

# Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101–115 nm range

Jean-Louis Lemaire, A. Heays, M. Eidelsberg, Lisseth Gavilan, G. Stark, S.

Federman, J. Lyons, N. de Oliveira

# ▶ To cite this version:

Jean-Louis Lemaire, A. Heays, M. Eidelsberg, Lisseth Gavilan, G. Stark, et al.. Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101–115 nm range. Astronomy and Astrophysics - A&A, 2018, 614, A114 (62p.). 10.1051/0004-6361/201732114 . hal-02307046

# HAL Id: hal-02307046 https://hal.science/hal-02307046

Submitted on 2 Nov 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101–115 nm range

# Transition energies of the v' = 0, 1, 2, and 3 to v'' = 0 bands of the $B^1\Sigma^+$ , $C^1\Sigma^+$ , and $E^1\Pi$ to $X^1\Sigma^+$ states, related term values, and molecular constants

J. L. Lemaire<sup>1,\*</sup>, A. N. Heays<sup>2</sup>, M. Eidelsberg<sup>2</sup>, L. Gavilan<sup>3</sup>, G. Stark<sup>4</sup>, S. R. Federman<sup>5</sup>, J. R. Lyons<sup>6</sup>, and N. de Oliveira<sup>7</sup>

<sup>1</sup> Institut des Sciences Moléculaires d'Orsay (ISMO), CNRS – Université Paris-Sud (UMR 8214), 91405 Orsay, France e-mail: jean-louis.lemaire@u-psud.fr

<sup>2</sup> Observatoire de Paris, LERMA, UMR 8112 du CNRS, Meudon, France

<sup>3</sup> Université Versailles St-Quentin, Sorbonne Universités, UPMC Paris 06, CNRS/INSU, LATMOS-IPSL, 78280 Guyancourt, France

<sup>4</sup> Department of Physics, Wellesley College, Wellesley, MA 02481, USA

<sup>5</sup> Department of Physics and Astronomy, University of Toledo, Toledo, OH 43606, USA

<sup>6</sup> School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281, USA

<sup>7</sup> DESIRS Beam Line, Synchrotron SOLEIL, Saint Aubin, France

Received 17 October 2017 / Accepted 15 November 2017

#### ABSTRACT

Our knowledge of astronomical environments containing CO depends on accurate molecular data to reproduce and interpret observed spectra. The recent and future improvements of ultraviolet space instrumentation, both in sensitivity and resolution, require increasingly detailed laboratory molecular spectroscopy as a reference. As part of a long-term experimental campaign at the SOLEIL Synchrotron facility, we have acquired gas-phase absorption spectra of six CO isotopologues in the vacuum ultraviolet. These spectra are recorded using the Fourier-transform spectrometer installed on the DESIRS beamline, providing a unique resolving power up to  $10^6$  in the 8–13 eV range. We have used resolutions in the 300 000–450 000 range for this campaign, which enable the analysis of individual line positions. We report new measurements on neighboring Rydberg states in the 101-115 nm range that could also be used as *f*-value calibrators, namely  $B^1\Sigma^+$ ,  $C^1\Sigma^+$ , and  $E^1\Pi$ , for six CO isotopologues. This range encompasses the absorption transitions B(v' = 0, 1, a, and 2), C(v' = 0, 1, 2, and 3), and E(v' = 0, 1, 2, and 3) from  $X^1\Sigma^+(v'' = 0)$ . Higher resolution laser-based measurements of CO isotopologues from the literature are used to improve the absolute calibration and accuracy of our data. The overall uncertainty of the great majority of the line positions presented in this atlas is estimated to be  $0.01 \text{ cm}^{-1}$ . In addition, some of the data derived from transition energies measurements, such as term values and molecular constants, are obtained for the first time, and others are improvements on previous sparser or lower spectral resolution datasets.

Key words. molecular data - methods: laboratory: molecular - techniques: spectroscopic - techniques: interferometric

# 1. Introduction

This work is part of a larger effort to catalog, interpret, and model the photoabsorption spectrum of CO in the 90–155 nm wavelength region. These measurements are performed at the third-generation SOLEIL synchrotron facility in Saint-Aubin, France. We employ the Fourier-transform spectrometer (FTS) installed on the DESIRS beam line, a unique instrument that combines high spectral resolution and a high signal-to-noise ratio (S/N) in the vacuum ultraviolet (VUV) wavelength range.

In the course of our earlier work (2008–2015) on CO photoabsorption spectroscopy in the 90–155 nm region, we were mainly interested in oscillator strengths and perturbations for several CO isotopologues. A large part of this work concerned the Rydberg W-X bands and Rydberg complexes in the 92.5– 97.5 nm range: Eidelsberg et al. (2012, 2014, 2017) for <sup>12</sup>C<sup>16</sup>O, <sup>13</sup>C<sup>16</sup>O, <sup>12</sup>C<sup>18</sup>O, and <sup>13</sup>C<sup>18</sup>O, respectively, and perturbations in the W-X bands (Heavs et al. 2014) and the *f*-value measurements of the lowest VUV states (Stark et al. 2014), while another part dealt with the A-X bands for  ${}^{13}C^{16}O$  (Gavilan et al. 2013) and  ${}^{13}C^{18}O$  (Lemaire et al. 2016). The common goal of these studies was the accurate determination of oscillator strengths, with an absolute calibration made by reference to the unperturbed  $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$  band that was previously well characterized by high-resolution (0.14 cm<sup>-1</sup>) laser-based measurements (Stark et al. 1999) and by synchrotron-based measurements (Federman et al. 2001). The  $B^{1}\Sigma^{+}-X^{1}\Sigma^{+}$  bands were already extensively investigated for four isotopologues (12C16O, <sup>13</sup>C<sup>16</sup>O, <sup>12</sup>C<sup>18</sup>O, and <sup>13</sup>C<sup>18</sup>O) in both absorption and emission (Eidelsberg et al. 1987) using the Observatoire de Paris (Meudon, France) 10 m VUV grating spectrograph. In that work, term values were derived for the B00, B10, and B20 absorption bands. The uncertainty on the absolute wavenumbers was estimated to be  $\pm 0.1$  cm<sup>-1</sup>.

Throughout this paper, the notation is simplified as follows: states are designed by their symmetry (e.g.,  $X^1\Sigma^+$  or  $E^1\Pi$ ), while a band is denoted  $E^1\Pi(v')-X^1\Sigma^+(v'')$  or for brevity EXv'v'', for example, EX20 for v' = 2 and v'' = 0, or shorter: E20. The notation indicating the isotopologues is also simplified in tables and figures, where we write, for example, 1216 for  ${}^{12}C{}^{16}O$ , etc.

The current investigation describes our high-resolution measurements of the  $B^1\Sigma^+$ ,  $C^1\Sigma^+$ , and  $E^1\Pi$  states for six CO isotopologues in the 101–115 nm range. This range encompasses the following absorption transitions: B(v'=0, 1 and 2), C(v'=0,1, 2 and 3), and E(v'=0, 1, 2 and 3) from the fundamental electronic state X(v''=0).

This work revisits and completes, 25 yr later, part of the CO atlas of transition frequencies started by the Paris-Meudon Observatory team (Eidelsberg et al. 1991; Le Floch 1992), and initiated by the work of Letzelter et al. (1987) and Viala et al. (1988) on the photoabsorption and photodissociation cross sections, either measured or calculated for the four isotopologues  ${}^{12}C^{16}O$ ,  ${}^{12}C^{18}O$ ,  ${}^{13}C^{16}O$ , and  ${}^{13}C^{18}O$ . It improves and completes calculations derived from the combination of earlier low-resolution measurements of term values and molecular constants of B00 and B10 for  ${}^{12}C^{16}O$  (Le Floch & Amiot 1985), of C00 and E00 for  ${}^{12}C^{16}O$  (Le Floch 1992), and of B00, B10, C00 and E00 for  ${}^{12}C^{16}O$  (Le Floch 1992), and of B00, B10, C00 and E00 for  ${}^{12}C^{18}O$  and  ${}^{13}C^{18}O$  (Haridass et al. 1994). Line positions of B20 for  ${}^{12}C^{16}O$  have been studied by Baker & Launay (1994).

This work also revisits and completes earlier experimental work at low resolution on E00 and E10 (Baker et al. 1993, 1994). Higher resolution work (Cacciani et al. 1995, 2001; Cacciani & Ubachs 2004; Drabbels et al. 1993a,b; Ubachs et al. 1995, 2000) is discussed in detail in Sect. 2.1 as these data are used in this work for the absolute calibration of our data.

It is also worth mentioning the extensive work of Morton & Noreau (1994), which provides a compilation of electronic transitions (including BX00 to BX20, CX00 to CX30, and EX00 to EX20) in the CO molecule ( $^{12}C^{16}O$ ,  $^{12}C^{18}O$ ,  $^{13}C^{16}O$ , and  $^{13}C^{18}O$ ). Line positions are limited in this work to  $J'' \leq 6$ . This paper includes all experimental data published up to 1994.

A first detailed model of CO photodissociation, based on laboratory data, including depth-dependent attenuation and isotopeselective self-shielding of photodissociation rates, was developed by van Dishoeck & Black (1988) to model in detail, coupled with a chemical network, the structure and chemistry of a variety of interstellar clouds. This work, updated by measurements produced in the subsequent 20 yr, was revisited by Visser et al. (2009), including self- and mutual-shielding of all isotopologues (in particular, for the first time,  ${}^{12}C{}^{17}O$  and  ${}^{13}C{}^{17}O$ ) as well as shielding by atomic and molecular hydrogen.

All term values are referenced to the  $X^1\Sigma^+(v''=0, J''=0)$ ground state of the respective isotopologues, according to the ground-state energy levels determined by Guelachvili et al. (1983) and Farreng et al. (1991).

This work only reports and is based on lines that are observed and clearly identified in spectra, with the exception of the extremely congested Q-branches of the E state (at low J) for which we report in our tables literature values obtained at very high resolution (for E00 and E10) or estimated (for E20) for the sake of completeness.

This article is organized as follows. Section 2 briefly describes the experimental setup and the analysis procedure. Section 3 presents our results: line assignments, term values, and molecular constants for each state (B, C, and E) and bands observed. The last section presents our concluding remarks.

#### 2. Experimental setup and data analysis

CO spectra are recorded at high resolution using the vacuumultraviolet Fourier-transform spectrometer (VUV-FTS) available on beamline DESIRS (Dichroïsme Et Spectroscopie par Interaction avec le Rayonnement Synchrotron) of the SOLEIL synchrotron. The beamline and spectrometer have been described in detail in previous publications (de Oliveira et al. 2009, 2011, 2016; Nahon et al. 2012, 2013).

Four bottles of isotopically purified gases, namely  ${}^{12}C^{16}O$  (Alphagaz, 99.997%),  ${}^{12}C^{18}O$  (ICON Isotopes,  ${}^{18}O$  99%),  ${}^{13}C^{16}O$  (Messer,  ${}^{13}C$  99.1%;  ${}^{16}O$  99.95%),  ${}^{13}C^{18}O$  (Cambridge Isotopes,  ${}^{13}C$  99%,  ${}^{18}O$  95%), and one bottle containing a  ${}^{12}C^{16}O/{}^{12}C^{17}O/{}^{12}C^{18}O$  mixture (ICON Isotopes, 41.5%, 48.5%, and 9.9% respectively), are used to obtain data for five isotopologues. The presence of a sixth isotopologue, the rarely studied  ${}^{13}C^{17}O$ , is detected as an impurity in the  ${}^{13}C^{16}O$  and  ${}^{13}C^{18}O$  bottles, and serves to complete this analysis, which provides a consistent dataset on six natural isotopologues.

Sample gases continuously flow through a 10 cm long windowless absorption cell that is open on both sides through capillary tubes. Most spectra are recorded at room temperature (295 K), but a few are obtained with the central part of the cell cooled by liquid nitrogen; this results in a gas temperature of  $90 \pm 5$  K. In some cases, these cooled spectra are useful for improved line assignations by reducing the number of lines in a spectrum and their Doppler broadening.

A total of 69 spectra, recorded at different pressures and spectral resolutions, were analyzed for this work (amounting to 3327 individual lines). The analysis was performed line by line, determining the line positions by modeling them as Gaussian or Voigt functions (for ~97% of the cases), and at times extracting them from simulations of the spectra of blended lines. In order to improve the accuracy, the present results rely on up to four different records for a given band and a given isotopologue. The bands observed in this work are reported in Table 1.

A key element of this work is the need for absolute wavelength calibration. The first step in the calibration procedure is provided by the FTS team. In summary, the raw FTS interferogram data based on the accurate measurement of the mirror displacement are first phase-corrected and then Fourier-transformed into a frequency spectrum. The resulting spectra are frequencycalibrated using atomic lines from different origins that appear in the spectra (de Oliveira et al. 2011, 2016). The accuracy of individual rovibrational lines is not only dependent on the accuracy of the absolute frequency calibration atomic lines, but also on the spectral resolution and on the strength and blendedness of each measured line. The parameters involved are the number, N, of independent scanning steps for a given line, which depends itself on the width, W, (mainly Doppler) of the measured line, and on the S/N compared to the background continuum signal. The final accuracy of line positions,  $\sigma$  in wavenumbers, reported by de Oliveira et al. (2011), is based on the empirical expression  $\Delta(\sigma) \sim W/(S/N \times \sqrt{N})$  (see also their reference 20).

Lemaire et al. (2016) reported line positions determined from VUV-FTS spectra with a relative accuracy better than  $\sim \pm 0.008 \text{ cm}^{-1}$  at  $87\,000 \text{ cm}^{-1}$  (or  $\sim \pm 0.01 \text{ pm}$  at 115 nm). A comparison of wavenumber measurements of common sets of lines from multiple independent spectra is consistent with this estimated accuracy.

Two methods were used to place all spectra on a unique wavelength scale. First, more than 30 atomic lines (mainly Xe I, Kr I, and sometimes O I) present in the studied range were

Table 1. Summary of bands measured at high resolution.

State	$X^1\Sigma^+$		$B^1\Sigma^+$			$C^1$	$\Sigma^+$			E	IП	
Band	X		BX			С	X			E	X	
v'-v''	v = 0	00	10	20	00	10	20	30	00	10	20	30
Isotopologue												
$^{12}C^{16}O$	*	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
$^{12}C^{17}O$	*	$\checkmark$	$\checkmark$	no	$\checkmark$	$\checkmark$	no	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
$^{12}C^{18}O$	*	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
<sup>13</sup> C <sup>16</sup> O	*	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
$^{13}C^{17}O$	*	$\checkmark$	$\checkmark$	no	$\checkmark$	$\checkmark$	no	no	$\checkmark$	$\checkmark$	no	no
<sup>13</sup> C <sup>18</sup> O	*	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$

Notes.  $\checkmark$ : observed, no: not observed. \* are data calculated from Farrenq et al. (1991).

Table 2. References to the high-resolution calibration band or lines used (reference labels sorted by publication dates are given at the bottom of the table).

State	$B^1$	$\Sigma^+$			$C^1\Sigma^+$				$E^{1}\Pi$		
Band	B	Χ			CX				EX		
<i>v'v''</i>	00	10	20	00	10	20	30	00	10	20	30
Isotopologue											
<sup>12</sup> C <sup>16</sup> O	$\mathbf{b}_{l\bullet}, \mathbf{c}_{l\bullet}, \mathbf{j}_l$	c <sub>l</sub> •	$a_{b\bullet}$	$\mathbf{b}_{l\bullet}, \mathbf{e}_{\bullet}, \mathbf{j}_{l}$	$e_{\bullet}, g_{b\bullet}$			$\mathbf{d}_{l\bullet}, \mathbf{h}_{b\bullet}, \mathbf{j}_l$	$\mathbf{a}_{\bullet}, \mathbf{d}_{l\bullet}, \mathbf{f}_{b}$		
$^{12}C^{17}O$				$e_{l\bullet}$	$\mathbf{g}_l$			d.	$\mathbf{f}_b$		
$^{12}C^{18}O$	$c_{l\bullet}$			e.	$e_{\bullet}, g_{h\bullet}$			a <b>.</b> , d <b>.</b>	$a_{\bullet}, d_{\bullet}, f_{b}$		
<sup>13</sup> C <sup>16</sup> O	$c_{l\bullet}, k_{\bullet}$			e.	$e_{\bullet}, g_{h\bullet}$			$a_{\bullet}, d_{\bullet}, h_{b\bullet}$	$a_{\bullet}, d_{\bullet}, f_{b}$		
<sup>13</sup> C <sup>17</sup> O					g/				$\mathbf{f}_{h}$		
<sup>13</sup> C <sup>18</sup> O					g <sub>b</sub> .			$a_{\bullet}, h_{l \bullet}$	$a_{\bullet}, f_b$		

**Notes.** References providing data for bands with fewer than about ten lines are indexed with l and for more than ten lines with b. References providing term values and/or molecular constants are indexed with a filled blue dot.

**References.** a: Baker et al. (1993, 1994); Baker (1994). b: Drabbels et al. (1993a). c: Drabbels et al. (1993b). d: Cacciani et al. (1995). e: Ubachs et al. (1995). f: Ubachs et al. (2000). g: Cacciani et al. (2001). h: Cacciani & Ubachs (2004). j: Daprà et al. (2016). k: Niu et al. (2016).

used with reference frequencies taken from the NIST atomic lines database<sup>1</sup>. The presence of these gases is due to unintentional minor contamination or to a column of rare gas introduced on the beamline intended to filter out high-frequency harmonics generated in the undulator. Most of these lines have been measured with an accuracy of  $10^{-3}$  nm and some with an accuracy of up to  $10^{-6}$  nm. These latter are O I: 115.21512 nm (Kaufman & Edlén 1974), Xe I: 106.125564 nm, 105.612829 nm, 104.383497 nm (Yoshino & Freeman 1985; Brandi et al. 2001), and Kr I: 100.1060639 nm (Brandi et al. 2002). The positions of these lines are shown in Fig. 1.

Second, the random error associated with calibrating the wavenumber scale via a small number of atomic transitions can sometimes be improved upon by including reference data for molecular lines. For this aim, high-resolution laser measurements of some CO lines (and isotopologues) available in the literature were employed (Cacciani et al. 1995, 2001; Cacciani & Ubachs 2004; Drabbels et al. 1993a,b; Ivanov et al. 2008; Philip et al. 2004; Ubachs et al. 1994, 1995, 2000, and recently Daprà et al. 2016). Most of these measurements, obtained by narrowband laser spectroscopy in one- or two-photon experiments, rely on the I<sub>2</sub>- or Te<sub>2</sub>-saturation spectrum as primary absolute calibrators, associated with the marks of an actively stabilized Fabry-Pérot étalon. They are summarized in the next subsection (in alphabetical order) and are cited in the corresponding sections.

To overcome the lack of calibration data for some bands, we considered the overlapping regions of contiguous scans. A given setting of the undulator delivers a quasi-Gaussian beam profile of width  $\sim$ 5 nm at 1/*e* of the peak signal. An absorption scan encompasses about 3–5 bands, as can be seen in Fig. 1. With the right choice of undulator settings, we were able to measure at least three bands in a single scan. In this way, a band with no calibration reference can be surrounded by two bands subject to accurate calibration, for instance, the B20 band surrounded by the B10 and C00 bands.

The final accuracy of our measurements also relied upon isotopologue cross calibrations. These were obtained through mixed isotopologue samples (as is the case for the available  ${}^{12}C^{16}O{-}^{12}C^{17}O$  bottle, which contains some small amount of  ${}^{12}C^{18}O$ , and as in the case of  ${}^{13}C^{17}O$ , which was present as an impurity in  ${}^{13}C^{16}O$  and  ${}^{13}C^{18}O$  bottles). Even with pure gas samples, isotopologue impurities may show up in spectra that were recorded at high pressures. We also prepared and used on purpose mixed isotopologue samples allowing for such cross calibrations.

It is worth noting that more data were collected for this work than are included in papers dedicated to oscillator strength measurements. Those are restricted in pressure range and consequently in number of lines observed, in order to keep optical depths <1.5, or absorption lower than 78%, for the accurate determination of oscillator strengths. For this study we used higher pressures in order to observe high J' levels and isotopologues present in small amounts. As described above, we also use cooled gases to remove possible ambiguities.

<sup>1</sup> http://physics.nist.gov/PhysRefData/ASD/lines\_form. html

#### 2.1. Laser calibration benchmarks and associated data

An absolute calibration of lines requires the availability of accurately determined standards, either atomic or molecular, as close as possible to the lines under study. There are many reported laser-based measurements of CO VUV transitions with accurate absolute calibrations based on primary standards. Some previous work has been limited to a few lines of each vibrational band, while others offer almost complete bands for use as comparisons for calibration purposes. Data like this exist for most CO isotopologues. They are summarized in detail in this section.

Reports of laser-based measurements that were used to accurately calibrate our spectra often also presented an analysis of the rotational structure of the bands under study, providing associated data such as term values, reduced term values, and molecular constants. These results are also mentioned in detail in this section as they are compared later to our own results.

Depending on the data available, laser calibrated benchmarks could in some cases be derived from transitions other than the one-photon P, R, and Q transitions of this study. When two-photon O, S, or Q transitions were available, the corresponding one-photon transitions for the R- and P-branches were recalculated by way of term values, taking into account that common-J' term values (TVs) of the excited state calculated from various one- and two-photon transition frequencies, that is,  $TV(O_{J'=i\leftarrow J''=i+2})$ ,  $TV(P_{J'=i\leftarrow J''=i+1})$ ,  $TV(Q_{J'=i\leftarrow J''=i})$ ,  $TV(R_{J'=i\leftarrow J''=i-1})$ , and  $TV(S_{J'=i\leftarrow J''=i-2})$ , have to be equal.

We summarize below all references providing laser calibration benchmarks that were used for this work, as well as the associated data mentioned above. They are sorted by alphabetical order of authors. With the exception of the first laser high-resolution measurements (Baker et al. at Paris-Meudon Observatory and Drabbels et al. at Nijmegen University), the majority of CO molecular calibration lines used here were measured using ultra-high resolution lasers at VU University Amsterdam (Cacciani et al., Daprà et al., Ivanov et al., Niu et al., and Ubachs et al.).

#### Baker (1994)

This paper reports some perturbations observed in the B20 state of  ${}^{12}C^{16}O$  that are due to the interaction with the  ${}^{3}\Pi(F1)$  spin-orbit component of the  $k^{3}\Pi(0)-X^{1}\Sigma^{+}(0)$  band. Line positions and term values are given for B20 and kX00.

Baker & Launay (1994)

This paper analyzes the  $k^{3}\Pi(v'=2, 3 \text{ and } 5)-X^{1}\Sigma^{+}(0)$  bands, the first one perturbing the E00 band, and the last one the E10 band. Line positions and term values are given for kX20, kX30, and kX50.

### Baker et al. (1993, 1994)

These papers provide a study of the E00 and E10 bands for four isotopologues,  ${}^{12}C^{16}O$ ,  ${}^{13}C^{16}O$ ,  ${}^{12}C^{18}O$ , and  ${}^{13}C^{18}O$ . Spectra were recorded using 2 + 1 resonantly enhanced multiphoton excitation showing the five rotational branches *O*, *P*, *Q*, *R*, and *S* at a resolution of ~0.1 cm<sup>-1</sup>. Spectra were acquired either separately for each isotopologue or with mixtures of several, and were then separated by time of flight mass spectrometry, in order to obtain an accurate relative calibration between isotopologues. Perturbations of E10 were analyzed. Term values (for three isotopologues of E00 and four of E10) and molecular constants (for E10) are also given for the four isotopologues.

