SO ¹⁸ O 26 _{4,22} –26 _{3,23}	280 724.381	17.5	345.0	280 727.5 ⁶⁸	5.7	0.25
SO ₂ $\nu_2 = 1$ 25 _{3,23} –24 _{4,20}	82 488.410	3.28	1066.4	82 489.5	5.0	0.02
SO ₂ $\nu_2 = 1$ 8 _{1,7} –8 _{0,8}	85 208.089	6.40	781.9	85 208.5	7.6	0.08
SO ₂ $\nu_2 = 1$ 24 _{6,18} –25 _{5,21}	88 029.007	3.67	1111.3	88 031.4 ¹⁷	0.7	0.04
SO ₂ $\nu_2 = 1$ 29 _{4,26} –28 _{5,23}	88 888.803	4.39	1186.5	¹⁷	...	...
SO ₂ $\nu_2 = 1$ 13 _{4,10} –14 _{3,11}	91 400.957	1.93	869.0	noise level	...	...
SO ₂ $\nu_2 = 1$ 8 _{3,5} –9 _{2,8}	92 660.362	1.13	800.8	92 661.5	5.4	0.03
SO ₂ $\nu_2 = 1$ 29 _{7,23} –30 _{6,24}	93 456.549	4.44	1268.1	93 457.5	6.1	0.02
SO ₂ $\nu_2 = 1$ 39 _{6,34} –38 _{7,31}	93 474.213	6.15	1555.0	⁸⁸	...	...
SO ₂ $\nu_2 = 1$ 16 _{2,14} –15 _{3,13}	98 264.696	2.99	882.8	98 265.5 ⁶	6.4	0.17
SO ₂ $\nu_2 = 1$ 27 _{3,25} –26 _{4,22}	99 177.397	3.14	1114.8	⁵	...	...
SO ₂ $\nu_2 = 1$ 18 _{5,13} –19 _{4,16}	102 335.197	2.69	965.1	102 337.0	3.7	0.06
SO ₂ $\nu_2 = 1$ 7 _{3,5} –8 _{2,6}	103 699.749	0.94	793.5	103 699.5 ¹⁷	9.6	0.09
SO ₂ $\nu_2 = 1$ 31 _{3,29} –30 _{4,26}	104 210.533	2.47	1222.2	³²	...	...
SO ₂ $\nu_2 = 1$ 22 ₀ –31 ₃	104 518.097	0.16	757.9	104 518.6 ⁴¹	7.5	0.02
SO ₂ $\nu_2 = 1$ 31 ₃ –20 ₂	105 117.218	2.01	752.9	105 118.5	5.4	0.08
SO ₂ $\nu_2 = 1$ 10 _{1,9} –10 _{0,10}	105 956.755	6.73	799.9	105 957.5	6.9	0.16
SO ₂ $\nu_2 = 1$ 29 _{3,27} –28 _{4,24}	106 870.586	2.85	1166.8	106 870.5 ¹⁷	9.3	0.10
SO ₂ $\nu_2 = 1$ 23 _{6,18} –24 _{5,19}	107 251.291	3.46	1089.2	107 253.5 ⁶	2.8	0.25
SO ₂ $\nu_2 = 1$ 22 _{3,19} –21 _{4,18}	110 003.703	3.68	1003.3	110 004.5	6.9	0.04
SO ₂ $\nu_2 = 1$ 35 _{5,31} –34 _{6,28}	114 050.625	5.45	1389.3	⁶	...	...
SO ₂ $\nu_2 = 1$ 28 _{7,21} –29 _{6,24}	114 467.268	4.23	1241.3	114 470.5 ³⁴	0.7	0.10
SO ₂ $\nu_2 = 1$ 12 _{2,10} –12 _{1,11}	131 530.479	9.89	827.9	131 531.4	6.9	0.21
SO ₂ $\nu_2 = 1$ 10 _{2,8} –10 _{1,9}	132 594.603	7.77	806.3	132 595.5	6.9	0.34
SO ₂ $\nu_2 = 1$ 12 _{1,11} –12 _{0,12}	133 003.613	6.69	821.6	133 005.1 ⁹⁰	5.5	0.19
SO ₂ $\nu_2 = 1$ 11 _{4,8} –12 _{3,9}	133 271.748	1.49	846.0	⁷	...	...