Cacciani & Ubachs (2004)

This paper gives *Q*-branch transition frequencies of E00 [*Q*: J' = 1-8] for <sup>12</sup>C<sup>16</sup>O and [*Q*: J' = 1-7] for <sup>13</sup>C<sup>16</sup>O and <sup>13</sup>C<sup>18</sup>O. Measured and calculated transition frequencies for E00 of <sup>12</sup>C<sup>16</sup>O [up to J' = 34 with gaps] and <sup>13</sup>C<sup>16</sup>O [up to J' = 42

with gaps], obtained by three different experimental methods, are accessible as supplementary data.

#### Cacciani et al. (1995)

This paper provides a few term values for  ${}^{12}C^{16}O$  (the E00 band [J' = 31, 41, and 44] and E10 band [J' = 5-13]), focused in both cases around perturbations. Molecular constants are also determined for  ${}^{12}C^{16}O$  (E00 and E10),  ${}^{13}C^{16}O$  (E00 and E10),  ${}^{12}C^{18}O$  (E00 and E10), and  ${}^{12}C^{17}O$  (E00). Transition frequencies were tabulated in a later paper (Cacciani & Ubachs 2004).

Cacciani et al. (2001)

This paper provides transition frequencies for *R*- and *P*-branch lines of the C10 band for  ${}^{12}C^{16}O[R: J' = 0-27; P: J' = 1-31]$ ,  ${}^{12}C^{18}O[R: J' = 0-13; P: J' = 1-8, 10]$ ,  ${}^{13}C^{16}O[R: J' = 0-15; P: J' = 1-5, 9-20]$ ,  ${}^{13}C^{18}O[R = J' = 0-5, 8-12; P: J' = 1, 3, 5-8]$ , and a few for  ${}^{12}C^{17}O[R: J' = 0-2; P: J' = 1]$  and  ${}^{13}C^{17}O[R: J' = 0-1, 3-5; P: J' = 1-3]$ . Molecular constants are also calculated for the six isotopologues, although at lower accuracy for  ${}^{12}C^{17}O$  and  ${}^{13}C^{17}O$ .

#### Daprà et al. (2016)

This paper is mainly based on data for <sup>12</sup>C<sup>16</sup>O published by the Amsterdam team over several years and gives measured wavelengths (Tables 6–8; called molecular parameters) for the *R* and *P* (and *Q* for E00) J' = 0-5 transitions of the B00, C00, and E00 bands. Their results are expressed with an accuracy of up to the sixth digit (in nanometers) and an error bar of between 3 and 13 in units of this digit. The restriction to the lowest rotational states ( $J' \leq 5$ ) is due to the fact that this paper is aimed at the comparison with quasar observations. These data are the most accurate to date. They result from measurements and not from calculations, as can be deduced from the fact that term values for a given level, determined through the *R*- and *P*-branches, are not strictly equal.

#### Drabbels et al. (1993a)

This paper reports observed transition frequencies for  ${}^{12}C^{16}O$  of the Q- and S-branch lines of B00 [J' = 0-14 for Q and 0-1 for S] and of C00 [J' = 0-6 for Q and 0-1 for S]. Corresponding molecular constants are also calculated from these data.

Drabbels et al. (1993b) This paper completes the previous paper with additional measurements of Q lines for B10 [J' = 0-2], for <sup>13</sup>C<sup>16</sup>O B00 [J' = 0-2], and for <sup>12</sup>C<sup>18</sup>O B00 [J' = 0-1]. There is also a slight revision of <sup>12</sup>C<sup>16</sup>O B00 [J' = 0-4 for Q and 0-1 for S], but as this paper was submitted earlier than the previous paper, it is not clear which should be considered as the more accurate.

Molecular constants are calculated for these four bands.

#### Ivanov et al. (2008)

This paper reports "extreme-ultraviolet laser metrology of O I transitions" (about 20 lines in the 94.86–102.82 nm range) that are used for absolute calibration purposes, when oxygen is present, for E20 and higher energy states.

#### Niu et al. (2016)

While focused on the spectroscopy and perturbation analysis of the  $A^{1}\Pi(v=0)$  state of  ${}^{13}C^{16}O$ , this paper provides deperturbed molecular constants for B00.

Ubachs et al. (1994)

This paper summarizes the work performed in the 91.2–115 nm range by the Amsterdam and Nijmegen teams over several years, reporting molecular constants for many states of four isotopologues and, of relevance to the present work, for  ${}^{12}C^{16}O$  (B00, B10, C00),  ${}^{13}C^{16}O$  (B00), and  ${}^{12}C^{18}O$  (B00).

Ubachs et al. (1995)

This is a laser spectroscopic study of  ${}^{12}C{}^{17}O$  (observed here for the first time) *R*- and *P*-branch lines of CO0 [J' = 10-17 for *R* and 10–15 for *P*] and derived molecular constants. The latter are also

given for C00 and C10 for  ${}^{12}C^{16}O$ ,  ${}^{13}C^{16}O$ , and  ${}^{12}C^{18}O$ , but no transition frequencies are available.

Ubachs et al. (2000)

This paper reports the transition frequencies of E10 for six isotopologues. For  ${}^{12}C{}^{16}O$  [*R*: J' = 0-26 with three gaps; *Q*: J' = 8-21 with two gaps; *P*: J' = 5-28 with three gaps],  ${}^{12}C{}^{18}O$  [*R*: J' = 0-11; *Q*: J' = 8-13 with one gap; *P*: J' = 2-13 with three gaps],  ${}^{13}C{}^{16}O$  [*R*: J' = 0-20 with five gaps; *Q*: J' = 7-23; *P*: J' = 2-20],  ${}^{13}C{}^{18}O$  [*R*: J' = 0-20 with two gaps; *Q*: J' = 1,18; no *P*], a few for  ${}^{12}C{}^{17}O$  [*R*: J' = 0-1; *Q*: J' = 1-2; no *P*] and for  ${}^{13}C{}^{17}O$  [*R*: J' = 0-12 with six gaps; *Q*: J' = 1-12; *P*: J' = 3]. The very high resolution (up to  $\sim 3 \times 10^6$ ) achieved by a narrow-band laser source allowed assigning the *Q*-branch lines with an absolute accuracy of 0.003 cm<sup>-1</sup> for all six natural CO isotopologues. Molecular constants are also derived for the ground-state X(v'' = 0), E10 and the perturbing k60 bands.

References to the available absolute high-resolution calibration band or lines we used are summarized in Table 2 for each band and for each isotopologue. The availability of term values and/or molecular constants derived from the laser-based measurements is also noted in the table.

We also mention the mainly theoretical work of Lefèbvre-Brion & Eidelsberg (2012), which presents molecular constants  $(T_v \text{ and } B_v)$  for E00, E10, E20, and E30 derived from our VUV-FTS high-resolution CO datasets, extracted before the absolute wavelength calibration of this work.

#### 2.2. Data analysis

#### 2.2.1. Atlas of measured wavelengths and wavenumbers

In order to place the atlas on an absolute wavelength scale, we compared our measured data with the entire set of calibration references from Table 2 (including all isotopologues when available). The average of their differences provides the value of a shift that was applied to correct the raw experimental wavelengths. As proof of the accuracy of the data delivered by the VUV-FTS team, this correction was usually very small ( $<3.4 \times 10^{-5}$  nm or 0.03 cm<sup>-1</sup>). Two sets of measured transition energies (including calibration shift corrections from the wavelength standards),  $R_{ms}$  and  $P_{ms}$ , corresponding to the *R*- and *P*-branches (and additionally  $Q_{ms}$  for <sup>1</sup> $\Pi$  states), were the result from this procedure.

In order to check the quality of our transition energy determinations, we compared for each J' the values of

$$A = R_{(J'=i+1 \leftarrow J''=i)} - P_{(J'=i+1 \leftarrow J''=i+2)}$$
to those of  
$$B = X_{J''=i+2} - X_{J''=i},$$

according to the method of combination differences (Herzberg et al. 1950). For each band and for each J', we calculated the difference A-B between these two quantities, which we defined as  $2 \times \delta_P$ .

These differences lead to uncertainties in the term values  $TV_R$  and  $TV_P$ . Some publications interested in precise term values shared equally for each J' the difference between  $TV_R$  and  $TV_P$  (or between R and P, in order to calculate corrected transition energies  $R_{corr} = (R_{ms} - \delta_P)$  and  $P_{corr} = (P_{ms} + \delta_P)$ , which produces a single best-term value based on both lines. We did not follow this procedure here, but kept the measured values.

#### 2.2.2. Atlas of term values and molecular constants

For each measured band, we used the line positions of *R*- and *P*-branch lines that terminate on the same upper rotational levels to calculate common upper-level term values with uncertainties.

The agreement of the term values calculated from independently measured P- and R-branch transitions with a common upper J-level,  $TV_R$ , and  $TV_P$ , is never perfect because of experimental noise and in some cases line broadening. However, as we described above, the excellent reproducibility of the measurements obtained with the VUV-FTS for a given band and a given isotopologue from spectra recorded at different times suggests that when the discrepancy is larger than the random fitting errors, it reveals the possible presence of a local perturbation that modifies the shape of one of the lines involved. For each J' = i + 1 level, the final term value was obtained by averaging the term values  $TV_R = R_{J'=i+1 \leftarrow J''=i} + X_{J''=i}$  and  $TV_P = P_{J'=i+1 \leftarrow J''=i+2} + X_{J''=i+2}$ that were calculated from measured line positions of each rotational branch,  $R_{ms}$  and  $P_{ms}$ . The relative difference is again  $2 \times \delta_P$ . As a final result,  $R_{ms}$ ,  $P_{ms}$  and  $\delta_P$  values are tabulated for each band and isotopologue. Both  $R_{ms}$  and  $P_{ms}$  are given in wavelengths and wavenumbers (and  $\delta_P$  in wavenumbers), and are presented in separate tables for <sup>12</sup>C- and <sup>13</sup>C-bearing CO species.

Term values of the upper levels for all six isotopologues were derived from these two independent measurements. They are presented in separate tables for each band, while reduced term values are shown with graphs for better visualization. We must be careful for high J' term values in two specific cases: (a) a high value of  $\delta_P$  (we adopted in this work a limit of 0.125 cm<sup>-1</sup>) might mean that one of the lines is less well identified than the other (or does not belong to the studied band), even if the two R and P lines are both clearly observed, and (b) no  $\delta_P$  value indicates that only one transition is present, either R or P. In the first case, we kept the TV derived from a single level, while in the second case, erratic TV values had to be rejected. All these tables and graphs are introduced for each state in the following sections.

For each band and isotopologue, the statistical uncertainty on term values was obtained by calculating over all J', when both R and P levels were measured, the average and standard deviation (at  $2\sigma$ ) of  $2 \times \delta_P/2$ . The division by a factor of two takes into account that each term value results from two independent measurements ( $R_{ms}$  and  $P_{ms}$ ) and that at least two different records (up to four in some cases, as described above) provide the same line position results. Each average is displayed in statistical tables, alongside its standard deviation (at  $2\sigma$ ), showing the dispersion in our measurements. An average closer to zero means that the  $\delta_P$  values are randomly distributed, ensuring no bias in our measurements. A standard deviation closer to zero signifies a high probability of the absence of perturbation(s).

The molecular constants  $T_v$ ,  $B_v$ , and  $D_v$  were least-squares fitted to the experimental term values using a second-order polynomial. Following the above remarks, only a subset of term values was considered at times, particularly for high J' term values. Reduced term values were finally calculated for each vibrational level by subtracting a model defined by

$$TV(J) = T_v + B_v \times J(J+1) - D_v \times J^2(J+1)^2$$

for the *e*-parity levels of the  $B^1\Sigma^+$  and  $C^1\Sigma^+$  sates and the *f*-parity levels of the  $E^1\Pi$  state, while for the *e*-parity levels of  $E^1\Pi$ , the additional term

$$q \times J(J+1) - q_D \times J^2(J+1)^2$$

takes the  $\Lambda$ -doubling of this state into account (so that  $q = B_e - B_f$  and  $q_D = D_e - D_f$ , where the *e* and *f* subscripts refer to the parity of the considered levels). For the  $E^1\Pi$  state, the  $\Lambda$ -doubling

components can be either calculated by subtracting the molecular constants deduced from the *e*- and *f*-parity levels, or they can be directly obtained by fitting the  $TV_e-TV_f$  differences for each level to a second-order polynomial. The results of both methods are presented in Sect. 3.5. Their values were graphically compared according to their oxygen isotopic content to check for anomalies that are due to perturbations. In almost every case, our molecular constants were generated by much larger datasets than those referenced in Sect. 2.1 (see also Table 2).

It is worth noting that the lines in the R- and P-branches are in general not observed up to the same J'. It is also possible, in the case of high-pressure spectra, that some lines observed at high J' values belong to a weak unidentified underlying band. As a consequence, some reduced term value graphs could present a break or jump for the last higher J' values. This break, however, could correspond in some cases to a real perturbation.

# 3. Results and discussion

The results presented here constitute the first part of an atlas of the Rydberg states at wavelengths below 115 nm for six isotopologues of CO. They update and complete the previous CO atlas at the higher resolution provided by the VUV-FTS coupled to the SOLEIL synchrotron (Eidelsberg et al. 1991; for revised band origin wavenumbers, see Eidelsberg et al. 1992). They also fill some gaps and provide higher J' lines that were previously not observed with high-resolution laser methods.

In addition to the atlas of absolute wavelengths and wavenumbers for the B, C, and E states of the six CO isotopologues, we provide for the derived term value atlas for each observed band. As a further step, we calculate reduced term values and molecular parameters. The latter are compared according to their oxygen isotopic content, and when possible, with previous determinations.

Figure 1 shows the bandhead wavelengths of the states and bands studied in this work. Table 1 summarizes the measured bands for each isotopologue. Some isotopologue bands are not recorded because of the combination of low oscillator strengths and low available pressures or partial pressures. Low partial pressure is particularly a problem in the case of <sup>13</sup>C<sup>17</sup>O, which is observed as a minor contaminant in high-pressure spectra of both <sup>13</sup>C<sup>16</sup>O and <sup>13</sup>C<sup>18</sup>O.

For all <sup>12</sup>C (or <sup>13</sup>C)-bearing isotopologues, the isotope shift spacing between bandheads increases almost linearly with v'vibrational number, allowing for an easier differentiation of the lines pertaining to a given isotopologue for increasing v' and J'.

# 3.1. Specific cases of ${}^{12}C{}^{17}O$ and ${}^{13}C{}^{17}O$

# 3.1.1. <sup>12</sup>C<sup>17</sup>O

As  ${}^{12}C^{17}O$  is mixed in almost equal proportions with  ${}^{12}C^{16}O$  in our sample, the absolute calibration of  ${}^{12}C^{17}O$  transitions benefits from the absolute calibration of  ${}^{12}C^{16}O$  (as well as  ${}^{12}C^{18}O$ , which is also present in a small amount).

# 3.1.2. <sup>13</sup>C<sup>17</sup>O

The case of  ${}^{13}C^{17}O$  is specific because it is observed in the high-pressure spectra of either  ${}^{13}C^{16}O$  or  ${}^{13}C^{18}O$ . The occurrence of the  ${}^{13}C^{17}O$  bands is due to isotopic contamination of the  ${}^{13}C^{16}O$  and  ${}^{13}C^{18}O$  bottles. Based on the relative strengths of identical absorption features, the ratio of the isotopologues



**Fig. 1.** Bandhead wavelengths of <sup>12</sup>C<sup>16</sup>O states and bands studied in this work. We also include the previously used numerical index notation (34–43) (Letzelter et al. 1987; Eidelsberg & Rostas 1990, etc.). Atomic line calibrators are indicated with |: for primary lines at high accuracy (1 fm or better) and with |: for secondary lines at medium accuracy (0.1 pm) (for the latter, mostly Xe I and a few Ar I and Kr I, see the NIST atomic line tables for identification), and the 1/e undulator bandwidth are shown as well.

in the  ${}^{13}C^{16}O$  gas sample, sorted by concentration, is found to be  ${}^{13}C^{16}O{:}^{13}C^{18}O{:}^{13}C^{17}O{:}^{12}C^{16}O=1{:}0.041{:}0.073{:}0{:}0045.$  The high CO pressure needed to observe the minor <sup>13</sup>C<sup>17</sup>O species leads to strong absorption and saturation of the main species spectrum. Combined with the fact that the isotopic shifts of v' = 0bands are very small ( $\leq 1 \text{ cm}^{-1}$  for B00 and C00 and  $\leq 3 \text{ cm}^{-1}$  for E00), <sup>13</sup>C<sup>17</sup>O lines for low J' are difficult to extract because of blending with saturated (broadened) lines. This effect is weaker for increasing J' because of the difference between molecular constants of the different isotopologues. <sup>13</sup>C<sup>17</sup>O lines of B00 with J' > 2 are measured nearly as accurately (~0.04 cm<sup>-1</sup>) as for the main isotopologue (either  ${}^{13}C^{16}O$  or  ${}^{13}C^{18}O$ ), similarly for C00 lines with J' > 6. The search for low J' line positions is facilitated by considering the values extrapolated from the clearly observed high J' line levels (up to J' = 23 for B00, J' = 21for B10, J' = 39 for C10, and J' = 26 for E00), which leads to an accuracy better than  $0.08 \text{ cm}^{-1}$  for the low J'. This effect is less noticeable for  $v' \ge 1$  as the spacing of spectra bandheads of the different isotopologues increases with v'.

All this concerns R- and P-branches, but there is an additional difficulty for Q-branches that we consider in the E-state subsection.

#### 3.2. $X^1\Sigma^+$ state

In order to calculate the term values of all the bands presented here, high-accuracy data provided by Guelachvili et al. (1983) and Farrenq et al. (1991) were used. From their set of Dunham coefficients, rotational levels of the  $v'' = 0 X^1 \Sigma^+$  ground state were calculated up to J'' = 48 with an uncertainty of  $10^{-3}$  cm<sup>-1</sup>, which is at least as good as our own high-resolution measurements. Table 9 lists the ground-state rotational levels of the six

**Table 3.** References to table and figure numbers for the  $B^1\Sigma^+$  state.

Band	, W	Transit /avelen	tion gths	Term values	Reduced TV
	Tat	oles	Figure	Table	Figure
	$^{12}C$	$^{13}C$			
B00	A.1	A.2	2	A.3	4
B10	A.4	A.5	3	A.6	5
B20	A.7	A.7	A.1	A.8	A.2

isotopologues studied here,  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ ,  ${}^{12}C^{18}O$ ,  ${}^{13}C^{16}O$ ,  ${}^{13}C^{17}O$ , and  ${}^{13}C^{18}O$ . For each isotopologue, these J'' levels are adjusted to a ninth-order polynomial to obtain their molecular constants. They are reported in Table A.31.

For the sake of consistency between all isotopologues, we did not use the data on the  ${}^{12}C^{16}O$  ground state by Varberg & Evenson (February 1992), which were published a few months after Farrenq et al. (October 1991). The latter provide data for six isotopologues, and a check on  ${}^{12}C^{16}O$  B00 revealed a better agreement at high *J'* between the term values TV<sub>*R*</sub> and TV<sub>*P*</sub> derived for the *R*- and *P*-branches.

# 3.3. $B^1\Sigma^+$ state

The B00 and B10 bands were observed for all isotopologues, while B20 was observed for all bands except for  ${}^{12}C^{17}O$  and  ${}^{13}C^{17}O$ . The lack of the B20 band in the  ${}^{12}C^{17}O$  spectra is explained by the low pressure used in scans of this isotopologue. For  ${}^{13}C^{17}O$ , the absence is due to the combination of a very low partial pressure and the decreasing oscillator strength with v'.

A total of 19 CO laser-calibrated lines (14 for  ${}^{12}C^{16}O$ , 2 for  ${}^{12}C^{18}O$ , and 3 for  ${}^{13}C^{16}O$ ) were used to determine a shift correction of  $-7.5 \times 10^{-6}$  nm (0.006 cm<sup>-1</sup>) for B00 and 3 lines for B10, resulting in a shift correction of  $-1.2 \times 10^{-5}$  nm (0.0095 cm<sup>-1</sup>). These low values attest to the accuracy of our measurements. These corrections were applied to all isotopologues as their spectra are placed, as mentioned above, on a unique scale. Our term values are consistent within the uncertainty with those calculated by Le Floch & Amiot (1985) and Haridass et al. (1994), the latter resulting from the combination of *B*–*A* data with high-resolution *A*–*X* data obtained with the former Ottawa 10.6 m vacuum-grating spectrograph. For  ${}^{12}C^{16}O$  B00, the average difference between our values and the Daprà et al. (2016) values is  $5.0 \times 10^{-6}$  nm.

For <sup>12</sup>C<sup>17</sup>O, the present results complete a preliminary version of our B00 data that was incorporated in Hakalla et al. (2016) in order to perform the deperturbation analysis of the  $A^{1}\Pi$  state of <sup>12</sup>C<sup>17</sup>O, for which earlier optical measurements of *B*–*A* and *C*–*A* transitions were combined with our vacuum ultraviolet *B*–*X* results. Similarly, for <sup>13</sup>C<sup>17</sup>O, our results of B00 and B10 were used in Hakalla et al. (2017) to perform the deperturbation analysis of the  $A^{1}\Pi$  state of <sup>13</sup>C<sup>17</sup>O.

The data for  ${}^{13}C^{18}O$  are slightly better calibrated than in our recent paper (Lemaire et al. 2016) for B00 and B10. In addition, they are extended to higher J' levels for B10.

As indicated above, the B20 band was calibrated using the surrounding B10 and C00 bands, leading to a common shift correction of  $+1.0 \times 10^{-5}$  nm (-0.0083 cm<sup>-1</sup>) that was applied to all isotopologues. Figure A.3 illustrates for the four observed isotopologues the perturbations observed in B20 (also studied in  $^{12}C^{16}O$  and  $^{13}C^{16}O$  by Baker 1994).

**Table 4.** Statistical uncertainty on the measured term values:  $\delta_P$  average and std. dev. (at  $2\sigma$ ) (see Sect. 2.2.2) for the  $B^1\Sigma^+$  state.

Band	Species	Ν	$\overline{\delta_P}$ (cm <sup>-1</sup> )	Std. dev. $(cm^{-1})$
B00	1216	62	0.000	0.007
	1217	44	0.007	0.023
	1218	60	0.003	0.022
	1316	60	0.011	0.026
	1317	36	0.001	0.026
	1318	54	0.002	0.006
B10	1216	60	0.00	0.02
	1217	30	-0.010	0.033
	1218	52	-0.001	0.009
	1316	54	-0.001	0.013
	1317	40	-0.011	0.027
	1318	38	0.007	0.010
B20	1216	22	-0.003	0.034
	1217			
	1218	22	0.019	0.038
	1316	30	-0.006	0.021
	1317			
	1318	30	-0.005	0.032

**Notes.** N: number of rotational transitions (R and P) involved in the statistics.

For  ${}^{12}C^{16}O$ ,  ${}^{12}C^{18}O$ ,  ${}^{13}C^{16}O$ , and  ${}^{13}C^{18}O$ , our absolutely calibrated data provide transition frequencies and term values for B00, B10, and B20 that are consistent at slightly higher accuracy with those measured by Eidelsberg et al. (1987), which were obtained with the Observatoire de Paris (Meudon, France) 10 m VUV grating spectrograph. The same remark applies to the line positions obtained by Baker (1994) for B20 of  ${}^{12}C^{16}O$  with the same instrument.

Table 3 lists table and figure numbers associated with the BX bands. Table 4 gives the statistical uncertainty on the term values for the BX bands (see text in Sect. 2.2.2).

#### 3.4. $C^1\Sigma^+$ state

C00, C10, C20, and C30 were observed for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{18}O$ ,  ${}^{13}C^{16}O$ , and  ${}^{13}C^{18}O$ . For  ${}^{12}C^{17}O$ , all bands were observed except for C20, for the same reason as for B20. For  ${}^{13}C^{17}O$ , only C00 and C10 were observed; C20 and C30 are not observed for the same reason as for B20.

It is worth noting that for  ${}^{12}C^{18}O$ , the C30 band does not appear in the same room-temperature spectra obtained at pressures where C20 is observed. It is only observed in a lowtemperature spectrum recorded at  $90 \pm 5$  K, showing a limited number of J' levels.

Sixteen CO laser-calibrated lines were used to determine a shift correction of  $1.3 \times 10^{-5}$  nm (-0.011 cm<sup>-1</sup>) for C00. Seventy-two laser-calibrated lines were considered (not including  $^{12}C^{17}O$  and  $^{13}C^{17}O$ , for which the number of lines in Cacciani et al. 2001 is limited) to determine the shift correction of  $3.4 \times 10^{-5}$  nm (-0.031 cm<sup>-1</sup>) for C10.

Our term values are consistent with those calculated by Haridass et al. (1994), which were obtained from the combination of *C*–*A* data with high-resolution *A*–*X* data obtained with the former Ottawa spectrograph. For <sup>12</sup>C<sup>16</sup>O C00, the average difference between our values and the values of Daprà et al. (2016) is  $4.4 \times 10^{-5}$  nm (-0.037 cm<sup>-1</sup>).

For C00, the present results complete a preliminary version of our  ${}^{12}C^{17}O$  data (as for B00) and provide new data on  ${}^{13}C^{17}O$ .



**Fig. 2.** Transition wavelengths of the  $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$  band for six CO isotopologues.





**Fig. 3.** Transition wavelengths of the  $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=0)$  band for six CO isotopologues.

Both were used in order to perform the deperturbation analysis of the  $A^1\Pi$  state of  ${}^{12}C^{17}O$  (Hakalla et al. 2016) and of  ${}^{13}C^{17}O$  (Hakalla et al. 2017).

As for B00 and B10, the present data for  ${}^{13}C^{18}O$  are slightly better calibrated and extend to higher J' levels than in our recent paper (Lemaire et al. 2016) for C00.

Band	W	Transiti vaveleng	on gths	Term values	Reduced TV
	Tał	oles	Figure	Table	Figure
	$^{12}C$	$^{13}C$			
C00	A.9	A.10	A.4	A.11	A.6
C10	A.12 A.13		A.5	A.14	A.7
C20	A.15	A.15	A.8	A.16	A.9
C30	A.17	A.17	A.10	A.18	A.11

The absolute calibration for C20 and C30 was obtained using the two surrounding primary atomic standards as calibrators (the Xe I line at 104.383497 nm for C20, and the Kr I line at 100.1060639 nm for C30, see Fig. 1) and checking that the numerous secondary standards (in the case of C20) are in agreement with each other (at an accuracy higher than 0.01 pm) for the five isotopologues.

Table 5 lists table and figure numbers associated with the CX bands. Table 6 gives the statistical uncertainty on the term values for the CX bands (see text in Sect. 2.2.2).

# *3.5. Е*<sup>1</sup>П *state*

E00, E10, E20, and E30 [the latter formerly labeled as the V ( $A^2\Pi$ )<sup>3</sup> $\Pi$  state by Eidelsberg & Rostas (1990), with the present assignment confirmed by Lefèbvre-Brion & Eidelsberg (2012)] were observed for all isotopologues, with the exception



J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

**Fig. 4.** Reduced term values  $(cm^{-1})$  of the  $B^{1}\Sigma^{+}(v'=0)$  levels for six CO isotopologues.



**Fig. 5.** Reduced term values (cm<sup>-1</sup>) of the  $B^{1}\Sigma^{+}(v'=1)$  levels for six CO isotopologues.

of E20 and E30 for  ${}^{13}C^{17}O$  (as for B20 because of the combination of a very low partial pressure and decreasing oscillator strength with v').

For E20 and E30 of  ${}^{12}C^{18}O$ , the same remark holds as for C30. These two bands do not appear in spectra taken at room-temperature at pressures where E10 is observed. It is only observed in low-temperature spectra recorded at  $90 \pm 5$  K, showing a limited number of J'.

For all isotopologues, the rotational spacing is extremely small for the *Q*-branch of E00, E10, and E20, giving rise to congested spectra that require better resolution than available with the VUV-FTS and smaller Doppler broadening. This is particularly noticeable for the *Q*-branch of E10, where the lines are very slightly blueshifted with J' compared to the *Q*-branch of E00, which is slightly blueshifted, and the *Q*-branch of E20, which is slightly redshifted. Only with the use of a very narrow-band laser were Cacciani & Ubachs (2004) able to separate the *Q*-branch of E00, and Ubachs et al. (2000) did this in combination with a deperturbation analysis for E10. The *Q*-branch of E30 has a very different aspect (similar to A-X transitions) with a redshifted *Q*-branch and a returning limb for the *R*-branch with increasing J' (see for comparison Figs. A.12, A.17, and A.25 vs. A.28, and also Figs. A.15, A.16, A.24, and A.27 vs. Figs. A.30–A.36).

A careful analysis is required to distinguish the lines in the E00 bands of the different isotopologues. Spectra recorded at different pressures were used for this purpose. Figure A.16 illustrates the difficulty of this task for E00 with three spectra for  ${}^{13}C^{18}O$  and 2 for  ${}^{13}C^{16}O$ . Figure A.27 shows the easier example of E20 for  ${}^{13}C^{16}O$  and  ${}^{13}C^{18}O$ , and Figs. A.30–A.36 show the example of E30 for  ${}^{13}C^{18}O$ .

There is very good agreement for the *R*- and *P*-branch line positions between our present results and other high-resolution measurements (Cacciani et al. 1995; Cacciani & Ubachs 2004 for E00 and Ubachs et al. 2000 for E10).

E00 was calibrated using a few levels observed by Cacciani et al. (1995) for  ${}^{12}C^{16}O$  [3 lines] and a large set of R and P levels (Cacciani & Ubachs 2004) for  ${}^{12}C^{16}O$  [60 lines] and  ${}^{13}C^{16}O$ [32 lines] obtained by their methods labeled 1 and 0 (these data have to be calculated from the supplementary data, but no data are available for  ${}^{13}C^{18}O$ ). The resulting shift correction is estimated as  $2.3 \times 10^{-5}$  nm (-0.020 cm<sup>-1</sup>). Comparison to Daprà et al. (2016) shows an average difference of  $3.8 \times 10^{-5}$  nm for E00. For <sup>12</sup>C<sup>18</sup>O and <sup>13</sup>C<sup>18</sup>O, our term values for E00 (e- and f-parity) match those calculated by Haridass et al. (1994) well, which were obtained from the combination of E-A data with high-resolution A-X data collected with the former Ottawa spectrograph. For the Q-branch of  ${}^{12}C^{16}O$ ,  ${}^{13}C^{16}O$ , and  ${}^{13}C^{18}O$ , which we cannot separate, we report the Cacciani & Ubachs (2004) observed transition frequencies (see their Table 1). We merged the Cacciani et al. data with our higher-J' measurements. For the other isotopologues,  ${}^{12}C^{17}O$  and  ${}^{12}C^{18}O$ , the Q bandhead up to  $J' \approx 9$  was simulated to reproduce the observed spectra. These calculated data were merged with our measured data at higher J'. For the last isotopologue,  ${}^{13}C^{17}O$ , the Q-branch was simulated by interpolation of the  ${}^{13}C^{16}O$  and  ${}^{13}C^{18}O$  transitions (but these data are not reported in the table) in order to assign the few observed high J' Q-lines.

E10 was calibrated by a few lines observed by Cacciani et al. (1995) for  ${}^{12}C^{16}O$  [9 lines] and a large set by Ubachs et al. (2000) of *R* and *P* lines for  ${}^{12}C^{16}O$  [42 *R* and *P* lines], for  ${}^{12}C^{17}O$  [2 *R* lines],  ${}^{12}C^{18}O$  [24 *P* and *R* lines],  ${}^{13}C^{16}O$  [25 *P* and *R* lines], and  ${}^{13}C^{18}O$  [18 *R* lines]. The absolute calibration for E10 obtained with the *R* and *P* levels is also confirmed by the presence of closely surrounding Xe I atomic lines (see Fig. 1).

<b>Table 6.</b> Statistical uncertainty on the measured term values: $\delta_P$ average
and std. dev. (at $2\sigma$ ) (see Sect. 2.2.2) for the $C^1\Sigma^+$ state.

Species	N	$\overline{\delta_P}$ (cm <sup>-1</sup> )	Std. dev. $(cm^{-1})$
1216	72	0.010	0.027
1217	66	-0.011	0.034
1218	70	0.000	0.010
1316	72	0.000	0.013
1317	70	0.004	0.021
1318	78	-0.001	0.007
1216	62	0.001	0.013
1217	42	0.001	0.010
1218	52	-0.008	0.022
1316	54	0.008	0.045
1317	44	0.006	0.043
1318	56	-0.003	0.017
1216	28	0.003	0.012
1217			
1218	14	0.007	0.044
1316	16	0.004	0.043
1317			
1318	14	-0.015	0.019
1216	32	0.025	0.038
1217	6	-0.007	0.048
1218	16	-0.002	0.053
1316	16	-0.004	0.056
1317			
1318	26	0.016	0.044
	Species 1216 1217 1218 1316 1317 1318 1216 1217 1218 1316 1317 1318 1216 1217 1218 1316 1317 1318 1216 1317 1318 1216 1317 1318 1216 1317 1318 1316 1317 1318	Species         N           1216         72           1217         66           1218         70           1316         72           1317         70           1318         78           1216         62           1217         42           1218         52           1316         54           1317         44           1318         56           1216         28           1217         14           1318         14           1316         16           1317         14           1318         14           1216         32           1217         6           1218         16           1317         16           1318         14           1216         32           1217         6           1218         16           1316         16           1316         16           1317         1318           1318         26	$\begin{array}{c c c c c c c c c c c c c c c c c c c $

**Notes.** N: number of rotational transitions (R and P) involved in the statistics.

The resulting shift correction is estimated to be  $5.0 \times 10^{-6}$  nm. As it is not possible to distinguish the *Q*-branch of E10 for all isotopologues, we report in the tables the values obtained by Ubachs et al. (2000), merged with our measured data at higher *J'*. Our dataset for *R*- and *P*-branches extends those of Ubachs et al. (2000) to high *J'* values. Sample spectra are shown for <sup>12</sup>C<sup>16</sup>O in Fig. A.20, <sup>12</sup>C<sup>17</sup>O in Fig. A.21, <sup>12</sup>C<sup>18</sup>O in Fig. A.22, <sup>13</sup>C<sup>16</sup>O in Fig. A.23, and <sup>13</sup>C<sup>18</sup>O in Fig. A.24. All of them show additional lines, and among them, lines that belong to the perturbing state  $k^3\Pi(v'=5 \text{ and } 6)-X^1\Sigma^+(v'=0)$ (Baker & Launay 1994; Ubachs et al. 2000). The lower panel of Fig. A.21 shows the simulated absorption spectrum of <sup>12</sup>C<sup>17</sup>O at room temperature.

For E20 and E30, only low-resolution spectra without absolute calibration are available (Ogawa & Ogawa 1974 for <sup>12</sup>C<sup>16</sup>O E20) and the Eidelsberg et al. (1991) atlas for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{18}O$ , <sup>13</sup>C<sup>16</sup>O, and <sup>13</sup>C<sup>18</sup>O for both E20 and E30, with either measured or extrapolated or calculated line positions. Consequently, the absolute calibration of E20 and E30, for which there are no previous high-resolution measurements, was obtained in the same way as for C20 and C30, using the two surrounding primary atomic standards as calibrators and checking that the numerous secondary standards (in the case of E20) are in agreement with each other (at an accuracy higher than 0.01 pm) for five isotopologues (with the exception of  ${}^{13}C{}^{17}O$  ). For E20, the Q-branch up to J' = 6 or 7 was obtained in the same way as for E10 by simulating our recorded spectra and merging them with the higher measurable J', up to  $\sim 10-20$ , depending on the isotopologue. Figure A.27 shows the simulated absorption spectra of  ${}^{12}C^{16}O$ at 90 K and at room temperature. Finally, as indicated above, all branches of E30 have well-resolved transitions for all observed

**Table 7.** References to table and figure numbers for the  $E^1\Pi$  state.

Band	v	Transitio /aveleng	on gths	Term values	Red T	uced V
	Tał	oles	Figure	Table	Fig	gure
	$^{12}C$	<sup>13</sup> C			<i>e</i> -par.	f-par.
E00	A.19	A.20	A.12	A.21	A.13	A.14
E10	A.22	A.23	A.17	A.24	A.18	A.19
E20	A.25	A.26	A.25	A.29	A.	.26
E30	A.27	A.28	A.28	A.30	A.	.29

isotopologues. Figures A.30–A.36 show spectra for all five isotopologues; in some cases, the results obtained at 293 K and 90 K are compared, which are useful to separate the *R*-branch lines.

In order to verify the quality of our frequency determinations for the *Q*-branch, we use a method similar to the combination differences. We compared the values of the  $\Lambda$ -type doubling of the upper state obtained through the *R*- and *P*-branches,  $\Lambda_R(J)$ and  $\Lambda_P(J)$  (for  $J \ge 1$ ) with

$$\Lambda_R(J) = [R(J-1) + X(J-1)] - [Q(J) + X(J)] \text{ and } \\ \Lambda_P(J) = [P(J+1) + X(J+1)] - [Q(J) + X(J)].$$

For all isotopologues and all bands (E00, E01, E02, and E03), the results are consistent with the value of  $\Lambda_d$  provided in the term value tables. The  $\Lambda$  doubling of the upper state is graphically represented for all isotopologues in each band, E00, E10, E20, and E30, in Fig. A.37 together with polynomial fits (linear in most cases).

Table 7 lists table and figure numbers associated with the EX bands. Table 8 gives the statistical uncertainty on the *e*-parity term values of the EX bands (see text in Sect. 2.2.2).

## 4. Concluding remarks

Our work presents a comprehensive and homogeneous set of absolutely calibrated line positions from which term values and molecular constants are derived. In most cases, these were obtained from larger sets of data than earlier determinations. Our data complete previous determinations and fill many gaps, particularly concerning the B20, C20, C30, E20, and E30 bands of all isotopologues. We also provide new data, particularly for the <sup>12</sup>C<sup>17</sup>O and <sup>13</sup>C<sup>17</sup>O isotopologues.

A final verification of the absolute accuracy of our whole set of results is provided by comparison with the data reported by Daprà et al. (2016). These datasets were not considered as calibrators because they were derived from others cited in Sect. 2.1, but we verified that they are in good agreement (at least for the six J' levels included therein) with our own results on B00, C00, and E00 for  ${}^{12}C{}^{16}O$ .

In conclusion, the overall uncertainty of our data is a combination of the relative fitting accuracy in line positions (for a well-resolved typical line ~0.008 cm<sup>-1</sup>) and of the accuracy in the calibrators and in the ground state (up to ~0.003 cm<sup>-1</sup>). Most of the line positions are thus determined to an accuracy of ~0.009 cm<sup>-1</sup>. For some weak (mainly at high J') or a few blended lines, the fitting errors are estimated to be as large as 0.10–0.15 cm<sup>-1</sup>. Uncertainties on term value data are reflected in the  $\delta_P$  values presented in the term value tables.

Molecular constants are compiled in Table A.31 for all states and bands. In this table the *E* state *e*- and *f*-parity are treated independently, and we calculate in Table A.32  $T_v(1)$  (average of

<b>Table 8.</b> Statistical uncertainty on the measured term values: $\delta_P$ average
and std. dev. (at $2\sigma$ ) (see Sect. 2.2.2) for the <i>e</i> -parity levels ( <i>R</i> and <i>P</i> )
for the $E^1\Pi$ state.

Band	Species	Ν	$\overline{\delta_P}$ (cm <sup>-1</sup> )	Std. dev. $(cm^{-1})$
E00	1216	58	0.002	0.014
	1217	48	0.003	0.015
	1218	64	0.001	0.014
	1316	74	0.009	0.018
	1317	30	-0.008	0.018
	1318	68	0.018	0.032
E10	1216	50	0.004	0.031
	1217	38	0.009	0.024
	1218	44	0.004	0.021
	1316	54	0.000	0.018
	1317	36	-0.001	0.002
	1318	62	0.009	0.026
E20	1216	36	0.003	0.015
	1217	18	-0.004	0.026
	1218	20	0.008	0.015
	1316	36	0.001	0.014
	1317			
	1318	48	-0.003	0.027
E30	1216	30	-0.001	0.046
	1217	16	-0.002	0.037
	1218	18	-0.005	0.030
	1316	18	0.003	0.019
	1317			
	1318	22	0.000	0.010

**Notes.** N: number of rotational transitions (R and P) involved in the statistics.

 $T_v$  for *e*- and *f*-parity),  $q_v = B_e - B_f$ , and  $q_{Dv} = D_e - D_f$ . These molecular constants are also obtained by a quadratic fit of the  $\Lambda$ -doubling data shown in Fig. A.37 and reported in Table A.33.

In order to check the consistency of our term values, we compare their trends for the six CO isotopologues in Fig. A.38. The term value differences between <sup>16</sup>O and <sup>18</sup>O bearing isotopologues are compared both for <sup>12</sup>C and <sup>13</sup>C versus the *B*, *C*, and *E* states. Term values are also compared as a function of v' for each states, and a linear fit is drawn through all isotopologues present in each  $(T_V, v')$  data point. Both comparisons show a similar behavior.

The statistical table for the term values (see Tables 4, 6, and 8) can reveal the possible presence of perturbations when there is a large spread in the standard deviation (>0.043 cm<sup>-1</sup>, namely for <sup>12</sup>C<sup>16</sup>O (E30), for <sup>12</sup>C<sup>17</sup>O (C30), for <sup>12</sup>C<sup>18</sup>O (C20 and C30), for <sup>13</sup>C<sup>16</sup>O (C10, C20 and C30), for <sup>13</sup>C<sup>17</sup>O (C10), and for <sup>13</sup>C<sup>18</sup>O (C30). Anomalies in the molecular constants also reveal evidence of perturbations, as shown in Fig. A.39, which illustrates this point more clearly than Table A.31. While  $T_v$  mainly depends on the absolute calibration,  $B_v$  and especially  $D_v$  are very sensitive to perturbations, as shown in Fig. A.39.

Perturbations will be discussed in detail in a subsequent paper. Another forthcoming development of this work will be a comprehensive atlas of oscillator strengths and cross sections for the states, bands, and isotopologues presented here.

Acknowledgements. We acknowledge SOLEIL for providing the synchrotron radiation facilities. All the data have been obtained on beamline DESIRS using the VUV-FTS spectrometer during proposals 20140051, 20120715, 20110121, 20100018, 20090021, and 20080025. We acknowledge assistance from the SOLEIL beamline staff (L. Nahon beamline manager), NdO (VUV-FTS manager and coauthor), and D. Joyeux (designer and builder of the VUV-FTS). This

**Table 9.** Rotational energy levels (cm<sup>-1</sup>) of the  $X^1\Sigma^+$  ground state for six CO isotopologues (calculated from the Farrenq et al. 1991 Dunham coefficients).

$\begin{array}{ c c c c c c c c c c c c c c c c c c c$
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
8         138.390         134.895         131.802         132.305         128.809         125.715           9         172.978         168.610         164.743         165.372         161.003         157.136           10         211.404         206.066         201.341         202.109         196.770         192.044           11         253.667         247.262         241.593         242.515         236.108         230.438           12         299.766         292.197         285.498         286.588         279.017         272.317           13         349.698         340.869         333.055         334.326         325.495         317.679           14         403.461         393.276         384.261         385.727         375.540         366.523           15         461.054         449.416         439.116         440.791         429.150         418.847           16         522.475         509.288         497.616         499.515         486.324         474.650           17         587.721         572.888         559.761         561.896         547.059         533.928           18         656.789         640.215         625.546         627.932         611.354
9172.978168.610164.743165.372161.003157.13610211.404206.066201.341202.109196.770192.04411253.667247.262241.593242.515236.108230.43812299.766292.197285.498286.588279.017272.31713349.698340.869333.055334.326325.495317.67914403.461393.276384.261385.727375.540366.52315461.054449.416439.116440.791429.150418.84716522.475509.288497.616499.515486.324474.65017587.721572.888559.761561.896547.059533.92818656.789640.215625.546627.932611.354596.68119729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.658 <t< td=""></t<>
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
15461.054449.416439.116440.791429.150418.84716522.475509.288497.616499.515486.324474.65017587.721572.888559.761561.896547.059533.92818656.789640.215625.546627.932611.354596.68119729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
16522.475509.288497.616499.515486.324474.65017587.721572.888559.761561.896547.059533.92818656.789640.215625.546627.932611.354596.68119729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
17587.721572.888559.761561.896547.059533.92818656.789640.215625.546627.932611.354596.68119729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
18656.789640.215625.546627.932611.354596.68119729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
19729.677711.266694.971697.622679.206662.90620806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
20806.383786.039768.033770.962750.612732.60121886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
21886.902864.530844.729847.950825.571805.76322971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
22971.233946.737925.056928.582904.079882.391231059.3721032.6571009.0111012.857986.133962.480241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
23         1059.372         1032.657         1009.011         1012.857         986.133         962.480           24         1151.315         1122.285         1096.591         1100.771         1071.731         1046.028           25         1247.059         1215.620         1187.794         1192.320         1160.870         1133.034           26         1346.601         1312.658         1282.615         1287.502         1253.546         1223.492
241151.3151122.2851096.5911100.7711071.7311046.028251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
251247.0591215.6201187.7941192.3201160.8701133.034261346.6011312.6581282.6151287.5021253.5461223.492
26 1346.601 1312.658 1282.615 1287.502 1253.546 1223.492
27 1449.936 1413.395 1381.051 1386.312 1349.757 1317.401
28 1557.061 1517.827 1483.099 1488.748 1449.498 1414.757
29 1667.971 1625.950 1588.755 1594.805 1552.767 1515.557
30 1782.662 1737.760 1698.015 1704.480 1659.559 1619.797
31 1901.131 1853.254 1810.876 1817.769 1769.870 1727.473
32 2023.371 1972.426 1927.332 1934.667 1883.698 1838.582
33 2149.380 2095.273 2047.380 2055.170 2001.037 1953.120
34 2279.151 2221.790 2171.015 2179.274 2121.884 2071.084
35 2412.680 2351.972 2298.233 2306.975 2246.234 2192.468
36 2549.962 2485.814 2429.030 2438.267 2374.083 2317.268
37 2690.991 2623.311 2563.400 2573.145 2505.427 2445.482
38 2835.763 2764.459 2701.339 2711.606 2640.260 2577.102
39 2984.271 2909.251 2842.841 2853.643 2778.577 2712.127
40 3136.509 3057.682 2987.901 2999.252 2920.375 2850.549
41 3292.473 3209.748 3136.515 3148.427 3065.647 2992.366
42 3452.156 3365.442 3288.676 3301.163 3214.389 3137.572
43 3615.552 3524.758 3444.380 3457.454 3366.596 3286.161
44 3782.655 3687.690 3603.619 3617.295 3522.261 3438.129
45 3953.457 3854.233 3766.390 3780.679 3681.380 3593.470
46 4127.954 4024.380 3932.685 3947.601 3843.946 3752.179
47 4306.137 4198.125 4102.499 4118.054 4009.954 3914.251
48 4488.001 4375.461 4275.825 4292.033 4179.399 4079.679

research was supported by NASA (grants NNG 06-GG70G and NNX10AD80G to the Univ. of Toledo and NNX09AC5GG to Wellesley College). J. R. L. and G. S. thank the NASA Origins of Solar System program (Grant NNX14AD49G) for funding. A. H., while in the Amsterdam team, acknowledges support from the Dutch astrochemistry network (DAN) from the Netherlands Organisation for Scientific Research (NWO) under grant 648.000.002 and the research fellow-ship program of PSL Research University Paris. J. L. L. thanks the ISMO-CNRS (Institut des Sciences Moléculaires d'Orsay at Université Paris-Sud) for hosting him as visiting researcher.