SO ₂ $\nu_2 = 1$ 27 _{7,21} –28 _{6,22}	134 483.137	4.01	1215.6	⁴	...	...
SO ₂ $\nu_2 = 1$ 14 _{2,12} –14 _{1,13}	135 531.563	11.7	853.4	135 532.6	6.7	0.31
SO ₂ $\nu_2 = 1$ 5 _{1,5} –4 _{0,4}	136 675.406	3.13	760.8	136 676.5	6.6	0.22
SO ₂ $\nu_2 = 1$ 8 _{2,6} –8 _{1,7}	137 234.335	5.68	788.5	¹⁶	...	...
SO ₂ $\nu_2 = 1$ 32 _{8,24} –33 _{7,27}	140 968.037	4.78	1391.0	³⁴	...	...
SO ₂ $\nu_2 = 1$ 16 _{5,11} –17 _{4,14}	142 044.339	2.26	932.9	³⁶	...	...
SO ₂ $\nu_2 = 1$ 6 _{2,4} –6 _{1,5}	143 663.844	3.83	774.5	143 664.5 ¹	7.7	0.42
SO ₂ $\nu_2 = 1$ 5 _{3,3} –6 _{2,4}	145 331.342	0.51	781.5	145 332.7	6.3	0.05
SO ₂ $\nu_2 = 1$ 16 _{2,14} –16 _{1,15}	145 739.989	13.0	882.8	145 741.5	5.9	0.39
SO ₂ $\nu_2 = 1$ 33 _{4,30} –32 _{5,27}	147 129.710	4.51	1302.6	¹³	...	...
SO ₂ $\nu_2 = 1$ 21 _{6,16} –22 _{5,17}	148 089.279	3.03	1047.8	¹⁶	...	...
SO ₂ $\nu_2 = 1$ 4 _{2,2} –4 _{1,3}	150 060.477	2.27	764.4	150 062.6	4.7	0.16
SO ₂ $\nu_2 = 1$ 37 _{5,33} –36 _{6,30}	151 196.604	5.66	1456.9	¹⁷	...	...
SO ₂ $\nu_2 = 1$ 22 ₀ –21 ₁	154 896.423	0.87	757.9	154 899.5 ¹⁷	3.0	0.25
SO ₂ $\nu_2 = 1$ 10 _{4,6} –11 _{3,9}	154 925.408	1.27	835.8	154 926.5	6.9	0.13
SO ₂ $\nu_2 = 1$ 26 _{7,19} –27 _{6,22}	154 937.399	3.80	1190.7	154 939.6	4.8	0.08
SO ₂ $\nu_2 = 1$ 18 _{2,16} –17 _{3,15}	157 562.692	3.70	916.0	157 563.9	6.7	0.16
SO ₂ $\nu_2 = 1$ 10 _{0,10} –9 _{1,9}	159 887.299	6.41	794.8	⁴	...	...
SO ₂ $\nu_2 = 1$ 31 _{8,24} –32 _{7,25}	161 118.533	4.57	1361.5	⁶	...	...

Table A.9. continued.

Species/Transition $J_{K_a,K_c}-J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ $\nu_2 = 1\ 15_{5,11}-16_{4,12}$	161 153.766	2.04	918.2	⁵	...	...
SO ₂ $\nu_2 = 1\ 3_{2,2}-3_{1,3}$	161 799.286	1.44	760.7	161 802.5	3.1	0.37
SO ₂ $\nu_2 = 1\ 18_{2,16}-18_{1,17}$	162 976.601	13.6	916.0	162 977.5	7.3	0.34
SO ₂ $\nu_2 = 1\ 14_{1,13}-14_{0,14}$	165 963.827	6.46	846.9	165 964.6	7.7	0.42
SO ₂ $\nu_2 = 1\ 7_{1,7}-6_{0,6}$	166 061.130	4.43	772.2	²⁴	...	...
SO ₂ $\nu_2 = 1\ 4_{3,1}-5_{2,4}$	166 507.963	0.30	776.9	⁷³	...	...
SO ₂ $\nu_2 = 1\ 35_{4,32}-34_{5,29}$	166 834.689	4.35	1366.1	166 836.5	5.7	0.05
SO ₂ $\nu_2 = 1\ 20_{6,14}-21_{5,17}$	168 508.840	2.81	1028.5	^{5,31}	...	...