## References

Baker, J. J. 1994, J. Mol. Spec., 167, 323

Baker, J., & Launay, F. 1994, J. Mol. Spec., 165, 75

Baker, J., Lemaire, J. L., Couris, S., et al. 1993, Chem. Phys., 178, 569

Baker, J., Lemaire, J. L., Couris, S., et al. 1994, AIP Conf. Proc., 312, 355

Brandi, F., Velchev, I., Hogervorst, W., & Ubachs, W. 2001, Phys. Rev. A, 64, 032505

Brandi, F., Hogervorst, W., & Ubachs, W. 2002, J. Phys. B, 35, 1071

J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

- Cacciani, P., & Ubachs, W. 2004, J. Mol. Spectr., 225, 62
- Cacciani, P., Hogervorst, W., & Ubachs, W. 1995, J. Chem. Phys, 102, 8308
- Cacciani, P., Brandi, F., Velchev, I., et al. 2001, Eur. Phys. J. D, 15, 47
- Daprà, M., Niu, M. L., Salumbides, E. J., Murphy, T., & Ubachs, W. 2016, ApJ, 826, 192
- de Oliveira, N., Joyeux, D., Phalippou, D., et al. 2009, Rev. Sci. Instrum., 80, 043101
- de Oliveira, N., Roudjane, M., Joyeux, D., et al. 2011, Nat. Photon., 5, 149
- de Oliveira, N., Joyeux, D., Roudjane, M., et al. 2016, J. Synchrotron Radiat, 23, 887
- Drabbels, M., Meerts, W. L., & ter Meulen, J. J. 1993a, J. Chem. Phys., 99, 2352
- Drabbels, M., Heinze, J., ter Meulen, J. J., & Meerts, W. L. 1993b, J. Chem. Phys., 99, 5701
- Eidelsberg, M., & Rostas, F. 1990, A&A, 235, 472
- Eidelsberg, M., Roncin, J.-Y., Le Floch, A., et al. 1987, J. Mol. Spectr., 121, 309
- Eidelsberg, M., Benayoun, J. J., Viala, Y. P., & Rostas, F. 1991, A&AS, 90, 231
- Eidelsberg, M., Benayoun, J. J., Viala, Y. P., et al. 1992, A&A, 265, 839
- Eidelsberg, M., Lemaire, J. L., Federman, S., et al. 2012, A&A, 543, A69
- Eidelsberg, M., Lemaire, J. L., Federman, S. R., et al. 2014, A&A, 566, A96
- Eidelsberg, M., Lemaire, J. L., Federman, S. R., et al. 2017, A&A, 602, A76
- Farrenq, R., Guelachvili, G., Sauval, A. J., Grevesse, N., & Farmer, C. B. 1991, J. Mol. Spectr., 149, 375
- Federman, S. R., Fritts, M., Cheng, S., Menningen, K. M., Knauth, D. C., & Fulk, K. 2001, ApJS, 134, 133
- Gavilan, L., Lemaire, J. L., Eidelsberg, M., et al. 2013, J. Phys. Chem. A, 117, 9644
- Guelachvili, G., de Villeneuve, D., Farrenq, R., Urban, W., & Verges, J. 1983, J. Mol. Spectr., 98, 64
- Hakalla, R., Niu, M. L., Field, R. W., et al. 2016, RSC Adv., 6, 31588
- Hakalla, R., Niu, M. L., Field, R. W., et al. 2017, J. Quant. Spectr. Rad. Transf., 189, 312

- Haridass, C., Paddy Teddy, S., & Le Floch, A. C. 1994, J. Mol. Spectr., 168, 429
- Heays, A. N., Eidelsberg, M., Stark, G., et al. 2014, J. Chem. Phys., 141, 144311
- Herzberg, G. 1950, in Spectra of Diatomic Molecules, Molecular Spectra and Molecular Structure, 2nd ed. (New York: Van Nostrand Reinhold), 1
- Ivanov, T. I., Salumbides, E. J., Vieitez, M. O., et al. 2008, MNRAS, 389, 4 Kaufman, V., & Edlén, B. 1974, J. Phys. Chem. Ref. Data, 3, 825
- Lefèbvre-Brion, H., & Eidelsberg, M. 2012, J. Mol. Spectr., 271, 59
- Le Floch, A. 1992, J. Mol. Spectr. 155, 177
- Le Floch, A., & Amiot, C. 1985, Chem. Phys., 97, 379
- Lemaire, J. L., Eidelsberg, M., Heays, A. N., et al. 2016, J. Phys. B, 49, 4001
- Letzelter, C., Eidelsberg, M., Rostas, F., Breton, J., & Thieblemont, B. 1987, Chem. Phys., 114, 273
- Morton, D. C., & Noreau, L. 1994, ApJS, 95, 301
- Nahon, L., de Oliveira, N., Garcia, G., et al. 2012, J. Synchrotron Radiat., 19, 508
- Nahon, L., de Oliveira, N., Garcia, G. A., et al. 2013, J. Phys. Conf. Ser., 425, 122004
- Niu, M. L., Hakalla, R., Madhu Trivikram, T., et al. 2016, Mol. Phys., 114, 2857
- Ogawa, S., & Ogawa, M. 1974, J. Mol. Spectr., 49, 4540
- Philip, J., Sprengers, J. P., Cacciani, P., de Lange, C. A., & Ubachs, W. 2004, Appl. Phys. B, 78, 737
- Stark, G., Lewis, B. R., Gibson, S. T., & England, J. P. 1999, ApJ, 520, 732
- Stark, G., Heays, A. N., Lyons, J. R., et al. 2014, ApJ, 788, 67
- Ubachs, W., Eikema, K. S. E., Levelt, P. F., et al. 1994, ApJ, 427, L55
- Ubachs, W., Hinnen, P. C., Hansen, P., et al. 1995, J. Mol. Spectr., 174, 388
- Ubachs, W., Velchev, I., & Cacciani, P. 2000, J. Chem. Phys., 113, 547
- van Dishoeck, E. F., & Black, J. H. 1988, ApJ, 334, 771
- Viala, Y. P., Letzelter, C., Eidelsberg, M., & Rostas, F. 1988, A&A, 193, 265
- Visser, R., van Dishoeck, E. F., & Black, J. H. 2009, A&A, 503, 323
- Yoshino, K., & Freeman, D. E. 1985, J. Opt. Soc. Am. B, 2, 1268

# Appendix A: Additional figures and tables



**Fig. A.1.** Transition wavelengths of the  $B^{1}\Sigma^{+}(v'=2)-X^{1}\Sigma^{+}(v''=0)$  band for the four observed CO isotopologues.



**Fig. A.2.** Reduced term values  $(cm^{-1})$  of the  $B^{1}\Sigma^{+}(v'=2)$  levels for the four observed CO isotopologues.



Fig. A.3. Sample of B20 spectra for the four observed isotopologues, in some cases showing perturbations.

$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $
$\begin{array}{c c c c c c c c c c c c c c c c c c c $
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
$T''$ $R_{ms} (\mathrm{nm})$ $P_{ms} (\mathrm{nm}^{-1})$ $P_{ms} (\mathrm{cm}^{-1})$ $p_{ms} (\mathrm{cm}^{-1})$ $\delta p_{ms} (\mathrm{cm}^{-1})$ 1115.04305115.0535586920.04386912.31562115.01374115.0635586922.03486912.31563115.02496115.0685086923.03186991.31565115.01390115.068508693.614086901.06696115.01390115.0087086993.614086901.06697115.01390115.0087086993.614086901.01669115.01463115.0087086994.30186901.0364115.01290115.0087086994.31109114.99876115.1012586996.173786893.3339114114.99876115.1012586961.73786897.413011498716115.1012586961.73786876.070211498716115.1012586991.31586876.070211498716115.102586991.31586876.070211497266115.102586991.31586876.070211497264115.102586991.31586877.305211495866115.102586991.31586897.3423311497266115.102586993.853211149586114.956685993.853221149149115.102586993.853221149149<
$J''$ $R_{ms}$ (mm) $P_{ms}$ (mm)
$1^{2}C^{16}O$ $1^{2}C^{16}O$ $J''$ $R_{ms}$ (nm) $P_{ms}$ (nm) $R_{ms}$ (nm) $115.04826$ $115.03744$ $115.03742$ $86923.034$ $115.04305$ $115.03744$ $115.03742$ $86923.031$ $115.03774$ $115.03744$ $115.03744$ $115.03744$ $115.03744$ $115.03742$ $86936.140$ $115.03744$ $115.03724$ $115.03733$ $86936.140$ $115.01590$ $115.03723$ $86936.140$ $8944.314$ $115.01290$ $115.03723$ $86947.379$ $86947.379$ $115.01290$ $115.02565$ $86947.379$ $86977.379$ $114.99724$ $115.1025$ $86997.379$ $86977.379$ $114.97524$ $115.10256$ $869979.365$ $114.9752.41$ $114.97524$ $115.10256$ $869993.5249$ $114.97524$ $114.97524$ $115.12566$ $86993.5249$ $114.97524$ $87993.3221$ $114.97524$ $115.12566$ $86993.6621$ $114.97524$ $87993.3221$ $114.97524$ </td
$J''$ $R_{ms}$ (mm) $P_{ms}$ (mm) $J''$ $R_{ms}$ (mm) $P_{ms}$ (mm) $0$ 115.04826         115.034826 $1$ 115.04305         115.05849 $2$ 115.01374         115.06850 $4$ 115.02696         115.06850 $5$ 115.01240         115.06850 $115.01240$ 115.007323 $6$ 115.01240         115.008204 $115.01290$ 115.008765 $111$ 114.99304         115.002665 $111$ $114.99304$ $115.002665$ $114.99304$ $115.1020$ $114.99304$ $115.1020$ $114.99304$ $115.11428$ $114.95686$ $115.13459$ $114.956304$ $115.14226$ $114.956304$ $115.14226$ $114.956304$ $115.14226$ $114.9184$ $115.14226$ $114.9184$ $115.14226$ $114.9184$ $115.16709$ $114.9184$ $115.16709$ $114.9184$ $115.16709$
$\begin{array}{c c c c c c c c c c c c c c c c c c c $
22222222222222222222222222222222222222

( )
$\sim$
2
2
a
$\cap$
$\sim$
÷.
$\circ$
2
•
$\circ$
<u>ہ</u>
Ē.
Ú.
2
5
,0
-
P
5
õ
-
6
Ű,
11
2
E
+
M
71
$\sim$
T
ш
à
$\mathcal{Z}$
÷
M
5
~
ē
ί.
0
Ś
8
Š.
4
Ħ
_
_
Ĩ
/eni
avenı
vavent
wavent
id waveni
and waven
and wavenu
ns and wavenu
ths and wavenu
gths and wavenu
ingths and waven
lengths and waven
elengths and waven
ivelengths and waven
vavelengths and waven
wavelengths and wavenu
n wavelengths and waven
on wavelengths and waven
tion wavelengths and wavenu
sition wavelengths and waven
nsition wavelengths and waven
ansition wavelengths and wavenu
transition wavelengths and waven
d transition wavelengths and waven
ed transition wavelengths and waven
tred transition wavelengths and wavenu
sured transition wavelengths and waven
asured transition wavelengths and waven
easured transition wavelengths and wavenu
Measured transition wavelengths and waven
Measured transition wavelengths and waven
1. Measured transition wavelengths and waven
.1. Measured transition wavelengths and waven
A.1. Measured transition wavelengths and waven
e A.1. Measured transition wavelengths and waven
ole A.1. Measured transition wavelengths and waven
able A.1. Measured transition wavelengths and waven

Ö

**Notes.** Column description (refer also to Sect. 2.2) for each isotopologue. Col. 1: J''. Cols. 2 and 3:  $R_c$  and  $P_c$  calibrated wavelengths. Cols. 4 and 5:  $R_c$  and  $P_c$  calibrated wavenumbers. Col. 6:  $\delta_P$ wavenumber corrections applied to TV<sub>P</sub> in units of the least significant digit ( $-\delta_P$  is applied to TV<sub>R</sub>). No value indicates the absence of one of the branches, either R or P. An asterisk indicates when both R- and P-branches are present at high J', either the potential presence of a perturbing state or that one of the lines shows a larger uncertainty than the other

÷
4
e)
5
al
Γ
H
Ð
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
a
Ē
IC
·Ξ
Б
÷E
5
ŝ
Ę
2
8
H
p
5
ŏ
d)
ğ
H
š
$\smile$
0
~
7
$\tilde{c}$
=
-Ct
ă
a
<u> </u>
0
11
ົ້
33
1
ć
Q
16
<b>(</b> )
~
Ξ.
H
2
_
·2
ъ
ã
Ô
Ĩ.
."
5
"a)
$(n')^{+}$
$\Sigma^+(v''$
$\chi^1 \Sigma^+(v''$
$X^{1}\Sigma^{+}(v''$
$-X^{1}\Sigma^{+}(v''$
$0)-X^{1}\Sigma^{+}(v'')$
$= 0) - X^{1} \Sigma^{+} (v'')$
$' = 0 - X^{1} \Sigma^{+} (v'')$
$[v' = 0) - X^1 \Sigma^+ (v'')$
$(v' = 0) - X^1 \Sigma^+ (v'')$
$\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
${}^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
$B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''$
$B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
he $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
the $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
of the $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
of the $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
s of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
ars of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
bers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
nbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
imbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
numbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
enumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
(venumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
/avenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
1 wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
nd wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
and wavenumbers of the $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
s and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
hs and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
ths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v'')$
ngths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
engths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v')$
elengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
velengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v')$
avelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
1 wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
on wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
ion wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
ition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
isition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
ansition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
I transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
d transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
red transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
ured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
asured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
easured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
Aeasured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
Measured transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
<b>?.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
<b>.2.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'')$
<b>A.2.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
A.2. Measured transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=0)-X^1\Sigma^+(v'')$
<b>le A.2.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
<b>ble A.2.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$
<b>able A.2.</b> Measured transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'')$

	_		_	_					_								_								_								_		
		$\delta_P$		11	-	ε	6	4	0	4	9	S	L-	-	9-	ŝ	9	18	S	7	10	13	0	9	ς	4	S	-2	-2	9-	13				
		$P_{ms} (\mathrm{cm}^{-1})$		86913.894	86910.435	86907.036	86903.675	86900.360	86897.120	86893.903	86890.732	86887.614	86884.542	86881.537	86878.563	86875.642	86872.752	86869.929	86867.115	86864.391	86861.659	86859.049	86856.469	86853.919	86851.415	86848.963	86846.557	86844.181	86841.873	86839.604	86837.402	86835.162			
	<sup>13</sup> C <sup>18</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	86920.935	86924.501	86928.128	86931.809	86935.527	86939.298	86943.115	86946.978	86950.879	86954.826	86958.834	86962.872	86966.963	86971.086	86975.276	86979.482	86983.704	86988.047	86992.414	86996.780	87001.216	87005.674	87010.186	87014.744	87019.333	87023.967	87028.655	87033.344	87038.056	87042.889	87047.594		
		$P_{ms}$ (nm)		115.05640	115.06098	115.06548	115.06993	115.07432	115.07861	115.08287	115.08707	115.09120	115.09527	115.09925	115.10319	115.10706	115.11089	115.11463	115.11836	115.12197	115.12559	115.12905	115.13247	115.13585	115.13917	115.14242	115.14561	115.14876	115.15182	115.15483	115.15775	115.16072			
		$R_{ms}$ (nm)	115.04708	115.04236	115.03756	115.03269	115.02777	115.02278	115.01773	115.01262	115.00746	115.00224	114.99694	114.99160	114.98619	114.98074	114.97520	114.96964	114.96406	114.95832	114.95255	114.94678	114.94092	114.93503	114.92907	114.92305	114.91699	114.91087	114.90468	114.89849	114.89227	114.88589	114.87968		
		$\delta_P$		-80	6	72	0	-1	0	-2	-22	16	6	-22	-17	0	8	18	-68	7	54	-2	1	45	1	2									
		$P_{ms}  ({\rm cm}^{-1})$		86913.675	86910.072	86906.484	86903.048	86899.665	86896.350	86893.020	86889.879	86886.633	86883.470	86880.382	86877.363	86874.359	86871.409	86868.488	86865.606	86862.965	86860.082	86857.246	86854.711	86852.108	86849.529	86847.070	86844.543								
$-X^{1}\Sigma^{+}(v''=0)$	<sup>13</sup> C <sup>17</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	86920.648	86924.396	86928.242	86931.869	86935.708	86939.533	86943.539	86947.402	86951.462	86955.491	86959.567	86963.711	86967.932	86972.160	86976.426	86980.738	86985.127	86989.500	86993.965	86998.476	87003.085	87007.635	87012.200										
$B^1\Sigma^+(v'=0)$		$P_{ms}$ (nm)		115.05669	115.06146	115.06621	115.07076	115.07524	115.07963	115.08404	115.08820	115.09250	115.09669	115.10078	115.10478	115.10876	115.11267	115.11654	115.12036	115.12386	115.12768	115.13144	115.13480	115.13825	115.14167	115.14493	115.14828								
		$R_{ms}$ (nm)	115.04746	115.04250	115.03741	115.03261	115.02753	115.02247	115.01717	115.01206	115.00669	115.00136	114.99597	114.99049	114.98491	114.97932	114.97368	114.96798	114.96218	114.95640	114.95050	114.94454	114.93845	114.93244	114.92641										
		$\delta_P$		12	8	8	4	5	7	9	9	8	14	22	-25	55	6-	39	-41	9-	0	9-	11	19	-25	9-	24	-30	68	18	26	18	38	LL	
		$P_{ms} (\mathrm{cm}^{-1})$		86913.131	86909.498	86905.925	86902.421	86898.917	86895.474	86892.106	86888.807	86885.500	86882.269	86879.099	86875.929	86872.933	86869.824	86866.876	86863.908	86861.161	86858.257	86855.473	86852.742	86850.034	86847.372	86844.875	86842.266	86839.762	86837.432	86834.883	86832.613	86830.261	86827.969	86825.813	86823.589
	<sup>13</sup> C <sup>16</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	86920.550	86924.320	86928.166	86932.005	86935.912	86939.895	86943.939	86947.976	86952.089	86956.270	86960.452	86964.695	86969.074	86973.325	86977.773	86982.183	86986.663	86991.203	86995.759	87000.383	87005.031	87009.732	87014.441	87019.272	87024.104	87029.011	87033.897	87038.806	87043.738	87048.852	87053.929	87059.015	87064.177
		$P_{ms}$ (nm)		115.05741	115.06222	115.06695	115.07159	115.07623	115.08079	115.08525	115.08962	115.09400	115.09828	115.10248	115.10668	115.11065	115.11477	115.11868	115.12261	115.12625	115.13010	115.13379	115.13741	115.14100	115.14453	115.14784	115.15130	115.15462	115.15771	115.16109	115.16410	115.16722	115.17026	115.17312	115.17607
		$R_{ms}$ (nm)	115.04759	115.04260	115.03751	115.03243	115.02726	115.02199	115.01664	115.01130	115.00586	115.00033	114.99480	114.98919	114.98340	114.97778	114.97190	114.96607	114.96015	114.95415	114.94813	114.94202	114.93588	114.92967	114.92345	114.91707	114.91069	114.90421	114.89776	114.89128	114.88477	114.87802	114.87132	114.86461	114.85780
		J''	0	-	6	ε	4	5	9	7	~	6	10	Ξ	12	13	4	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32

<b>Table A.3.</b> Term values (cm <sup>-1</sup> ) of the $B^{1}\Sigma^{+}(v'=0)$ levels for six CO isotopologue	Table A.3. Term values	s (cm <sup>-1</sup> ) of the $B^1\Sigma^+(v')$	= 0) levels for six	CO isotopologues.
-----------------------------------------------------------------------------------------------------------------	------------------------	------------------------------------------------	---------------------	-------------------

			$B^1\Sigma^+$	v' = 0)		
J'	<sup>12</sup> C <sup>16</sup> O	$^{12}C^{17}O$	<sup>12</sup> C <sup>18</sup> O	<sup>13</sup> C <sup>16</sup> O	<sup>13</sup> C <sup>17</sup> O	<sup>13</sup> C <sup>18</sup> O
0	86916.160	86916.397	86916.748	86916.807	86917.254	86917.387
1	86920.036 (6)	86920.242 (-17)	86920.441 (10)	86920.538 (12)	86920.728 (-80)	86920.924 (11)
2	86927.828 (1)	86927.866 (-17)	86927.860 (16)	86927.988 (8)	86927.965 (9)	86927.993 (1)
3	86939.524 (9)	86939.261 (5)	86939.012 (26)	86939.186 (8)	86938.906 (72)	86938.604 (3)
4	86955.091 (9)	86954.456 (20)	86953.860 (3)	86954.056 (4)	86953.341 (0)	86952.756 (9)
5	86974.588 (0)	86973.474 (51)	86972.402 (14)	86972.664 (5)	86971.495 (-1)	86970.457 (-4)
6	86997.979 (6)	86996.185 (0)	86994.635 (-4)	86995.022 (7)	86993.210 (0)	86991.686 (0)
7	87025.233 (3)	87022.801 (9)	87020.633 (9)	87021.118 (6)	87018.686 (-2)	87016.452 (4)
8	87056.375 (4)	87053.147 (-5)	87050.312 (-15)	87050.879 (6)	87047.613 (-22)	87044.756 (6)
9	87091.422 (-12)	87087.316 (16)	87083.682 (-11)	87084.386 (8)	87080.255 (16)	87076.590 (5)
10	87130.365 (-8)	87125.255 (11)	87120.766 (-9)	87121.628 (14)	87116.492 (2)	87111.969 (-7)
11	87173.190 (2)	87167.015 (17)	87161.557 (-21)	87162.539 (22)	87156.359 (-22)	87150.879 (-1)
12	87219.893 (3)	87212.529 (-5)	87206.032 (-1)	87207.234 (-25)	87199.837 (-17)	87193.316 (-6)
13	87270.486 (9)	87261.933 (63)	87254.234 (20)	87255.606 (55)	87246.948 (0)	87239.278 (3)
14	87324.954 (-8)	87314.967 (-17)	87306.112 (10)	87307.659 (-9)	87297.646 (8)	87288.771 (-6)
15	87383.326 (-2)	87371.844 (-2)	87361.707 (2)	87363.461 (39)	87351.948 (18)	87341.782 (18)
16	87445.528 (1)	87432.507 (-1)	87420.944 (-1)	87423.016 (-41)	87409.956 (-68)	87398.324 (5)
17	87511.644 (-17)	87496.935 (6)	87483.946 (-23)	87486.183 (-6)	87471.444 (7)	87458.347 (7)
18	87581.619 (-7)	87565.139 (-9)	87550.575 (10)	87553.097 (2)	87536.506 (54)	87521.965 (10)
19	87655.461 (-10)	87637.152 (-23)	87620.923 (-4)	87623.698 (-6)	87605.321 (-2)	87589.082 (13)
20	87733.196 (9)	87712.873 (2)	87694.934 (-3)	87697.994 (11)	87677.680 (1)	87659.685 (2)
21	87814.750 (-8)	87792.393 (-5)	87772.643 (-3)	87775.973 (19)	87753.653 (45)	87733.811 (6)
22	87900.174 (-7)	87875.682 (-8)	87854.007 (0)	87857.707 (-25)	87833.204 (1)	87811.440 (-3)
23	87989.471 (3)	87962.700 (51)	87939.097 (-9)	87943.030 (-6)	87916.277 (2)	87892.581 (-4)
24	88082.606 (-3)	88053.582	88027.794 (-18)	88032.105 (24)		87977.219 (5)
25	88179.588 (-2)	88148.060	88120.189 (-9)	88124.904 (-30)		88065.363 (-2)
26	88280.407 (-6)	88246.337	88216.236 (16)	88221.263 (68)		88157.003 (-2)
27	88385.089 (2)	88348.346	88315.945 (-1)	88321.380 (18)		88252.153 (-6)
28	88493.603 (6)		88419.326 (1)	88425.092 (26)		88350.732 (13)
29	88605.938 (9)		88526.311 (18)	88532.467 (18)		88452.813
30	88722.072 (-1)		88636.981 (-10)	88643.620 (38)		88558.446
31	88842.065 (6)		88751.216 (99)	88758.333 (77)		88667.391
32	88965.864 (0)		88869.201	88876.784		
33	89093.476		88990.811	88998.843		
34	89224.889					
35	89360.095					
36	89499.139					
37	89641.888					

**Notes.** The  $\delta_P$  value in parentheses (in units of the least significant digit) corresponds to the wavenumber correction applied to  $TV_P$  and  $TV_R$ . There is no value when the term value is derived from a single transition, either *R* or *P*. An asterisk indicates when both *R*- and *P*-branches are present at high *J'*, either the potential presence of a perturbing state or that one of the lines shows a larger uncertainty than the other (see also Sect. 2.2.2).

**Table A.4.** Transition wavelengths and wavenumbers of the  $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ , and  ${}^{12}C^{18}O$  (same column description as for Table A.1).

-			F		_	_		_				_						_	_				_				_		_		_	_					-
		$\delta_P$		-17	0	-		S	4	- S	4	0	-5		0	ŝ	6-	24	0	-24	0	15	4	-12	-12	5	-8	-11	-13	5	-2						
		$P_{ms}  ({\rm cm}^{-1})$		88946.569	88942.939	88939.252	88935.609	88931.939	88928.281	88924.639	88920.982	88917.313	88913.669	88910.015	88906.360	88902.705	88899.035	88895.409	88891.714	88888.060	88884.462	88880.767	88877.101	88873.449	88869.811	88866.158	88862.453	88858.814	88855.135	88851.472	88847.753	88844.088					
	<sup>12</sup> C <sup>18</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	88953.892	88957.565	88961.238	88964.891	88968.564	88972.240	88975.886	88979.547	88983.209	88986.856		88994.166	88997.804	89001.453	89005.116	89008.710	89012.345	89015.982	89019.617	89023.214	89026.808	89030.416	89033.999	89037.580	89041.137	89044.704	89048.246	89051.787	89055.274		89062.303				
		$P_{ms}$ (nm)		112.42705	112.43163	112.43630	112.44090	112.44554	112.45017	112.45477	112.45940	112.46404	112.46865	112.47327	112.47789	112.48252	112.48716	112.49175	112.49643	112.50105	112.50560	112.51028	112.51492	112.51955	112.52415	112.52878	112.53347	112.53808	112.54274	112.54738	112.55209	112.55673					
		$R_{ms}$ (nm)	112.41779	112.41315	112.40851	112.40389	112.39925	112.39461	112.39000	112.38538	112.38075	112.37615		112.36692	112.36232	112.35772	112.35309	112.34856	112.34397	112.33938	112.33479	112.33025	112.32572	112.32116	112.31664	112.31213	112.30764	112.30314	112.29867	112.29421	112.28981		112.28095				
		$\delta_P$		12	-13	4	-5	6	4	21	7	ξ	η	5	-96	-41	-63	0	28	100	*	*	*	*	*	*											
		$P_{ms} (\mathrm{cm}^{-1})$		88969.244	88965.451	88961.774	88958.002	88954.249	88950.496	88946.726	88942.973	88939.259	88935.505	88931.794	88928.041	88924.274	88920.464	88916.751	88913.022	88909.310	88905.485	88901.793	8897.890	88894.129	88890.442	8886.540	88882.780										
(n = n) = 7 - (n = n)	<sup>12</sup> C <sup>17</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	88976.717	88980.487	88984.226	88987.965	88991.734	88995.443	88999.214	89002.959	89006.668	89010.440	89014.181	89017.688	89021.460	89025.172	89029.034	89032.839	89036.613	89040.502	89044.308	89048.141	89051.886	89055.692	89059.499												
I = 0, $Z = 0$		$P_{ms}$ (nm)		112.39839	112.40319	112.40783	112.41260	112.41734	112.42208	112.42685	112.43159	112.43629	112.44103	112.44573	112.45047	112.45523	112.46005	112.46475	112.46947	112.47416	112.47900	112.48367	112.48861	112.49337	112.49804	112.50297	112.50773										
		$R_{ms}$ (nm)	112.38895	112.38419	112.37947	112.37475	112.36999	112.36530	112.36054	112.35582	112.35113	112.34637	112.34165	112.33723	112.33246	112.32778	112.32291	112.31811	112.31335	112.30844	112.30364	112.29881	112.29409	112.28929	112.28449												
		$\delta_P$		-39	-36	- S	4	0	7	-16	19	-	6	-8	S	6-	8	-2	6-	- 14	6	41	16	-33	16	17	5	25	L-	20	4	6	- 19	-44	*		
		$P_{ms}  ({\rm cm}^{-1})$		88994.440	88990.621	88986.858	88982.983	88979.108	88975.232	88971.357	88967.538	88963.663	88959.843	88955.968	88952.149	88948.274	88944.399	88940.523	88936.704	88932.829	88928.954	88925.086	88921.147	88917.328	88913.509	88909.555	88905.646	88901.770	88897.839	88893.964	88890.032	88886.157	88882.158	88878.251	88874.289	88870.484	
	<sup>12</sup> C <sup>16</sup> O	$R_{ms}$ (cm <sup>-1</sup> )	89002.078	89006.010	89009.885	89013.704	89017.523	89021.342	89025.162	89029.037	89032.856	89036.675	89040.494	89044.313	89048.076	89051.895	89055.714	89059.477	89063.240	89067.059	89070.822	89074.585	89078.292	89082.055	89085.762	89089.469	89093.175	89096.826	89100.533	89104.183	89107.778	89111.372	89114.911	89118.505	89122.156	89125.526	100.42160
		$P_{ms}$ (nm)		112.36657	112.37139	112.37614	112.38104	112.38593	112.39083	112.39572	112.40055	112.40544	112.41027	112.41517	112.41999	112.42489	112.42979	112.43469	112.43952	112.44442	112.44932	112.45421	112.45919	112.46402	112.46885	112.47385	112.47880	112.48370	112.48867	112.49358	112.49855	112.50346	112.50852	112.51347	112.51848	112.52330	
		$R_{ms}$ (nm)	112.35693	112.35196	112.34707	112.34225	112.33743	112.33261	112.32779	112.32290	112.31809	112.31327	112.30845	112.30363	112.29889	112.29407	112.28926	112.28451	112.27977	112.27495	112.27021	112.26547	112.26080	112.25605	112.25138	112.24671	112.24204	112.23744	112.23277	112.22818	112.22365	112.21912	112.21467	112.21014	112.20554	112.20130	700/11711
		<i>J</i> ,,	0	1	0	m	4	S	9	2	8	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	5

A&A 614, A114 (2018)

÷
-
-i-
-
le
9
Б
- C
5
Ŧ
S
8
. <u> </u>
F.
÷E
5
S
ц,
ž
H
Ξ
1
0
S
e,
Ξ
a
S
õ
$\tilde{\mathcal{C}}$
15
C
13
.g
ar
0
5
7)
Š
Ξ
ć
$\mathcal{O}$
16
$\mathbf{O}$
3
Ξ.
5
£
q
L L
g
~
-
$\widehat{}$
(0=
(0=
o'' =0)
(v'' = 0)
$C^+(v''=0)$
$^{1}\Sigma^{+}(v^{\prime\prime}=0)$
$X^1\Sigma^+(v^{\prime\prime}=0)$
$-X^1\Sigma^+(v''=0)$
$1){-}X^1\Sigma^+(v^{\prime\prime}=0)$
= 1)– $X^1\Sigma^+(v''=0)$
$x = 1) - X^1 \Sigma^+ (v'' = 0)$
$v' = 1) - X^1 \Sigma^+ (v'' = 0)$
$^{+}(v' = 1) - X^{1} \Sigma^{+}(v'' = 0)$
$\Sigma^+(v'=1){-}X^1\Sigma^+(v''=0)$
$^{\mathrm{il}}\Sigma^{+}(v'=1){-}X^{\mathrm{l}}\Sigma^{+}(v''=0)$
$B^1\Sigma^+(v'=1){-}X^1\Sigma^+(v''=0)$
e $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
he $B^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=0)$
; of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=0)$
rs of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
bers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
nbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
unbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
numbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
sumbers of the $B^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
venumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
/avenumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
wavenumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
d wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
nd wavenumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=0)$
is and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
ths and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
gths and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
ing this and wavenumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
lengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
elengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
a velengths and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=0)$
vavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
on wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
ion wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
ition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
is ition wavelengths and wavenumbers of the $B^1\Sigma^+(\nu'=1)-X^1\Sigma^+(\nu'=0)$
ansition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
ransition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
Transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
<b>5.</b> Transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
5. Transition wavelengths and wavenumbers of the $B^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
<b>A.5.</b> Transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
e A.5. Transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
ble A.5. Transition wavelengths and wavenumbers of the $B^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
<b>able A.5.</b> Transition wavelengths and wavenumbers of the $B^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$

			_																																
		$\delta_P$		4-	47	4	9	4	-5	4	-S	-2	6	4	6	<del>.</del>	4	1	6	Π	4		З	0	0	1	4	С	0	9	9	-21	-45	-26	
		$P_{ms} (\mathrm{cm}^{-1})$		88901.262	88897.755	88894.190	88890.780	88887.293	88883.815	88880.345	88876.865	88873.407	88869.908	88866.432	88862.974	88859.508	88856.052	88852.576	88849.121	88845.655	88842.179	88838.754	88835.276	88831.822	88828.356	88824.905	88821.442	88817.981	88814.508	88811.056	88807.582	88804.129	88800.668	88797.245	88793.700
	<sup>13</sup> C <sup>18</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	88908.224	88911.748	88915.235	88918.736	88922.237	88925.731	88929.232	88932.750	88936.232	88939.751	88943.255	88946.766	88950.256	88953.752	88957.250	88960.754	88964.233	88967.723	88971.194	88974.684	88978.149	88981.624	88985.082	88988.542	88991.979	88995.424	88998.859	89002.272	89005.666	89009.072	89012.434	89015.745	
		$P_{ms}$ (nm)		112.48434	112.48878	112.49329	112.49761	112.50202	112.50642	112.51081	112.51522	112.51960	112.52403	112.52843	112.53281	112.53720	112.54158	112.54598	112.55035	112.55474	112.55915	112.56349	112.56790	112.57227	112.57666	112.58104	112.58543	112.58982	112.59422	112.59859	112.60300	112.60738	112.61177	112.61611	112.62060
		$R_{ms}$ (nm)	112.47553	112.47108	112.46667	112.46224	112.45781	112.45339	112.44896	112.44452	112.44011	112.43566	112.43124	112.42680	112.42239	112.41797	112.41355	112.40912	112.40472	112.40031	112.39593	112.39152	112.38714	112.38275	112.37839	112.37402	112.36968	112.36533	112.36099	112.35668	112.35240	112.34810	112.34386	112.33968	
		$\delta_P$		14	7	21	~	-10	-19	ς	0	6	4	0	23	9	-13	-10	4	-25	-75	-42		-16	-82										
		$P_{ms}  ({\rm cm}^{-1})$		88924.534	88920.988	88917.351	88913.731	88910.174	88906.648	88903.091	88899.498	88895.920	88892.353	88888.802	88885.244	88881.657	88878.094	88874.569	88870.989	88867.414	88863.923	88860.443	88856.779		88849.754	88846.247									
$-X^{1}\Sigma^{+}(v''=0)$	<sup>13</sup> C <sup>17</sup> O	$R_{ms}$ (cm <sup>-1</sup> )	88931.752	88935.259	88938.822	88942.395	88945.987	88949.566	88953.154	88956.732	88960.317	88963.898	88967.491	88971.089	88974.629	88978.199	88981.753	88985.332	88988.903	88992.439	88995.953	88999.520	89003.189	89006.647											
$B^{\mathrm{L}}\Sigma^{\mathrm{T}}(v'=1)$		$P_{ms}$ (nm)		112.45491	112.45939	112.46399	112.46857	112.47307	112.47753	112.48203	112.48657	112.49110	112.49562	112.50011	112.50461	112.50915	112.51366	112.51813	112.52266	112.52719	112.53161	112.53601	112.54065		112.54955	112.55399									
		$R_{ms}$ (nm)	112.44578	112.44134	112.43684	112.43232	112.42778	112.42326	112.41872	112.41420	112.40967	112.40515	112.40061	112.39606	112.39159	112.38708	112.38259	112.37807	112.37356	112.36910	112.36466	112.36016	112.35553	112.35116											
		$\delta_P$		0	1	1	8	9	4	- n	0	0	-5	ŝ	9	0	7	9	L-	-	9-	ς	S	-12	0	0	0	-16	7	31	-51				
		$P_{ms}  ({\rm cm}^{-1})$		88950.428	88946.745	88943.079	88939.408	88935.739	88932.044	88928.376	88924.670	88921.043	88917.372	88913.710	88910.028	88906.362	88902.694	88899.019	88895.363	88891.703	88888.012	88884.355	88880.676	88876.993	88873.325	88869.645	88865.954	88862.268	88858.615	88854.858	88851.165	88847.525			
	<sup>13</sup> C <sup>16</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	88957.775	88961.460	88965.140	88968.803	88972.484	88976.160	88979.784	88983.506	88987.179	88990.843	88994.512	88998.185	89001.833	89005.499	89009.138	89012.793	89016.428	89020.070	89023.699	89027.330	89030.942	89034.552	89038.146	89041.731	89045.313	89048.863	89052.475	89055.917	89059.467	89063.191			
		$P_{ms}$ (nm)		112.42217	112.42682	112.43146	112.43610	112.44074	112.44541	112.45005	112.45473	112.45932	112.46396	112.46859	112.47325	112.47789	112.48253	112.48718	112.49181	112.49644	112.50111	112.50574	112.51040	112.51506	112.51970	112.52436	112.52904	112.53370	112.53833	112.54309	112.54776	112.55238			
		$R_{ms}$ (nm)	112.41288	112.40823	112.40358	112.39895	112.39430	112.38966	112.38508	112.38038	112.37574	112.37111	112.36648	112.36184	112.35724	112.35261	112.34802	112.34340	112.33882	112.33422	112.32964	112.32506	112.32050	112.31595	112.31141	112.30689	112.30237	112.29790	112.29334	112.28900	112.28453	112.27983			
		J''	0	-	0	ε	4	S	9	7	×	6	10	Π	12	13	4	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32

Table A.6.	Ferm values	$(cm^{-1})$ of t	he $B^1\Sigma^+(v' =$	= 1) levels	for six	CO isotop	ologues.
------------	-------------	------------------	-----------------------	-------------	---------	-----------	----------

			$B^{1}\Sigma^{+}($	v' = 1)		
J'	$^{12}C^{16}O$	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	$^{13}C^{17}O$	<sup>13</sup> C <sup>18</sup> O
0	88998.285	88972.992	88950.231	88954.104	88928.113	88904.754
1	89002.117 (-39)	88976.706 (12)	88953.908 (-17)	88957.774 (2)	88931.738 (14)	88908.229 (-4)
2	89009.891 (-36)	88984.248 (-13)	88961.225 (2)	88965.135 (1)	88938.830 (7)	88915.193 (47)
3	89021.425 (-5)	88995.474 (-4)	88972.225 (-1)	88976.167 (1)	88949.538 (21)	88925.709 (4)
4	89036.776 (-2)	89010.457 (-5)	88986.863 (-1)	88990.866 (-8)	88963.859 (8)	88939.686 (6)
5	89055.970 (2)	89029.202 (9)	89005.177 (5)	89009.235 (6)	88981.783 (-10)	88957.159 (4)
6	89079.006 (7)	89051.653 (4)	89027.160 (4)	89031.290 (4)	89003.262 (-19)	88978.124 (-5)
7	89105.913 (-16)	89077.889 (21)	89052.781 (-3)	89056.972 (-3)	89028.303 (-3)	89002.576 (-4)
8	89136.660 (19)	89107.875 (7)	89082.060 (4)	89086.415 (0)	89056.922 (0)	89030.538 (-5)
9	89171.247 (-1)	89141.567 (-3)	89115.010 (0)	89119.482 (2)	89089.125 (2)	89061.950 (-2)
10	89209.644 (9)	89179.052 (-3)	89151.604 (-5)	89156.220 (-5)	89124.906 (-4)	89096.879 (9)
11	89251.906 (-8)	89220.242 (5)	89191.858	89196.619 (3)	89164.261 (0)	89135.295 (4)
12	89297.976 (5)	89265.046 (-96)	89235.759 (0)	89240.694 (6)	89207.174 (23)	89177.195 (9)
13	89347.851 (-9)	89313.698 (-41)	89283.299 (3)	89288.421 (0)	89253.640 (6)	89222.574 (-1)
14	89401.585 (8)	89366.104 (-63)	89334.517 (-9)	89339.818 (7)	89303.706 (-13)	89271.427 (4)
15	89459.177 (-2)	89422.310 (0)	89389.354 (24)	89394.872 (-6)	89357.303 (-10)	89323.772 (1)
16	89520.541 (-9)	89482.227 (28)	89447.823 (2)	89453.591 (-7)	89414.478 (4)	89379.593 (9)
17	89585.729 (-14)	89545.800 (100)	89509.985 (-24)	89515.943 (-1)	89475.252 (-25)	89438.872 (11)
18	89654.772 (9)	89613.225 (*)	89575.740 (2)	89581.971 (-6)	89539.574 (-75)	89501.656 (-4)
19	89727.571 (41)	89684.226 (*)	89645.149 (15)	89651.635 (-3)	89607.349 (-42)	89567.876 (-1)
20	89804.246 (16)	89759.033 (*)	89718.182 (4)	89724.947 (5)	89678.726	89637.588 (3)
21	89884.708 (-33)	89837.552 (*)	89794.854 (-12)	89801.906 (-2)	89753.817 (-16)	89710.749 (2)
22	89968.942 (16)	89919.709 (*)	89875.157 (-12)	89882.502 (0)	89832.299 (-82)	89787.386 (2)
23	90056.978 (17)	90005.651 (*)	89959.050 (5)	89966.726 (2)		89867.472 (1)
24	90148.835 (5)		90046.599 (-8)	90054.588 (0)		89951.018 (4)
25	90244.465 (25)		90137.739 (-11)	90146.100 (-16)		90038.004 (3)
26	90343.893 (-7)		90232.510 (-13)	90241.177 (7)		90128.457 (0)
27	90447.113 (20)		90330.857 (5)	90339.945 (31)		90222.345 (6)
28	90554.124 (-4)		90432.841 (-2)	90442.280 (-51)		90319.679 (-6)
29	90664.829 (9)		90538.373	90548.215		90420.444 (-21)
30	90779.363 (-19)			90657.996		90524.674 (-45)
31	90897.617 (-44)		90760.318			90632.256 (-26)
32	91019.750 (114)					90743.218
33	91145.527					
34	91274.905					
35	91408.240					

**Notes.** See note to Table A.3.

						$B^{1}\Sigma^{+}(v'=2)-X^{1}\Sigma^{+}(v''=0)$						
			<sup>12</sup> C <sup>16</sup> O			12C <sup>17</sup> 0				<sup>12</sup> C <sup>18</sup> O		
J''	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} \ (\mathrm{cm}^{-1})$	$P_{ms}  ({\rm cm}^{-1})$	$\delta_P$	$R_{ms}$ (nm) $P_{ms}$ (nm) $R_{ms}$ (cm <sup>-1</sup> ) $P_{ms}$ (cr	$n^{-1}$ ) $\delta_P$	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} (\mathrm{cm}^{-1})$	$P_{ms} (\mathrm{cm}^{-1})$	$\delta_P$
0 -	109.89971	100 00002	90992.051 00005 610	00064 416	26			110.00738	110 01622	90902.992 00006 380	00005 600	30
- 0	1109.891	109.91378	90999.172	90980.403	6 42			1109.99911	110.02077	90909.826	90891.929	29
ŝ	109.88689	109.91868	91002.666	90976.347	17			109.99518	110.02550	90913.075	90888.021	2
4	109.88291	109.92366	91005.963	90972.226	22			109.99130	110.03015	90916.282	90884.180	31
Ś	109.87893	109.92874	91009.259	90968.022	-34			109.98750	110.03514	90919.423	90880.059	14
9	109.87509	109.93391	91012.440	90963.744	0			109.98375	110.04008	90922.523	90875.979	0
2	109.87134	109.93930	91015.546	90959.284	26			109.98016	110.04511	90925.491	90871.825	28
~	109.86773	109.94480	91018.537	90954.734	5			109.97668	110.05028	90928.368	90867.556	42
6	109.86416	109.95028	91021.494	90950.200	-10			109.97346	110.05558	90931.030	90863.180	-13
10	109.86082	109.95591	91024.261	90945.544	33			109.96986	110.06082	90934.007	90858.854	-63
= 9	109.85751	109.96172	91027.004	90940.738	-75			109.96646	110.06633	90936.818	90854.306	46
12		109.96/39		90936.049	-41			109.90340	110.0/184	909.59.299	801.64806	۰. ۱
т 1		109.97343		90931.055				109.96039	110.07739	90941.838	90845.177 00830 870	*
± 4									10000.011		610.60006	
с ;		10686.601		90921.431								
01		100.0900001		569.01606								
-		07066.601	21 01	C01.21606						91 01		
			1 <sup>5</sup> C <sup>10</sup> O			<sup>13</sup> C <sup>17</sup> O				13C18O		
J''	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms}  ({\rm cm}^{-1})$	$P_{ms}  ({\rm cm}^{-1})$	$\delta_P$	$R_{ms}R_{ms}(\operatorname{nm})  P_{ms}(\operatorname{nm})  R_{ms}(\operatorname{cm}^{-1})  P_{ms}(\operatorname{cr}^{-1})$	$n^{-1}$ ) $\delta_P$	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} (cm^{-1})$	$P_{ms}  ({\rm cm}^{-1})$	$\delta_P$
0%	109.99898		90909.934					110.10911		90819.007		
-	109.99477	110.00782	90913.413	90902.629	19			110.10544	110.11722	90822.034	90812.318	-15
0	109.99069	110.01237	90916.786	90898.869	6-			110.10190	110.12178	90824.954	90808.558	0
ŝ	109.98662	110.01699	90920.150	90895.052	-32			110.09829	110.12662	90827.932	90804.567	-39
4	109.98274	110.02175	90923.358	90891.119	0			110.09475	110.13145	90830.853	90800.584	11
Ś	109.97887	110.02665	90926.557	90887.071	7			110.09121	110.13643	90833.773	90796.479	0
9	109.97513	110.03168	90929.649	90882.917	10			110.08767	110.14133	90836.694	90792.439	L-
2	109.97160	110.03671	90932.568	90878.762	18			110.08427	110.14624	90839.500	90788.392	12
~	109.96807	110.04188	90935.487	90874.493	9-			110.08086	110.15121	90842.314	90784.296	0
6	109.96460	110.04718	90938.357	90870.116	-53			110.07753	110.15625	90845.062	90780.142	7
10	109.96121	110.05242	90941.160	90865.789	-13			110.07426	110.16130	90847.760	90775.980	- S
Ξ	109.95794	110.05793	90943.865	90861.240	- V			110.07106	110.16641	90850.402	90771.770	L-
12	109.95471	110.06344	90946.536	90856.691	4			110.06807	110.17159	90852.870	90767.502	21
13	109.95157	110.06907	90949.133	90852.046	30			110.06501	110.17691	90855.395	90763.119	-37
14	109.94868	110.07477	90951.524	90847.337	6-			110.06230	110.18223	90857.632	90758.737	-10
15	109.94531	110.08041	90954.312	90842.685	-11			110.05929	110.18768	90860.117	90754.248	*
16		110.08638		90837.758	-29			110.05610	110.19314	90862.751	90749.751	-84
17	109.93942	110.09183	90959.185	90833.264				110.05283	110.19866	90865.451	90745.205	59
18		110.09781		90828.328				110.04901	110.20425	90868.605	90740.602	*
19								110.04562	110.20978	90871.404	90736.049	*
20								110.04167	110.21522	90874.666	90731.570	*
21								110.03767	110.22149	90877.969	90726.409	

**Table A.7.** Transition wavelengths and wavenumbers of the  $B^1\Sigma^+(v'=2)-X^1\Sigma^+(v'=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{16}O$ , and  ${}^{13}C^{18}O$  (same column description as for Table A.1).