SO ₂ $\nu_2 = 1\ 5_{2,4}-5_{1,5}$	168 826.259	2.46	768.9	⁵¹	...	...
SO ₂ $\nu_2 = 1\ 24_{3,21}-23_{4,20}$	171 566.838	4.21	1047.8	171 567.5	7.9	0.13
SO ₂ $\nu_2 = 1\ 9_{4,6}-10_{3,7}$	173 495.943	1.05	826.6	²⁶	...	...
SO ₂ $\nu_2 = 1\ 25_{7,19}-26_{6,20}$	174 901.050	3.58	1166.8	174 903.5 ⁷⁰	4.8	0.56
SO ₂ $\nu_2 = 1\ 30_{4,26}-29_{5,25}$	176 012.893	4.91	1217.2	176 015.1 ⁴¹	5.3	0.37
SO ₂ $\nu_2 = 1\ 37_{4,34}-36_{5,31}$	177 865.345	4.04	1433.2	noisy spectrum	...	...
SO ₂ $\nu_2 = 1\ 22_{3,19}-22_{2,20}$	199 756.971	17.6	1003.3	199 758.7 ⁵	6.5	0.62
SO ₂ $\nu_2 = 1\ 13_{5,9}-14_{4,10}$	200 888.344	1.60	891.5	¹⁶	...	...
SO ₂ $\nu_2 = 1\ 29_{8,22}-30_{7,23}$	201 308.491	4.14	1305.4	⁵	...	...
SO ₂ $\nu_2 = 1\ 20_{3,17}-20_{2,18}$	201 972.010	15.4	962.7	201 974.4	5.4	0.40
SO ₂ $\nu_2 = 1\ 12_{0,12}-11_{1,11}$	202 562.326	8.41	815.2	202 564.4	5.9	0.47
SO ₂ $\nu_2 = 1\ 16_{1,15}-16_{0,16}$	203 652.511	6.21	875.8	203 654.4	6.2	0.44
SO ₂ $\nu_2 = 1\ 24_{3,21}-24_{2,22}$	204 331.692	19.4	1047.8	204 333.2	6.8	0.28
SO ₂ $\nu_2 = 1\ 34_{9,25}-35_{8,28}$	207 420.884	4.91	1494.9	⁶	...	...
SO ₂ $\nu_2 = 1\ 18_{6,12}-19_{5,15}$	208 172.440	2.38	992.6	^{2,4,6}	...	...
SO ₂ $\nu_2 = 1\ 18_{3,15}-18_{2,16}$	209 433.722	12.9	926.1	209 434.9 ¹⁸	7.4	1.15
SO ₂ $\nu_2 = 1\ 11_{2,10}-11_{1,11}$	209 454.261	4.56	815.5	209 456.1	6.3	0.48
SO ₂ $\nu_2 = 1\ 3_{2,2}-2_{1,1}$	212 177.612	1.67	760.7	212 179.9	5.7	0.14
SO ₂ $\nu_2 = 1\ 7_{4,4}-8_{3,5}$	212 726.193	0.63	811.0	212 728.6 ³⁴	5.5	0.11
SO ₂ $\nu_2 = 1\ 23_{7,17}-24_{6,18}$	214 835.983	3.15	1121.7	214 837.5 ⁵	7.0	0.25
SO ₂ $\nu_2 = 1\ 26_{3,23}-26_{2,24}$	216 758.559	20.5	1096.2	216 759.9 ⁵	7.1	0.60
SO ₂ $\nu_2 = 1\ 20_{2,18}-19_{3,17}$	218 995.835	4.59	953.0	218 997.4	6.9	0.31
SO ₂ $\nu_2 = 1\ 22_{2,20}-22_{1,21}$	219 465.546	13.3	993.7	219 467.4 ^{4,7}	6.5	1.00
SO ₂ $\nu_2 = 1\ 16_{3,13}-16_{2,14}$	220 165.252	10.6	893.4	⁵	...	...
SO ₂ $\nu_2 = 1\ 12_{5,7}-13_{4,10}$	220 657.897	1.39	879.5	⁴	...	...