			$B^1\Sigma^+$	v'=2)		
J'	$^{12}C^{16}O$	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	$^{13}C^{17}O$	<sup>13</sup> C <sup>18</sup> O
0	90988.263		90899.350	90906.304		90815.811
1	90991.994 (56)		90902.953 (39)	90909.915 (19)		90819.021 (-15)
2	90999.441 (24)		90910.021 (29)	90917.098 (-9)		90825.525 (2)
3	91010.690 (17)		90920.805 (7)	90927.845 (-32)		90835.471 (-39)
4	91025.714 (22)		90935.014 (31)	90942.205 (0)		90848.877 (11)
5	91044.445 (-34)		90952.885 (14)	90960.108 (7)		90865.779 (0)
6	91066.928 (2)		90974.345 (2)	90981.681 (10)		90886.168 (-7)
7	91093.150 (26)		90999.386 (28)	91006.816 (18)		90910.023 (12)
8	91123.183 (5)		91027.966 (42)	91035.483 (-6)		90937.280 (2)
9	91156.937 (-10)		91060.182 (-13)	91067.845 (-53)		90968.026 (2)
10	91194.439 (33)		91095.836 (-63)	91103.742 (-13)		91002.203 (-5)
11	91235.740 (-75)		91135.302 (46)	91143.274 (-5)		91039.811 (-7)
12	91280.712 (-41)		91178.322 (90)	91186.375 (4)		91080.819 (21)
13			91224.469 (*)	91233.094 (30)		91125.223 (-37)
14	91382.486		91274.893	91283.468 (-9)		91173.085 (-10)
15	91439.170			91337.262 (-11)		91224.278 (122)
16	91499.886			91395.131 (-29)		91279.049 (-84)
17				91456.260		91337.342 (59)
18				91521.080		91399.167 (*)
19						91464.729 (*)
20						91533.242 (*)
21						91607.267
22						91683.733

<b>Table A.8.</b> Term values (cm <sup>-1</sup> ) of the $B^{1}\Sigma^{+}(v'=2)$ levels for ${}^{12}C^{1}$	<sup>6</sup> O, <sup>12</sup> C <sup>18</sup> O	$^{13}C^{16}O$ ,	and ${}^{13}C{}^{18}O.$
------------------------------------------------------------------------------------------------------------	-------------------------------------------------	------------------	-------------------------

Notes. See note to Table A.3.

J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range



**Fig. A.4.** Transition wavelengths of the  $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$  band for six CO isotopologues.



**Fig. A.5.** Transition wavelengths of the  $C^{1}\Sigma^{+}(v'=1)-X^{1}\Sigma^{+}(v''=0)$  band for six CO isotopologues.



**Fig. A.6.** Reduced term values  $(cm^{-1})$  of the  $C^{1}\Sigma^{+}(v'=0)$  levels for six CO isotopologues.



**Fig. A.7.** Reduced term values  $(cm^{-1})$  of the  $C^{1}\Sigma^{+}(v'=1)$  levels for six CO isotopologues.





**Fig. A.8.** Transition wavelengths of the  $C^1\Sigma^+(v'=2)-X^1\Sigma^+(v''=0)$  band for the four observed CO isotopologues.



**Fig. A.9.** Reduced term values  $(cm^{-1})$  of the  $C^{1}\Sigma^{+}(v'=2)$  levels for the four observed CO isotopologues.



**Fig. A.10.** Transition wavelengths of the  $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$  band for the four observed CO isotopologues.



**Fig. A.11.** Reduced term values  $(cm^{-1})$  of the  $C^1\Sigma^+(v'=3)$  levels for the five observed CO isotopologues.

$\square$
1
<
e
p
Б
- L
.5
4
as
2
5
÷Ē
Ъ.
Ξ.
S
<u>e</u>
.0
E
H
<u>–</u>
0
0
e
Ħ
Sa
5
0
18
Č)
2
_
Ъ
ar
_
0
5
ັນ
5
Ö
°,
7)
$\sum_{n=1}^{\infty}$
2
Ŀ
Ę
q
ġ
23
_
6
(0=
() = ()
v'' = 0
$^{+}(v'' = 0)$
$\Sigma^+(v^{\prime\prime}=0)$
$\ell^1\Sigma^+(v^{\prime\prime}=0)$
$-X^1\Sigma^+(v^{\prime\prime}=0)$
$)-X^{1}\Sigma^{+}(v''=0)$
$: 0) - X^1 \Sigma^+ (v'' = 0)$
$= 0) - X^1 \Sigma^+ (v'' = 0)$
$v' = 0) - X^1 \Sigma^+ (v'' = 0)$
$^{+}(v' = 0) - X^{1}\Sigma^{+}(v'' = 0)$
$\Sigma^{+}(v'=0){-}X^{1}\Sigma^{+}(v''=0)$
$\sum^{1} \Sigma^{+}(v' = 0) - X^{1} \Sigma^{+}(v'' = 0)$
$C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
ie $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
f the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v' = 0)$
of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v' = 0)$
s of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v' = 0)$
ers of the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
there of the $C^{1} \Sigma^{+} (v' = 0) - X^{1} \Sigma^{+} (v'' = 0)$
mbers of the $C^1 \Sigma^+(v'=0) - X^1 \Sigma^+(v''=0)$
numbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
enumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
we numbers of the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
vavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v' = 0)$
nd wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v' = 0)$
s and wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
hs and wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
gths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
angths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
lengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'=0)$
velengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v' = 0)$
avelengths and wavenumbers of the $C^1\Sigma^+(\nu'=0)-X^1\Sigma^+(\nu'=0)$
wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
n wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v'=0)$
on wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
tion wavelengths and wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v' = 0)$
sition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v' = 0)$
insition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v' = 0)$
ransition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'' = 0)$
<b>9.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v'' = 0)$
<b>1.9.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v'' = 0)$
A.9. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
<b>4e A.9.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v'' = 0)$
<b>ble A.9.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
<b>Table A.9.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 0)-X^{1}\Sigma^{+}(v'' = 0)$

		$m^{-1}$ $\delta_P$		5.189 -16	.593 0	.980 –6	1.463 –2	1.960 1	7.496 0	.089 3	0.714 -11	7.395 6	1- 1601	.852 –1	7.644 2	.479 0	.362 –8	309 3	.244 –1	2.266 5	).315 -5	5.413 -3	1.542 -8	).744 –6	7.963 2	3.224 -8	.538 9	.871 6	7.270 0	1.712 6	2.192 –6	0.735 -5		/309 -5	.309 -5 .908 4	.309 -5 -5 -5 -5 -5 -5 -5 -5 -5 -5 -5 -5 -5				
		$m^{-1}$ ) $P_{ms}$ (6	.547	.288 9191:	.082 9191	.910 9190	.773 9190-	.681 91900	.629 9189	599 9189-	.642 91890	701 9188	.799 9188-	.944 9188(	.125 9187	.353 9187-	.605 9187	.909 91868	.255 9186	.613 91862	.023 9185	.485 9185	.972 9185	.510 91850	.058 9184	.672 9184:	.306 91842	970 9183	.690 9183	.428 91834	.216 9183.	.018 9182	.910 9182		.804 9182	.804 9182⁄ .720 9182′	.804 91824 .720 91822 .671 91829	.804 9182 <sup>2</sup> .720 91822 .671 91820 .678 91818		.804 91822 .720 91822 .671 91820 .678 91812 .772 91812 .772 91812
		1) $R_{ms}$ (cr.	91922.	95 91926.	20 91930.	48 91933.	54 91937.	79 91941.	39 91945.	33 91949.	32 91953.	35 91957.	77 91961.	50 91965.	40 91970.	15 91974	35 91978.	46 91982.	.01 91987.	53 91991.	12 91996.	56 92000.	36 92004.	28 92009.	58 92014.	82 92018.	01 92023.	17 92027.	25 92032.	29 92037.	27 92042.	19 92047.	37 92051.	31 92056	11 10000	67 92061.	57 92061. 39 92066.	57 92061. 39 92066. 37 92071.	57         92061.0           39         92066.0           37         92071.0           37         92071.0	57         92061.           39         92066.           77         92071.           57         92071.           57         92071.
		$P_{ms}$ (nn	_	108.795	2 108.800	108.804	2 108.8080	108.8127	3 108.8168	3 108.820	5 108.8249	5 108.828	108.832	108.836	5 108.840	5 108.844	1 108.8478	5 108.851	108.855	5 108.8580	5 108.862	3 108.865	3 108.8689	2 108.8723	5 108.8755	108.878	2 108.8820	2 108.885	4 108.888	108.8912	108.894	108.897	5 108.900	3 108.902		3 108.905	3 108.905 1 108.908	8 108.9056 1 108.9080 108.9110	8 108.9056 1 108.9087 1 108.9087 1 108.9110 1 108.9136	8 108.9056 108.9083 108.9083 108.9136 108.9136 108.9136
		$R_{ms}$ (nm)	108.7872	108.7828	108.7783	108.77379	108.7692	108.7646	108.75993	108.7552	108.7504	108.7456	108.7408	108.73590	108.73090	108.7259	108.7209	108.7158	108.7107	108.7055	108.7003	108.6950	108.6897	108.6844	108.6790	108.6736	108.6681	108.6626	108.6570	108.6514	108.6458	108.6401	108.6343	108.6285		108.6227	108.6227	108.6227 108.6169 108.6110	108.62273 108.61692 108.61103 108.60503	108.6227 108.61694 108.61103 108.60509 108.59913
		$\delta_P$		-52	-58	36	-76	-20	-13	-2	Э	7	-12	-11	-8	-10	-12	-8	ŝ	9-	Э	7	-	2	-5	-2	-4	5	Π	-43	8	7	-81	-44		-22	-22 99	-22 99 -96	-22 99 -96	-22 99 -96
		$P_{ms} (cm^{-1})$		91915.191	91911.542	91907.920	91904.114	91900.721	91897.084	91893.581	91890.114	91886.678	91883.316	91879.999	91876.729	91873.477	91870.267	91867.137	91864.033	91860.944	91857.931	91854.934	91851.998	91849.105	91846.243	91843.442	91840.671	91837.960	91835.280	91832.630	91830.151	91827.518	91825.006	91822.732		91820.244	91820.244 91817.820	91820.244 91817.820 91815.413	91820.244 91817.820 91815.413 91813.231	91820.244 91817.820 91815.413 91813.231
$0 = (n) \cdot 7 \cdot X - (n)$	12C1/O	$R_{ms} \ ({\rm cm}^{-1})$	91922.681	91926.542	91930.420	91934.295	91938.264	91942.265	91946.310	91950.370	91954.490	91958.627	91962.839	91967.067	91971.326	91975.661	91980.030	91984.421	91988.847	91993.318	91997.836	92002.367	92006.945	92011.558	92016.215	92020.915	92025.663	92030.427	92035.234	92040.089	92044.945	92049.875	92054.823	92059.796		92064.974	92064.974 92069.738	92064.974 92069.738	92064.974 92069.738	92064.974 92069.738
$C_{-}Z_{-}(v = 0)$		$P_{ms}$ (nm)		108.79594	108.80026	108.80455	108.80906	108.81307	108.81738	108.82153	108.82563	108.82970	108.83369	108.83761	108.84149	108.84534	108.84914	108.85285	108.85653	108.86019	108.86376	108.86731	108.87079	108.87422	108.87762	108.88094	108.88422	108.88744	108.89061	108.89376	108.89670	108.89982	108.90280	108.90549		108.90844	108.90844 108.91132	108.90844 108.91132 108.91418	108.90844 108.91132 108.91418 108.91676	108.90844 108.91132 108.91418 108.91676
		$R_{ms}$ (nm)	108.78708	108.78251	108.77792	108.77334	108.76864	108.76391	108.75912	108.75432	108.74945	108.74455	108.73957	108.73458	108.72954	108.72442	108.71925	108.71406	108.70883	108.70355	108.69821	108.69286	108.68745	108.68200	108.67650	108.67095	108.66534	108.65972	108.65404	108.64831	108.64258	108.63676	108.63092	108.62505	100 /1001	108.01894	108.61332	108.61332	108.61332	108.61332
		$\delta_P$		-5	-10	23	- 14	17	-15	17	-17	-11	4	0	-27	-19	-6	4	19	2	23	17	5		0	-31	6	-18	-4	48	-18	-18	37	62		43 5	4 7 7 7	43 47 66	44 47 66 74 74 75	43 66 51 51
		$P_{ms} (\mathrm{cm}^{-1})$		91915.182	91911.406	91907.638	91903.863	91900.222	91896.582	91893.010	91889.439	91885.935	91882.498	91879.054	91875.686	91872.385	91869.085	91865.845	91862.612	91859.448	91856.343	91853.246	91850.209	91847.248	91844.346	91841.453	91838.619	91835.785	91833.027	91830.329	91827.563	91825.033	91822.457	91819.920	1010	91817.421	91817.421 91814.992	91817.421 91814.992 91812.600	91817.421 91814.992 91812.600 91810.205	91817.421 91814.992 91812.600 91810.205 91807.922
21 01	12C10O	$R_{ms} (\mathrm{cm}^{-1})$	91922.930	91926.842	91930.823	91934.795	91938.903	91942.952	91947.128	91951.237	91955.490	91959.735	91964.048	91968.362	91972.743	91977.184	91981.634	91986.153	91990.671	91995.250	91999.837	92004.484	92009.199	92013.923	92018.639	92023.491	92028.276	92033.197	92038.118	92043.032	92048.022	92053.155	92058.253	92063.327		92068.473	92068.473 92073.638	92068.473 92073.638 92078.827	92008.473 92073.638 92078.827 92084.091	92068.473 92073.638 92078.827 92084.091 92089.363
		$P_{ms}$ (nm)		108.79595	108.80042	108.80488	108.80935	108.81366	108.81797	108.82220	108.82643	108.83058	108.83465	108.83873	108.84272	108.84663	108.85054	108.85438	108.85821	108.86196	108.86564	108.86931	108.87291	108.87642	108.87986	108.88329	108.88665	108.89001	108.89328	108.89648	108.89976	108.90276	108.90582	108.90883	100 01170	6/116.001	108.91467	108.91467 108.91467 108.91751	108.91179 108.91467 108.91751 108.92035	108.92306 108.9235 108.9235 108.9236
		$R_{ms}$ (nm)	108.78678	108.78215	108.77744	108.77274	108.76788	108.76309	108.75815	108.75329	108.74826	108.74324	108.73814	108.73304	108.72786	108.72261	108.71735	108.71201	108.70667	108.70126	108.69584	108.69035	108.68478	108.67920	108.67363	108.66790	108.66225	108.65644	108.65063	108.64483	108.63894	108.63289	108.62687	108.62088	108 61/81	10110.001	108.60872	108.60872 108.60260	108.60872 108.60260 108.59639	108.60872 108.60260 108.59639 108.59017
		J''	0	-	6	m	4	S	9	7	~	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	5	33	8 8	33 35 4 23 33	35 <del>2</del> 33 36 35 33 36 35 4

Ċ
÷.
$\mathbf{A}$
0
μ
ab
Ĥ
H
fc
S
а
E
·H
pl
Ξ.
S
ĕ
q
E
н
h
0
0
B
9
SS
$\tilde{}$
0
18
Ú
13
ŭ
aı
ć
$\sim$
Ę.
$\mathcal{O}$
13
ć
$\mathcal{O}$
16
$\mathcal{O}$
13
÷
Ð.
ă
0a
4
Ô
0
() = ()
(v'' = 0)
$(v'' = 0)^+$
$\Sigma^+(v''=0)$
$Y^1\Sigma^+(v''=0)$
$-X^1\Sigma^+(v''=0)$
$))-X^{1}\Sigma^{+}(v''=0)$
$= 0) - X^{1} \Sigma^{+} (v'' = 0)$
$( = 0) - X^{1} \Sigma^{+} (v'' = 0)$
$(v' = 0) - X^1 \Sigma^+ (v'' = 0)$
$^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
$\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
$C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
$C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
ie $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
: of the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
rs of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'' = 0)$
bers of the $C^{1}\Sigma^{+}(v' = 0) - X^{1}\Sigma^{+}(v'' = 0)$
nbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
imbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
numbers of the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
enumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
avenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
1 wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
nd wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
is and wavenumbers of the $C^1 \Sigma^+ (v' = 0) - X^1 \Sigma^+ (v'' = 0)$
ths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
ngths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
engths and wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
slengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
welengths and wavenumbers of the $C^1 \Sigma^+(v' = 0) - X^1 \Sigma^+(v'' = 0)$
vavelengths and wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
in wavelengths and wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
ion wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
ition wavelengths and wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
nsition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
ansition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
Transition wavelengths and wavenumbers of the $C^1\Sigma^+(v'=0)-X^1\Sigma^+(v''=0)$
. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
10. Transition wavelengths and wavenumbers of the $C^1 \Sigma^+(v'=0) - X^1 \Sigma^+(v''=0)$
<b>10.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
<b>A.10.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
e A.10. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$
<b>ble A.10.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=0)-X^{1}\Sigma^{+}(v''=0)$

_	_	_																																									
		$\delta_P$	ç	n o	ν η	-5	L-	13	4	ξ	-12	10	-11	- S	9-	ī	9	-12	1	L-	٢	-4	9	- 4	0	9-	4	0	0	- S	-12	4	-	4	41		4	6	∞ (	10	0 LC_	1 *	
		$P_{ms} (\mathrm{cm}^{-1})$	01015 201	100.01616	91908.426	91905.072	91901.736	91898.442	91895.182	91891.982	91888.832	91885.691	91882.593	91879.554	91876.549	91873.594	91870.665	91867.804	91864.952	91862.158	91859.407	91856.682	91854.016	91851.375	91848.802	91846.265	91843.757	91841.320	91838.900	91836.513	91834.194	91831.919	91829.634	91827.425	91825.285	91823.178	91821.081	91819.065	91817.068	811.CI816	91813.234 01811 361	91809.568	91806.803
	<sup>13</sup> C <sup>18</sup> O	$R_{ms}$ (cm <sup>-1</sup> )	91922.332	91929.514	91933.157	91936.842	91940.604	91944.365	91948.178	91952.017	91955.915	91959.804	91963.779	91967.788	91971.831	91975.918	91980.029	91984.191	91988.371	91992.616	91996.865	92001.176	92005.510	92009.903	92014.297	92018.776	92023.267	92027.778	92032.340	92036.935	92041.558	92046.214	92050.924	92055.671	92060.442	92065.241	92070.086	92074.967	92079.883	00000 22 00000	708 10000	02000 830	92099.703 02100 574
		$P_{ms}$ (nm)	105 70501	1066/.001	108.80395	108.80792	108.81187	108.81577	108.81963	108.82342	108.82715	108.83087	108.83454	108.83814	108.84170	108.84520	108.84867	108.85206	108.85544	108.85875	108.86201	108.86524	108.86840	108.87153	108.87458	108.87759	108.88056	108.88345	108.88632	108.88915	108.89190	108.89460	108.89731	108.89993	108.90247	108.90496	108.90745	108.90984	108.91221	2010 901	108.910/0	108 92111	108.92439
		$R_{ms}$ (nm)	108.78749	106.77899	108.77468	108.77032	108.76587	108.76142	108.75691	108.75237	108.74776	108.74316	108.73846	108.73372	108.72894	108.72411	108.71925	108.71433	108.70939	108.70438	108.69936	108.69426	108.68914	108.68395	108.67876	108.67347	108.66817	108.66284	108.65746	108.65203	108.64657	108.64108	108.63552	108.62992	108.62429	108.61863	108.61291	108.60715	108.60135	CCC6C.001	1/680.001	108 57783	108.57798
		$\delta_P$	ć	07- 07-	<sup>1</sup> η	26	69	4	4	33	-12	-10	-29	-12	ŝ	m	-2	1	ŝ	-2	9-	-5	10	7	-	9-	6	-8	-28	11	6-	-12	_	39	27		50	1	m				
		$P_{ms}  (\mathrm{cm}^{-1})$	01015 202	105.01616 1911 786	91908.347	91904.798	91901.356	91897.889	91894.639	91891.401	91888.099	91884.980	91881.814	91878.722	91875.596	91872.517	91869.542	91866.574	91863.684	91860.794	91857.967	91855.184	91852.428	91849.707	91847.057	91844.449	91841.879	91839.346	91836.866	91834.463	91832.017	91829.656	91827.337	91825.077	91822.860	91820.676		91816.326	91814.361	160.21016			
$-X^{-}\Sigma^{-}(v''=0)$	<sup>13</sup> C <sup>17</sup> O	$R_{ms}$ (cm <sup>-1</sup> )	91922.475	91920.164 91929 841	91933.613	91937.386	91941.240	91945.073	91948.978	91952.917	91956.900	91960.911	91964.959	91969.045	91973.203	91977.349	91981.595	91985.830	91990.109	91994.430	91998.782	92003.193	92007.634	92012.105	92016.604	92021.164	92025.736	92030.358	92035.049	92039.699	92044.437	92049.219	92054.105	92058.917	92063.747	92068.583	92073.551	92078.579	92083.214	72000.011			
$C^{-}\Sigma^{-}(v'=0)$		P <sub>ms</sub> (nm)	10202 001	1066/ 201	108.80405	108.80825	108.81232	108.81643	108.82028	108.82411	108.82802	108.83171	108.83547	108.83913	108.84283	108.84648	108.85000	108.85352	108.85694	108.86037	108.86372	108.86702	108.87028	108.87351	108.87665	108.87974	108.88279	108.88579	108.88873	108.89158	108.89448	108.89728	108.90003	108.90271	108.90534	108.90/93		108.91309	108.91542	C//16.001			
		$R_{ms}$ (nm)	108.78732	108.77861	108.77414	108.76968	108.76512	108.76059	108.75597	108.75131	108.74660	108.74185	108.73707	108.73224	108.72732	108.72242	108.71740	108.71240	108.70734	108.70223	108.69709	108.69188	108.68663	108.68135	108.67604	108.67065	108.66525	108.65980	108.65426	108.64877	108.64318	108.63753	108.63177	108.62609	108.62039	108.61468	108.60882	108.60289	108.59743	0/160.001			
		$\delta_P$	ç	1 1	-1	0	16	9	6	-35	-1	0	-14	1	L-	-22	24	ε	-11	9	ŝ	-1	-11	8-	7	13	ε	22	×	S	6	e	4	ή	∞ ;	Ξ	13	-29	-16				
		$P_{ms} (\mathrm{cm}^{-1})$	01015 200	065.01616 217 11919	91908.138	91904.602	91901.075	91897.609	91894.186	91890.817	91887.500	91884.153	91880.913	91877.680	91874.506	91871.365	91868.311	91865.222	91862.243	91859.293	91856.366	91853.484	91850.661	91847.891	91845.142	91842.425	91839.763	91837.133	91834.547	91832.025	91829.547	91827.113	91824.715	91822.364	91820.064	91817.793	91815.573	91813.387	91811.339	91809.219			
	<sup>13</sup> C <sup>16</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	91922.763	91920.340 91930 317	91934.154	91938.068	91941.973	91945.955	91949.893	91953.956	91958.056	91962.130	91966.319	91970.491	91974.733	91979.057	91983.354	91987.688	91992.080	91996.504	92000.988	92005.489	92010.033	92014.628	92019.251	92023.871	92028.583	92033.286	92038.051	92042.851	92047.685	92052.558	92057.459	92062.416	92067.399	92072.405	92077.453	92082.526	92087.637	970000000	0/0.86026		
		$P_{ms}$ (nm)	100 70570	108 80006	108.80429	108.80848	108.81266	108.81676	108.82081	108.82480	108.82873	108.83269	108.83653	108.84036	108.84412	108.84784	108.85146	108.85512	108.85865	108.86215	108.86562	108.86903	108.87238	108.87566	108.87892	108.88214	108.88530	108.88842	108.89148	108.89447	108.89741	108.90030	108.90314	108.90593	108.90866	08.91135	108.91399	108.91658	108.91901	20126.001			
		$R_{ms}$ (nm)	108.78698	108/7801	108.77350	108.76887	108.76425	108.75954	108.75488	108.75008	108.74523	108.74041	108.73546	108.73053	108.72551	108.72040	108.71532	108.71020	108.70501	108.69978	108.69448	108.68917	108.68380	108.67837	108.67291	108.66746	108.66189	108.65634	108.65071	108.64505	108.63934	108.63359	108.62781	108.62196	108.61608	1019.801	108.60422	108.59824	108.59221	C108C.801	066/0.001		
		J''	0 -	- ~	1 ლ	4	Ś	9	2	~	6	10	11	12	13	4	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	333	34	35	36	37	000	607	94	64 6

<b>Table A.11.</b> Term values (cm <sup>-1</sup> ) of the $C^{1}\Sigma^{+}(v'=0)$ levels for six CO isotopologue	es.
------------------------------------------------------------------------------------------------------------------	-----

			$C^1\Sigma^+$	(v' = 0)		
J'	<sup>12</sup> C <sup>16</sup> O	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	<sup>13</sup> C <sup>17</sup> O	<sup>13</sup> C <sup>18</sup> O
0	91919.027	91918.939	91918.851	91919.074	91918.886	91918.794
1	91922.935 (-5)	91922.733 (-52)	91922.563 (-16)	91922.751 (12)	91922.499 (-23)	91922.329 (3)
2	91930.698 (-10)	91930.348 (-58)	91929.950 (0)	91930.204 (11)	91929.791 (-28)	91929.390 (9)
3	91942.334 (23)	91941.627 (36)	91941.074 (-6)	91941.352 (-7)	91940.580 (-3)	91939.995 (-3)
4	91957.879 (-14)	91956.858 (-76)	91955.883 (-2)	91956.209 (0)	91955.059 (26)	91954.118 (-5)
5	91977.334 (17)	91975.760 (-20)	91974.389 (1)	91974.809 (16)	91973.103 (69)	91971.775 (-7)
6	92000.638 (-15)	91998.492 (-13)	91996.606 (0)	91997.101 (6)	91994.873 (44)	91992.978 (13)
7	92027.846 (17)	92025.008 (-2)	92022.518 (3)	92023.131 (9)	92020.214 (4)	92017.701 (4)
8	92058.896 (-17)	92055.291 (3)	92052.127 (-11)	92052.837 (-35)	92049.134 (33)	92045.965 (-3)
9	92093.891 (-11)	92089.383 (2)	92085.437 (6)	92086.262 (-1)	92081.738 (-12)	92077.734 (-2)
10	92132.717 (-4)	92127.249 (-12)	92122.444 (-1)	92123.428 (0)	92117.912 (-10)	92113.041 (10)
	92175.452 (0)	92168.915 (-11)	92163.141 (-1)	92164.253 (-14)	92157.710 (-29)	92151.859 (-11)
12	92222.056 (-27)	92214.337 (-8)	92207.535 (2)	92208.833 (1)	92201.079 (-12)	92194.222 (-5)
13	92272.528 (-19)	92263.533 (-10)	92255.623 (0)	92257.085 (-7)	92248.060 (3)	92240.111 (-6)
14	92326.890 (-9)	92316.541 (-12)	92307.416 (-8)	92309.080 (-22)	92298.695 (3)	92289.512 (-1)
15	92385.092 (4)	923/3.313(-8)	92362.863 (3)	92364.760 (24)	92352.893(-5)	92342.447(-6)
10	92447.188 (19)	92433.833(3)	92422.025(-1)	92424.142(3) 02487214(-11)	92410.744(1) 02472.151(2)	92398.878(-2)
1/	92313.139(7) 02582.047(22)	92498.140(-0)	92464.607 (3)	92487.214(-11) 02552.082(-6)	92472.131(3) 02527171(-2)	92436.640(1) 02522.207(-7)
10	92382.947 (23)	92300.203(3) 02638(044(7))	92331.379(-3) 02621572(-3)	92333.982(-0) 02624.441(-5)	92337.171(-2) 92605.700(-6)	92322.307(-7)
20	92030.009 (17)	92038.044(7) 92713634(-1)	92021.372(-3) 92695.465(-8)	92024.441(-3) 02608.610(-1)	92003.790(-0) 92677.003(-5)	92389.290(7) 92659.775(-4)
20	92754.150 (5)	92713.034(-1) 92702.982(2)	92093.403(-8) 92773.012(-6)	92098.010(-1) 92776.462(-11)	92077.995(-5) 92753705(10)	92039.773(-4) 92733771(6)
$\frac{21}{22}$	92900 825 (0)	92876.094(-5)	92854 237 (2)	92857 991 (-8)	92833 197 (7)	92811277(-4)
23	92989903(-31)	92962954(-2)	92939122(-8)	92943 203 (7)	92916 182 (1)	92892 294 (0)
24	93082 854 (9)	93053576(-4)	93027 674 (9)	93032.096 (13)	93002.743 (-6)	92976784(-6)
25	93179.610 (-18)	93147.943 (5)	93119.891 (6)	93124.638 (3)	93092.894 (2)	93064.809 (-4)
26	93280.260 (-4)	93246.036 (11)	93215.764 (0)	93220.881 (22)	93186.615 (-8)	93156.301 (0)
27	93384.671 (48)	93347.935 (-43)	93315.298 (6)	93320.780 (8)	93283.933 (-28)	93251.270 (0)
28	93492.986 (-18)	93453.476 (8)	93418.485 (-6)	93424.358 (5)	93384.795 (11)	93349.746 (-5)
29	93605.101 (-18)	93562.769 (2)	93525.320 (-5)	93531.596 (2)	93489.206 (-9)	93451.704 (-12)
30	93721.089 (37)	93675.906 (-81)	93635.779 (-5)	93642.487 (3)	93597.205 (-2)	93557.111 (4)
31	93840.854 (62)	93792.627 (-44)	93749.921 (4)	93757.034 (4)	93708.777 (1)	93666.009 (1)
32	93964.415 (43)	93913.072 (-22)	93867.675 (4)	93875.231 (-3)	93823.936 (39)	93778.401 (-4)
33	94091.798 (47)	94037.302 (99)	93989.048 (4)	93997.075 (8)	93942.588 (27)	93894.258 (-4)
34	94222.951 (66)	94165.107 (-96)	94114.061 (-10)	94122.558 (11)	94064.784	94013.556 (7)
35	94357.931 (47)		94242.709 (-16)	94251.666 (13)	94190.438 (29)	94136.329 (-4)
36	94496.720 (51)		94374.916 (43)	94384.456 (-29)	94319.787 (-1)	94262.552 (2)
37	94639.295 (29)		94510.802	94520.809 (-16)	94452.659 (3)	94392.228 (8)
38	94785.681			94660.782	94588.641	94525.363 (2)
39				94804.384	94728.331	94661.919 (8)
40				94951.719		94801.907 (-27)
41						94944.865 (*)
42						95092.196
45						95251.215
44						95395.735

Notes. The  $\delta_P$  value in parentheses (in units of the least significant digit) corresponds to the wavenumber correction applied to  $TV_P$  and  $TV_R$ . There is no value when the term value is derived from a single transition, either *R* or *P*. An asterisk indicates when both *R*- and *P*-branches are present at high *J'*, either the potential presence of a perturbing state or that one of the lines shows a larger uncertainty than the other (see also Sect. 2.2.2).

-
-
<b></b>
-
le
-g
Ë
÷
PG
ŝ
a
E
·Ξ
pi
. 🗖
S
<u>e</u>
.0
8
Ξ
1
8
~
ñ
ar
્ઝ્ર
$\tilde{}$
$\tilde{\mathcal{C}}$
Ę.
$\mathcal{O}$
12
Ч
ġ
9
Ć
5
ເງ
2
Ċ.
<u>و</u>
7)
5
Ξ.
ō
÷
р
ar
ã,
$\widehat{}$
$\sim$
11
" =
$^{+}(v'' =$
$\Sigma^+(v'' =$
$^{1}\Sigma^{+}(v'' =$
$X^1\Sigma^+(v'' =$
$)-X^{1}\Sigma^{+}(v''=$
$:1)-X^{1}\Sigma^{+}(v'' =$
$= 1) - X^1 \Sigma^+ (v'' =$
$v'=1){-}X^1\Sigma^+(v''=$
$^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' =$
$\Sigma^+(v'=1) - X^1 \Sigma^+(v''=$
${}^{-1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
$C^{1}\Sigma^{+}(v'=1){-}X^{1}\Sigma^{+}(v''=$
ie $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' =$
the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' =$
if the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' =$
of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' =$
rs of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=$
bers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=$
nbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=$
imbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=$
numbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' =$
enumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' =$
avenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' =$
wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' =$
1 wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 1)$
nd wavenumbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=1)$
and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 1)$
is and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 1)$
ths and wavenumbers of the $C^1 Σ^+(v' = 1) - X^1 Σ^+(v') = 1$
ngths and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' =$
engths and wavenumbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v''=1)$
elengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 1)$
welengths and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 1)$
vavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
1 wavelengths and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 1)$
on wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
tion wavelengths and wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' =$
sition wavelengths and wavenumbers of the $C^1\Sigma^+(v' = 1) - X^1\Sigma^+(v'' =$
insition wavelengths and wavenumbers of the $C^1\Sigma^+(v' = 1) - X^1\Sigma^+(v'' = 1)$
ransition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 1)$
<b>2.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
<b>12.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 1)$
<b>A.12.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
<b>a</b> A.12. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
Me A.12. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$
<b>able A.12.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 1)$

-	$\delta_P$		0	-25	- 14	6	-21	-4	10	25	-26	-4	14	-	-10	-18	e	-4	30	4	-v	-	10	-13	- 	-24	-42	-87	-4	*	*				
	$P_{ms} (\mathrm{cm}^{-1})$		94010.626	94006.985	94003.353	93999.713	93996.073	93992.433	93988.793	93985.153	93981.514	93977.937	93974.299	93970.660	93967.093	93963.517	93959.941	93956.304	93952.738	93949.163	93945.659	93942.085	93938.511	93934.937	93931.434	93927.931	93924.429	93920.933	93917.500	93913.817	93910.957	93908.060			
12C18O	$R_{ms} (\mathrm{cm}^{-1})$	94017.971	94021.613	94025.318	94029.031	94032.665	94036.379	94040.084	94043.790	94047.425	94051.140	94054.846	94058.553	94062.260	94065.967	94069.666	94073.374	94077.153	94080.861	94084.561	94088.271	94091.980	94095.690	94099.462	94103.163	94106.873	94110.584	94114.294	94118.122	94121.778	94125.599	94129.342	94132.877		
	$P_{ms}$ (nm)		106.37095	106.37507	106.37918	106.38330	106.38742	106.39154	106.39566	106.39978	106.40390	106.40795	106.41207	106.41619	106.42023	106.42428	106.42833	106.43245	106.43649	106.44054	106.44451	106.44856	106.45261	106.45666	106.46063	106.46460	106.46857	106.47254	106.47643	106.48060	106.48385	106.48713			
	$R_{ms}$ (nm)	106.36264	106.35852	106.35433	106.35013	106.34602	106.34182	106.33763	106.33344	106.32933	106.32513	106.32094	106.31675	106.31256	106.30837	106.30419	106.30000	106.29573	106.29154	106.28736	106.28317	106.27898	106.27479	106.27053	106.26635	106.26216	106.25797	106.25379	106.24946	106.24534	106.24102	106.23680	106.23281		
	$\delta_P$		-22	L	15	22	10	2	-2	ς. Γ	2	-	ς	9-	-5	14	14	-	-2	L-	11	4	-13	-23	*	*	*	*							
	$P_{ms} ({ m cm}^{-1})$		94034.805	94031.033	94027.265	94023.493	94019.761	94016.061	94012.353	94008.641	94004.922	94001.204	93997.511	93993.810	93990.109	93986.430	93982.719	93979.043	93975.381	93971.716	93968.063	93964.360	93960.741	93957.114	93953.519	93949.534	93945.943	93942.297	93938.724						
17C1/O	$R_{ms} (\mathrm{cm}^{-1})$	94042.231	94045.990	94049.756	94053.531	94057.300	94061.066	94064.835	94068.602	94072.379	94076.165	94079.935	94083.704	94087.499	94091.294	94095.082	94098.852	94102.639	94106.428	94110.206	94114.012	94117.785	94121.600	94125.379	94129.175	94132.927	94137.251	94141.623	94146.158	94150.192					
	$P_{ms}$ (nm)		106.34360	106.34787	106.35213	106.35640	106.36062	106.36480	106.36900	106.37320	106.37741	106.38162	106.38580	106.38998	106.39417	106.39834	106.40254	106.40670	106.41085	106.41500	106.41913	106.42333	106.42743	106.43154	106.43561	106.44012	106.44419	106.44832	106.45237						
	$R_{ms}$ (nm)	106.33521	106.33096	106.32670	106.32243	106.31817	106.31391	106.30965	106.30540	106.30113	106.29685	106.29259	106.28833	106.28404	106.27976	106.27548	106.27122	106.26695	106.26267	106.25840	106.25410	106.24984	106.24554	106.24127	106.23699	106.23275	106.22787	106.22294	106.21782	106.21327					
	$\delta_P$		L	-12	23	Ϋ́	ю	5	13	-10	0	11	19	7	L	11	4	19	17	-17	13	16	-5	-28	L-	8	4	9	S	-8	9-	9-	6	-33	
	$P_{ms}  ({\rm cm}^{-1})$		94061.694	94057.872	94054.059	94050.175	94046.363	94042.542	94038.722	94034.902	94031.082	94027.263	94023.443	94019.624	94015.806	94012.041	94008.223	94004.467	94000.641	93996.877	93993.122	93989.296	93985.533	93981.832	93978.070	93974.299	93970.537	93966.775	93963.048	93959.280	93955.606	93951.883	93948.135	93944.416	93940.752
12C16O	$R_{ms} \ (\mathrm{cm}^{-1})$	94069.392	94073.259	94077.135	94080.959	94084.836	94088.704	94092.582	94096.398	94100.276	94104.155	94108.025	94111.851	94115.722	94119.601	94123.473	94127.344	94131.225	94135.044	94138.917	94142.790	94146.672	94150.483	94154.366	94158.240	94162.053	94165.936	94169.750	94173.625	94177.471	94181.283	94185.143	94188.935	94192.771	
	$P_{ms}$ (nm)		106.31320	106.31752	106.32183	106.32622	106.33053	106.33485	106.33917	106.34349	106.34781	106.35213	106.35645	106.36077	106.36509	106.36935	106.37367	106.37792	106.38225	106.38651	106.39076	106.39509	106.39935	106.40354	106.40780	106.41207	106.41633	106.42059	106.42481	106.42908	106.43324	106.43746	106.44171	106.44592	106.45007
	$R_{ms}$ (nm)	106.30450	106.30013	106.29575	106.29143	106.28705	106.28268	106.27830	106.27399	106.26961	106.26523	106.26086	106.25654	106.25217	106.24779	106.24342	106.23905	106.23467	106.23036	106.22599	106.22162	106.21724	106.21294	106.20856	106.20419	106.19989	106.19551	106.19121	106.18684	106.18251	106.17821	106.17386	106.16958	106.16526	
	J''	0	-	2	m	4	Ś	9	2	~	6	10	Ξ	12	13	4	15	16	17	18	19	20	21	52	53	54	52	26	27	28	59	30	31	32	33

÷
~
<u> </u>
9
'a
F
H
2
-
a a
H
· Ħ
G.
·Ħ
5
š
e
q
ц
Я
=
Ē
8
g
Ħ
g
5
$\widetilde{}$
ĩ
U
3
p
H
-
Ć
$\sim$
÷.
$\mathbf{O}$
13
_
Ċ.
Š
÷.
$\circ$
13
<u> </u>
,ö
44
Ч
ц.
g
<u> </u>
$\widehat{}$
0
=0)
(0= ,,
(v'' = 0)
$^{+}(v'' = 0)$
$\Sigma^+(v^{\prime\prime}=0)$
$\sum_{i=1}^{n-1} \sum_{i=1}^{n-1} (v'' = 0)$
$\cdot X^1 \Sigma^+(v^{\prime\prime}=0)$
$)-X^{1}\Sigma^{+}(v^{\prime\prime}=0)$
$1) - X^1 \Sigma^+(v'' = 0)$
$= 1) - X^{1} \Sigma^{+} (v'' = 0)$
$' = 1) - X^1 \Sigma^+ (v'' = 0)$
$[v' = 1) - X^1 \Sigma^+ (v'' = 0)$
$(v' = 1) - X^1 \Sigma^+ (v'' = 0)$
$\Sigma^{+}(\nu' = 1) - X^{1} \Sigma^{+}(\nu'' = 0)$
$^{1}\Sigma^{+}(v'=1)-X^{1}\Sigma^{+}(v''=0)$
$C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
; $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
ie $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
f the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
s of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
ars of the $C^{1}\Sigma^{+}(v'=1)-X^{1}\Sigma^{+}(v''=0)$
bers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
nbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
imbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
numbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
enumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v'' = 0)$
venumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
a venumbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
wavenumbers of the $C^1 \Sigma^+(v' = 1) - X^1 \Sigma^+(v' = 0)$
1 wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
nd wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
s and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
hs and wavenumbers of the $C^1\Sigma^+(v'=1)-X^1\Sigma^+(v'=0)$
ths and wavenumbers of the <i>C</i> <sup>1</sup> Σ <sup>+</sup> ( $v' = 1$ )− <i>X</i> <sup>1</sup> Σ <sup>+</sup> ( $v' = 0$ )
ngths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
engths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
slengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
velengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v' = 0)$
avelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
ı wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
in wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
ion wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
ition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
is ition wavelengths and wavenumbers of the $C^1 \Sigma^+(v'=1) - X^1 \Sigma^+(v''=0)$
insition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v' = 0)$
ransition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
<b>3.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
.13. Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
<b>A.13.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
<b>A.13.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1) - X^{1}\Sigma^{+}(v'' = 0)$
<b>le A.13.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$
<b>ble A.13.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v'' = 0)$
<b>able A.13.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 1)-X^{1}\Sigma^{+}(v' = 0)$