SO ₂ $\nu_2 = 1\ 28_{8,20}-29_{7,23}$	221 277.998	3.92	1278.7	⁵	...	...
SO ₂ $\nu_2 = 1\ 11_{1,11}-10_{0,10}$	222 424.457	7.70	805.5	222 423.7 ^{5,7}	10.1	1.21
SO ₂ $\nu_2 = 1\ 17_{6,12}-18_{5,13}$	227 808.377	2.16	976.0	¹⁶	...	...
SO ₂ $\nu_2 = 1\ 13_{2,12}-13_{1,13}$	229 545.293	4.98	838.3	229 548.6 ⁵⁴	4.7	0.22
SO ₂ $\nu_2 = 1\ 14_{3,11}-14_{2,12}$	231 980.527	8.58	864.6	⁷	...	...
SO ₂ $\nu_2 = 1\ 6_{4,2}-7_{3,5}$	232 210.300	0.43	804.6	³⁹	...	...
SO ₂ $\nu_2 = 1\ 16_{1,15}-15_{2,14}$	233 724.927	6.02	875.8	233 728.8	4.0	0.25
SO ₂ $\nu_2 = 1\ 22_{7,15}-23_{6,18}$	234 679.037	2.93	1100.5	¹⁶	...	...
SO ₂ $\nu_2 = 1\ 26_{3,23}-25_{4,22}$	237 062.226	4.84	1096.2	¹⁸	...	...
SO ₂ $\nu_2 = 1\ 28_{3,25}-28_{2,26}$	237 602.207	20.8	1148.5	237 603.6 ³²	7.2	0.51
SO ₂ $\nu_2 = 1\ 4_{2,2}-3_{1,3}$	238 697.756	1.72	764.4	238 698.9	7.6	0.37
SO ₂ $\nu_2 = 1\ 38_{5,33}-37_{6,32}$	239 753.000	6.11	1495.2	¹⁶	...	...
SO ₂ $\nu_2 = 1\ 11_{5,7}-12_{4,8}$	240 057.470	1.17	868.5	240 060.5	5.3	0.07
SO ₂ $\nu_2 = 1\ 27_{8,20}-28_{7,21}$	241 126.743	3.70	1252.9	241 128.6	6.7	0.13
SO ₂ $\nu_2 = 1\ 32_{4,28}-31_{5,27}$	241 193.824	5.36	1276.8	¹⁶	...	...
SO ₂ $\nu_2 = 1\ 12_{3,9}-12_{2,10}$	242 872.869	6.88	839.6	⁵	...	...
SO ₂ $\nu_2 = 1\ 14_{0,14}-13_{1,13}$	243 522.666	10.5	839.0	243 523.9 ¹²	7.5	1.18
SO ₂ $\nu_2 = 1\ 18_{1,17}-18_{0,18}$	244 386.673	6.03	908.2	¹⁸	...	...
SO ₂ $\nu_2 = 1\ 5_{2,4}-4_{1,3}$	245 002.780	2.12	768.9	245 004.5	6.9	0.46
SO ₂ $\nu_2 = 1\ 32_{9,23}-33_{8,26}$	247 275.019	4.47	1433.3	³²	...	...
SO ₂ $\nu_2 = 1\ 16_{6,10}-17_{5,13}$	247 485.487	1.94	960.4	247 490.1 ^{32,91}	3.4	0.29
SO ₂ $\nu_2 = 1\ 5_{4,2}-6_{3,3}$	251 401.371	0.25	799.1	⁴³	...	...
SO ₂ $\nu_2 = 1\ 10_{3,7}-10_{2,8}$	251 428.540	5.43	818.3	251 428.8 ⁶	8.7	1.04
SO ₂ $\nu_2 = 1\ 13_{1,13}-12_{0,12}$	251 450.180	9.61	827.3	251 452.6 ^{6,34}	6.2	0.83
SO ₂ $\nu_2 = 1\ 15_{2,14}-15_{1,15}$	252 731.060	5.29	864.6	252 733.5	6.1	0.47
SO ₂ $\nu_2 = 1\ 21_{7,15}-22_{6,16}$	254 381.132	2.71	1080.3	254 385.1 ³⁶	4.3	0.20
SO ₂ $\nu_2 = 1\ 8_{3,5}-8_{2,6}$	257 099.338	4.13	800.8	⁴⁹	...	...
SO ₂ $\nu_2 = 1\ 24_{2,22}-24_{1,23}$	257 420.276	12.8	1038.0	257 422.7 ³¹	6.2	0.38
SO ₂ $\nu_2 = 1\ 10_{5,5}-11_{4,8}$	259 525.559	0.96	858.4	⁵	...	...
SO ₂ $\nu_2 = 1\ 6_{3,3}-6_{2,4}$	260 176.150	2.89	787.0	260 178.9	5.8	0.46

Table A.9. continued.

Species/Transition $J_{K_a,K_c}-J'_{K'_a,K'_c}$	Predicted freq. (MHz)	S_{ij}	E_u (K)	Observed freq. (MHz)	Observed v_{LSR} (km s ⁻¹)	Observed T_A^* (K)
SO ₂ $\nu_2 = 1\ 26_{8,18}-27_{7,21}$	260 920.931	3.48	1228.1	260 922.6	7.1	0.52
SO ₂ $\nu_2 = 1\ 4_{3,1}-4_{2,2}$	261 450.266	1.61	776.9	261 453.8	4.9	0.53
SO ₂ $\nu_2 = 1\ 3_{3,1}-3_{2,2}$	261 855.237	0.89	773.3	⁴⁴	...	...
SO ₂ $\nu_2 = 1\ 5_{3,3}-5_{2,4}$	262 144.899	2.26	781.5	262 145.2	8.7	0.36
SO ₂ $\nu_2 = 1\ 7_{3,5}-7_{2,6}$	262 999.768	3.48	793.5	263 004.5 ²⁶	3.7	0.66
SO ₂ $\nu_2 = 1\ 32_{4,28}-32_{3,29}$	264 129.781	25.5	1276.8	264 128.9 ¹⁷	10.1	0.19
SO ₂ $\nu_2 = 1\ 9_{3,7}-9_{2,8}$	264 846.220	4.65	809.1	264 849.5	5.3	0.22
SO ₂ $\nu_2 = 1\ 30_{4,26}-30_{3,27}$	266 030.564	23.2	1217.2	266 032.6	6.7	0.42
SO ₂ $\nu_2 = 1\ 30_{3,27}-30_{2,28}$	266 815.527	20.5	1204.5	⁵	...	...
SO ₂ $\nu_2 = 1\ 15_{6,10}-16_{5,11}$	267 006.778	1.72	945.7	267 008.5	7.1	0.15
SO ₂ $\nu_2 = 1\ 31_{9,23}-32_{8,24}$	267 091.922	4.25	1403.8	⁴⁷	...	...
SO ₂ $\nu_2 = 1\ 11_{3,9}-11_{2,10}$	268 169.791	5.78	828.4	⁴⁹	...	...
SO ₂ $\nu_2 = 1\ 34_{4,30}-34_{3,31}$	270 528.378	27.1	1340.3	⁵	...	...
SO ₂ $\nu_2 = 1\ 4_{4,0}-5_{3,3}$	270 633.756	0.10	794.5	¹⁷	...	...
SO ₂ $\nu_2 = 1\ 13_{3,11}-13_{2,12}$	273 467.380	6.87	851.4	⁴⁹	...	...
SO ₂ $\nu_2 = 1\ 20_{7,13}-21_{6,16}$	274 039.760	2.49	1060.9	274 041.3	7.3	0.05
SO ₂ $\nu_2 = 1\ 28_{4,24}-28_{3,25}$	274 778.408	20.5	1161.7	274 780.5	6.7	0.36
SO ₂ $\nu_2 = 1\ 7_{2,6}-6_{1,5}$	274 789.404	2.67	780.8	274 791.5	6.8	0.27
SO ₂ $\nu_2 = 1\ 17_{2,16}-17_{1,17}$	278 755.123	5.50	894.5	278 757.4	6.5	0.59
SO ₂ $\nu_2 = 1\ 9_{5,5}-10_{4,6}$	278 849.605	0.76	849.2	278 851.5 ³⁶	7.0	0.49
SO ₂ $\nu_2 = 1\ 25_{8,18}-26_{7,19}$	280 629.381	3.26	1204.2	280 631.5 ⁷³	6.7	0.40