			12		-		(1 = n) = 2	(n = n) = v = n					- 01- 01		
<sup>13</sup> C <sup>16</sup> O	<sup>13</sup> C <sup>16</sup> O	<sup>13</sup> C <sup>16</sup> O						<sup>13</sup> C <sup>17</sup> O					<sup>13</sup> C <sup>18</sup> O		
$R_{ms}$ (nm) $P_{ms}$ (nm) $R_{ms}$ (cm <sup>-1</sup>	$P_{ms}$ (nm) $R_{ms}$ (cm <sup>-1</sup>	$R_{ms} \ (\mathrm{cm}^{-1})$	(	$P_{ms}  ({ m cm}^{-1})$	$\delta_P$	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} \ (\mathrm{cm}^{-1})$	$P_{ms}  ({ m cm}^{-1})$	$\delta_P$	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} (\mathrm{cm}^{-1})$	$P_{ms} (\mathrm{cm}^{-1})$	$\delta_P$
106.35798 94022.091	94022.091	94022.091				106.38925		93994.456			106.41767		93969.353		
106.35378 106.36630 94025.804	106.36630 94025.804	94025.804		94014.736	-38	106.38582	106.39786	93997.486	93986.849	79	106.41366	106.42556	93972.895	93962.387	-17
106.34953 106.37037 94029.561	106.37037 94029.561	94029.561		94011.139	-63	106.38175	106.40159	94001.082	93983.562	-93	106.40972	106.42950	93976.374	93958.908	0
106.34565 106.37443 94032.992	106.37443 94032.992	94032.992		94007.551	*	106.37762	106.40587	94004.732	93979.779	-18	106.40571	106.43344	93979.916	93955.430	6-
106.34108 106.37888 94037.033	106.37888 94037.033	94037.033		94003.618	-81	106.37371	106.41007	94008.187	93976.069	-16	106.40177	106.43739	93983.396	93951.943	6
106.33689 106.38289 94040.738	106.38289 94040.738	94040.738	~	94000.075	59	106.36942	106.41404	94011.979	93972.559	*	106.39776	106.44133	93986.938	93948.466	-25
106.33276 106.38695 94044.39	106.38695 94044.391	94044.39]	_	93996.488	6	106.36529	106.41802	94015.629	93969.049	-36	106.39369	106.44522	93990.533	93945.032	9-
106.32857 106.39096 94048.09	106.39096 94048.09	94048.09		93992.945	-13	106.36123	106.42199	94019.222	93965.539	-19	106.38969	106.44916	93994.067	93941.555	13
106.32444 106.39509 94051.750	106.39509 94051.750	94051.750	_	93989.296	6-	106.35716	106.42600	94022.816	93962.003	-27	106.38575	106.45304	93997.548	93938.131	8
106.32019 106.39922 94055.51	106.39922 94055.51	94055.51	0	93985.648	-23	106.35309	106.43001	94026.414	93958.463	-20	106.38174	106.45693	94001.091	93934.699	Ţ
106.31593 106.40336 94059.27	106.40336 94059.27	94059.27	~	93981.991	-15	106.34894	106.43405	94030.087	93954.896	-53	106.37768	106.46087	94004.679	93931.222	-31
106.31206 106.40743 94062.70	106.40743 94062.70	94062.70	0	93978.397		106.34480	106.43799	94033.744	93951.414	-33	106.37367	106.46469	94008.223	93927.852	-12
106.30756 106.41150 94066.68	106.41150 94066.68	94066.68	4	93974.802	-17	106.34087	106.44197	94037.223	93947.905	53	106.36967	106.46857	94011.758	93924.429	-8
106.30337 106.41589 94070.39	106.41589 94070.39	94070.39	2	93970.925	*	106.33658	106.44611	94041.013	93944.251	-22	106.36560	106.47246	94015.355	93920.997	-12
106.29943 106.41996 94073.878	106.41996 94073.878	94073.878	$\sim$	93967.331	63	106.33246	106.45008	94044.661	93940.743	32	106.36154	106.47634	94018.944	93917.575	6-
106.29512 106.42396 94077.69	106.42396 94077.69	94077.69	ŝ	93963.800	-58	106.32845	106.45399	94048.203	93937.293	48	106.35747	106.48016	94022.542	93914.206	21
106.29080 106.42803 94081.51	106.42803 94081.51	94081.51	9	93960.206	8-	106.32430	106.45797	94051.878	93933.781	-14	106.35347	106.48405	94026.078	93910.775	1
106.28655 106.43211 94085.27	106.43211 94085.27	94085.27	8	93956.604	44	106.32013	106.46189	94055.563	93930.322	16	106.34946	106.48781	94029.623	93907.459	4
106.28236 106.43618 94088.98	106.43618 94088.98	94088.98	88	93953.012	40	106.31598	106.46587	94059.239	93926.815	27	106.34540	106.49169	94033.213	93904.037	-12
106.27824 106.44019 94092.63	106.44019 94092.63	94092.63	5	93949.472	39	106.31185	106.46978	94062.893	93923.362	49	106.34133	106.49551	94036.812	93900.669	-4
106.27399 106.44426 94096.39	106.44426 94096.39	94096.39	×	93945.880	10	106.30773	106.47373	94066.538	93919.882	50	106.33721	106.49933	94040.455	93897.301	-16
106.26980 106.44833 94100.10	106.44833 94100.10	94100.10	~	93942.288	14	106.30354	106.47764	94070.246	93916.428	48	106.33308	106.50309	94044.108	93893.986	24
106.26555 106.45234 94103.87	106.45234 94103.87	94103.87	-	93938.749	-S	106.29947	106.48156	94073.843	93912.975	67	106.32914	106.50691	94047.593	93890.618	44
106.26137 106.45635 94107.57	106.45635 94107.57	94107.57	Э	93935.211	S	106.29532	106.48544	94077.520	93909.549	34	106.32508	106.51067	94051.184	93887.304	-17
106.25718 106.46036 94111.28	106.46036 94111.28	94111.28	4	93931.672	14	106.29085	106.48933	94081.477	93906.123	56	106.32100	106.51443	94054.793	93883.990	-23
106.25293 106.46443 94115.04	106.46443 94115.04	94115.04	8	93928.081	36	106.28666	106.49324	94085.185	93902.671	*	106.31694	106.51819	94058.387	93880.676	15
106.24875 106.46851 94118.75	106.46851 94118.75	94118.75	_	93924.482	29	106.28244	106.49720	94088.921	93899.183	*	106.31286	106.52202	94062.002	93877.300	-14
106.24450 106.47246 94122.51	106.47246 94122.51	94122.51	9	93920.997	-35	106.27825	106.50102	94092.626	93895.815	*	106.30881	106.52571	94065.581	93874.048	1
106.24032 106.47634 94126.21	106.47634 94126.21	94126.21	6	93917.575	-34	106.27400	106.50484	94096.393	93892.448	*	106.30473	106.52947	94069.195	93870.735	-25
106.23611 106.48029 94129.95	106.48029 94129.95	94129.95	33	93914.091	*	106.26982	106.50866	94100.095	93889.076	*	106.30066	106.53317	94072.791	93867.475	8
106.23191 106.48405 94133.6	106.48405 94133.6	94133.6	78	93910.775	*	106.26560	106.51242	94103.832	93885.766	*	106.29662	106.53692	94076.367	93864.171	
106.22771 106.48780 94137.3	106.48780 94137.3	94137.3	98	93907.468	*	106.26062	106.51616	94108.237	93882.469	*	106.29249		94080.021		
106.22343 106.49169 94141.18	106.49169 94141.18	94141.18	68	93904.037	*	106.25634	106.51995	94112.032	93879.129	*	106.28886		94083.236		
106.21927 106.49551 94144.8	106.49551 94144.8	94144.8		93900.669	*	106.25206	106.52371	94115.823	93875.810	*					
106.21510 106.49933 94148.5	106.49933 94148.57	94148.5′	71	93897.301	*	106.24775	106.52743	94119.641	93872.532	*					
106.21083 106.50309 94152.3	106.50309 94152.3	94152.3	57	93893.986	*	106.24347	106.53116	94123.433	93869.249	*					
106.20666 106.50685 94156.0	106.50685 94156.0	94156.03	51	93890.671	*	106.23919	106.53490	94127.225	93865.957	*					
106.51067	106.51067			93887.309	*	106.23485	106.53852	94131.067	93862.764						
106.51444	106.51444			93883.980		106.23064		94134.799							
106.51829	106.51829			93880.594		106.22641		94138.552							
106.52203	106.52203			93877.296		106.22206		94142.402							
106.52577	106.52577			93874.003		106.21780		94146.181							
106.52941	106.52941			93870.787											
106.53316	106.53316			93867.491											
106.53738	106.53738			93863.773											
106.54105	106.54105			93860.535											

	$C^{1}\Sigma^{+}(v'=1)$ $^{12}C^{16}O$ $^{12}C^{17}O$ $^{12}C^{18}O$ $^{13}C^{16}O$ $^{13}C^{17}O$ $^{13}C^{18}O$												
J'	$^{12}C^{16}O$	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	$^{13}C^{17}O$	$^{13}C^{18}O$							
0	94065.539	94038.553	94014.288	94018.412	93990.428	93965.880							
1	94069.399 (-7)	94042.254 (-22)	94017.971 (0)	94022.129 (-38)	93994.252 (*)	93969.370 (-17)							
2	94077.116 (-12)	94049.745 (-7)	94025.300 (-25)	94029.543 (-63)	94001.158 (-93)	93976.387 (0)							
3	94088.647 (23)	94060.985 (15)	94036.317 (-14)	94040.482 (107)	94011.837 (-18)	93986.861 (-9)							
4	94104.031 (-3)	94075.996 (22)	94050.999 (2)	94055.128 (-81)	94026.220 (-16)	94000.863 (9)							
5	94123.281 (3)	94094.767 (10)	94069.303 (-21)	94073.731 (59)	94044.084 (*)	94018.347 (-25)							
6	94146.370 (5)	94117.278 (2)	94091.307 (-4)	94095.863 (9)	94065.692 (-36)	94039.332 (-6)							
7	94173.305 (13)	94143.533 (-2)	94116.965 (10)	94121.589 (-13)	94090.793 (-19)	94063.860 (13)							
8	94204.050 (-10)	94173.529 (-3)	94146.282 (25)	94151.013 (-7)	94119.439 (-27)	94091.842 (8)							
9	94238.667 (0)	94207.272 (2)	94179.252 (-26)	94184.078 (-23)	94151.645 (-20)	94123.265 (-1)							
10	94277.122 (11)	94244.774 (1)	94215.887 (-4)	94220.897 (-15)	94187.469 (-53)	94158.259 (-31)							
11	94319.409 (19)	94286.003 (-3)	94256.173 (14)	94261.389 (-1)	94226.890 (-33)	94196.734 (-12)							
12	94365.511 (7)	94330.972 (-6)	94300.147 (-1)	94305.234 (-17)	94269.799 (53)	94238.669 (-8)							
13	94415.494 (-7)	94379.701 (-5)	94347.768 (-10)	94353.165 (106)	94316.262 (-22)	94284.086 (-12)							
14	94469.288 (11)	94432.149 (14)	94399.040 (-18)	94404.654 (63)	94366.475 (32)	94333.044 (-9)							
15	94526.938 (-4)	94488.344 (14)	94453.924 (3)	94459.663 (-58)	94420.153 (48)	94385.446 (21)							
16	94588.380 (19)	94548.269 (-1)	94512.494 (-4)	94518.492 (-8)	94477.368 (-14)	94441.388 (1)							
17	94653.683 (17)	94611.929 (-2)	94574.739 (30)	94580.988 (44)	94538.186 (16)	94500.723 (4)							
18	94722.782 (-17)	94679.323 (-7)	94640.626 (-4)	94647.134 (40)	94602.595 (27)	94563.564 (-12)							
19	94795.693 (13)	94750.410 (11)	94710.113 (-5)	94716.881 (39)	94670.543 (49)	94629.898 (-4)							
20	94872.451 (16)	94825.275 (4)	94783.241 (1)	94790.247 (10)	94742.049 (50)	94699.734 (-16)							
21	94953.060 (-5)	94903.838 (-13)	94860.003 (10)	94867.346 (14)	94817.102 (48)	94773.033 (24)							
22	95037.414 (-28)	94986.153 (-23)	94940.432 (-13)	94948.063 (-5)	94895.749 (67)	94849.828 (44)							
23	95125.607 (-7)	95071.968 (*)	95024.520 (-3)	95032.448 (5)	94977.888 (34)	94930.001 (-17)							
24	95217.604 (8)	95161.698 (*)	95112.198 (-24)	95120.416 (14)	95063.597 (56)	95013.686 (-23)							
25	95313.372 (-4)	95255.084 (*)	95203.506 (-42)	95212.019 (36)	95152.969 (*)	95100.807 (15)							
26	95412.990 (6)	95352.495 (*)	95298.465 (-87)	95307.339 (29)	95245.814 (*)	95191.435 (-14)							
27	95516.346 (5)	95454.281	95396.912 (-4)	95406.288 (-35)	95342.207 (*)	95285.493 (1)							
28	95623.569 (-8)	95559.553	95499.443 (*)	95508.862 (-34)	95442.113 (*)	95383.007 (-25)							
29	95734.539 (-6)	95668.018	95605.477 (*)	95615.111 (*)	95545.608 (*)	95483.960 (-8)							
30	95849.260 (-6)		95/14.354	95724.997 (*)	95652.600 (*)	95588.347							
31	95967.797 (9)		95827.358	95838.431 (*)	95/63.109 (*)	95696.164							
32	96090.099 (-33)		95943.752	95955.503 (*)	95877.478 (*)	95807.494							
33	96216.142			960/6.216 (*)	95995.073 (*)	95921.819							
34				96200.504 (*)	96116.172 (*)								
35				96328.391 (*)	96240.783 (*)								
30				96459.893 (*)	96368.929 (*)								
20				90394.932()	90301.308								
20 20				90/34.237	90030.494								
39				908/0.348	90773.039								
40				97022.430	90917.129								
41				9/1/1.930	07211 829								
42				07/81 067									
43				07641 214									
44		1		7/041.214									

Notes. See note to Table A.11.

																								_													
		$\delta_P$	ç	-10	17-	-10	8	-52	55	75															$\delta_P$		66-	1	-36	-23	0	-36	11	-23			
		$P_{ms}  ({ m cm}^{-1})$		900/27092	96065.217	96061.369	96057.613	96053.784	96049.964	96045.915	96041.985	96037.309													$P_{ms}  ({\rm cm}^{-1})$		95977.841	95974.415	95970.546	95967.065	95963.418	95959.762	95956.162	95952.405	95948.750		
	<sup>12</sup> C <sup>18</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	96079.966	000 39030	96090.547	96094.074	96097.454	96100.935	96104.362															<sup>13</sup> C <sup>18</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	95984.695	95988.012	95991.440	95994.803	95998.176	96001.484	96004.802	96008.056	96011.264	96014.463	96017.772	90U21.248
		$P_{ms}$ (nm)		20/00/01	104.09595	104.10012	104.10419	104.10834	104.11248	104.11687	104.12113	104.12620													$P_{ms}$ (nm)		104.19072	104.19444	104.19864	104.20242	104.20638	104.21035	104.21426	104.21834	104.22231		
		$R_{ms}$ (nm)	104.07997	104.07036	104.06851	104.06469	104.06103	104.05726	104.05355																$R_{ms}$ (nm)	104.18328	104.17968	104.17596	104.17231	104.16865	104.16506	104.16146	104.15793	104.15445	104.15098	104.14739	104.14502
		$\delta_P$																							$\delta_P$												_
		$P_{ms}  ({\rm cm}^{-1})$																							$P_{ms}  ({\rm cm}^{-1})$												
$(-X^{1}\Sigma^{+}(v''=0))$	<sup>12</sup> C <sup>17</sup> O	$R_{ms}  (\mathrm{cm}^{-1})$																						<sup>13</sup> C <sup>17</sup> O	$R_{ms} (\mathrm{cm}^{-1})$												
$C^{\mathrm{I}}\Sigma^{+}(v'=2)$		$P_{ms}$ (nm)																							$P_{ms}$ (nm)												
		$R_{ms}$ (nm)																							$R_{ms}$ (nm)												
		$\delta_P$	ę	90 - 90 0	0 V 	-14	0	7	13	6-	27	6	20	4	6-	L	-2	*							$\delta_P$		-35	56	-60	64	-33	-10	19	13	-16		
		$P_{ms}  ({\rm cm}^{-1})$		200.6/106	96165.252	96161.320	96157.299	96153.289	96149.188	96145.089	96140.933	96136.721	96132.508	96128.240	96123.971	96119.647	96115.266	96110.886	96107.066						$P_{ms}  ({\rm cm}^{-1})$		96080.561	96076.850	96072.982	96069.438	96065.414	96061.705	96057.792	96053.815	96049.802	96045.881	
	<sup>12</sup> C <sup>16</sup> O	$R_{ms}  (\mathrm{cm}^{-1})$	96180.696	90104.40U	96191.872	96195.579	96199.174	96202.769	96206.251	96209.789	96213.215	96216.641	96220.010	96223.324	96226.638	96229.896	96233.040	96236.298	96239.275	96242.364	96245.509	96248.430	96251.540	<sup>13</sup> C <sup>16</sup> O	$R_{ms}  (\mathrm{cm}^{-1})$	96087.808	96091.474	96095.047	96098.621	96102.066	96105.548	96108.974	96112.291	96115.653	96119.025	96122.388	466.62104
		$P_{ms}$ (nm)		102.097925	103.98767	103.99192	103.99627	104.00060	104.00504	104.00947	104.01397	104.01853	104.02308	104.02770	104.03232	104.03700	104.04175	104.04649	104.05062						$P_{ms}$ (nm)		104.07933	104.08335	104.08754	104.09138	104.09574	104.09976	104.10400	104.10831	104.11266	104.11691	
		$R_{ms}$ (nm)	103.97097	06006.001	103.95889	103.95488	103.95100	103.94711	103.94335	103.93953	103.93583	103.93213	103.92849	103.92491	103.92133	103.91781	103.91441	103.91090	103.90768	103.90435	103.90095	103.89780	103.89444		$R_{ms}$ (nm)	104.07148	104.06751	104.06364	104.05977	104.05604	104.05227	104.04856	104.04497	104.04133	104.03768	104.03404	COUCU.FUI
		J"	0,	- (	1 (1	4	5	9	2	8	6	10	11	12	13	14	15	16	17	18	19	20	21		J″	0	-	6	ŝ	4	S	9	2	~	6	10	11

**Table A.15.** Transition wavelengths and wavenumbers of the  $C^{1}\Sigma^{+}(v' = 2)-X^{1}\Sigma^{+}(v'' = 0)$  band for  $^{12}C^{16}O$ ,  $^{12}C^{16}O$ ,  $^{13}C^{16}O$ , and  $^{13}C^{18}O$  (same column description as for Table A.1).

# A&A 614, A114 (2018)

# J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

Table A.16. Term values	$(cm^{-1})$	) of the $C^1\Sigma^+$	(v' = 2) levels for	$^{12}C^{16}O$ ,	$^{12}C^{18}O$	$^{13}C^{16}O$ and	$^{13}C^{18}O.$
-------------------------	-------------	------------------------	---------------------	------------------	----------------	--------------------	-----------------

			$C^1\Sigma^+$	(v'=2)		
J'	$^{12}C^{16}O$	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	$^{13}C^{17}O$	<sup>13</sup> C <sup>18</sup> O
0	96176.847		96076.354	96084.237		95981.334
1	96180.735 (-39)		96079.976 (-10)	96087.843 (-35)		95984.794 (-99)
2	96188.313 (-8)		96087.167 (-21)	96095.093 (56)		95991.504 (1)
3	96199.763 (-5)		96097.982 (-4)	96106.135 (-60)		96001.954 (-36)
4	96214.956 (-14)		96112.527 (-10)	96120.612 (64)		96015.782 (-23)
5	96234.026 (2)		96130.683 (8)	96138.856 (-33)		96033.102 (0)
6	96256.838 (7)		96152.430 (-52)	96160.691 (-10)		96053.908 (-36)
7	96283.492 (13)		96177.772 (55)	96186.140 (19)		96078.132 (11)
8	96313.902 (-9)		96206.804 (75)	96215.187 (13)		96105.863 (-23)
9	96348.152 (27)		96238.649	96247.974 (-16)		96136.979
10	96386.184 (9)			96284.397		96171.599
11	96428.026 (20)			96324.497		96209.816
12	96473.673 (4)			96368.054		96251.686
13	96523.099 (-9)					
14	96576.328 (7)					
15	96633.359 (-2)					
16	96694.441 (*)					
17	96758.774					
18	96826.996					
19	96899.153					
20	96975.186					
21	97054.812					
22	97138.442					

Notes. See note to Table A.11.

$\overline{}$	
×.	
e	
Ē	
La	
5	
,ē	
sf	
9	
ñ	
Ĕ	
đ	
.8	
S	
qe	
Ē	
Ē	
E	
0	
0	
ne	
an	
ŝ	
õ	
°.	
ັບ	
13(	
-	
ŭ	
а	
Ó	
او <b>ر</b>	
ັບ	
3	
0	
18	
C	
12	
ć	
$\tilde{\mathbf{O}}$	
Ę.	
S.	
8	
Ó	
Š	
້ເວ	
17	
÷ –	
for	
d for	
und for	
band for	
)) band for	
= 0) band for	
(=0) band for	
(v'' = 0) band for	
$^{+}(v''=0)$ band for	
$\Sigma^+(v''=0)$ band for	
$X^1\Sigma^+(v''=0)$ band for	
$-X^{1}\Sigma^{+}(v''=0)$ band for	
3)– $X^{1}\Sigma^{+}(v'' = 0)$ band for	
$= 3) - X^{1} \Sigma^{+} (v'' = 0)$ band for	
$v' = 3 - X^{1} \Sigma^{+} (v'' = 0)$ band for	
$^{+}(v' = 3) - X^{1}\Sigma^{+}(v'' = 0)$ band for	
$\Sigma^{+}(v' = 3) - X^{1}\Sigma^{+}(v'' = 0)$ band for	
${}^{-1}\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
$C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
he $C^1 \Sigma^+(v' = 3) - X^1 \Sigma^+(v'' = 0)$ band for	
the $C^{1}\Sigma^{+}(v' = 3) - X^{1}\Sigma^{+}(v'' = 0)$ band for	
of the $C^{1}\Sigma^{+}(v' = 3) - X^{1}\Sigma^{+}(v' = 0)$ band for	
s of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
ers of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
here of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
imbers of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
numbers of the $C^{1}\Sigma^{+}(v' = 3) - X^{1}\Sigma^{+}(v'' = 0)$ band for	
/enumbers of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
avenumbers of the $C^{1}\Sigma^{+}(v' = 3)-X^{1}\Sigma^{+}(v'' = 0)$ band for	
wavenumbers of the $C^1\Sigma^+(\nu'=3)-X^1\Sigma^+(\nu''=0)$ band for	
d wavenumbers of the $C^{1}\Sigma^{+}(v' = 3)-X^{1}\Sigma^{+}(v' = 0)$ band for	
and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
s and wavenumbers of the $C^1\Sigma^+(v'=3)-X^1\Sigma^+(v''=0)$ band for	
ths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
igths and wavenumbers of the $C^1 \Sigma^+(v' = 3) - X^1 \Sigma^+(v'' = 0)$ band for	
engths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
elengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
we lengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 3) - X^{1}\Sigma^{+}(v'' = 0)$ band for	
<i>w</i> avelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
1 wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
on wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(\nu'=3)-X^{1}\Sigma^{+}(\nu'=0)$ band for	
ition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
isition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
ansition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
<b>7.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
<b>17.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
<b>A.17.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	
e <b>A.17.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v' = 3)-X^{1}\Sigma^{+}(v' = 0)$ band for	
<b>Je A.17.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v'=0)$ band for	
<b>able A.17.</b> Transition wavelengths and wavenumbers of the $C^{1}\Sigma^{+}(v'=3)-X^{1}\Sigma^{+}(v''=0)$ band for	

																								_																
		$\delta_P$	×	94	27	-13	48	55	-38	-70	-71	*													$\delta_P$	1	1	-23	16	56	-43	<u> </u>	05	† ~	46	92	*	58	-65	
		$P_{ms} (\mathrm{cm}^{-1})$	98093 834	98090.158	98086.346	98082.443	98078.486	98074.319	98070.216	98066.160	98061.876	98057.429	98052.647												$P_{ms}  ({ m cm}^{-1})$	07054 035	97951.347	97947.826	97944.123	97940.257	97936.334	9/932.526	9/928.498	97920 155	97916.176	97911.699	97907.395	97902.803	97898.490	97893.909 97888.974
	$^{12}C^{18}O$	$R_{ms} (\mathrm{cm}^{-1})$	98101.159 98104 744	98108.129	98111.413	98114.689	98117.920	98120.995	98123.961	98126.827	98129.738	98132.605	98135.471											<sup>13</sup> C <sup>18</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	97961.854 07065 280	97968.524	97971.720	97974.859	97977.834	97980.858	CZ8.586/6	1/5.086/6	04302.063	97994.819	97997.451	97999.775	98001.907		
		$P_{ms}$ (nm)	101 94321	101.94703	101.95099	101.95505	101.95916	101.96349	101.96776	101.97198	101.97643	101.98105	101.98603												$P_{ms}$ (nm)	107 08776	102.09150	102.09517	102.09903	102.10306	102.10715	102.11112	25011.201	102 12402	102.12817	102.13284	102.13733	102.14212	102.14662	102.15140 102.15655
		$R_{ms}$ (nm)	101.93560	101.92835	101.92494	101.92154	101.91818	101.91499	101.91191	101.90893	101.90591	101.90293	101.89995												$R_{ms}$ (nm)	102.08055	102.07360	102.07027	102.06700	102.06390	102.06075	102.05/66	024201	102 04908	102.04621	102.04347	102.04105	102.03883		
		$\delta_P$	*	-61	*	10	31	*	*																$\delta_P$															
		$P_{ms}  ({\rm cm}^{-1})$	98163 179	98159.489	98155.558	98151.675	98147.389	98143.131	98138.826	98134.116															$P_{ms}  ({\rm cm}^{-1})$															
$(v'' = 0) - X^{1} \Sigma^{+} (v'' = 0)$	<sup>12</sup> C <sup>17</sup> O	$R_{ms} (\mathrm{cm}^{-1})$	98171.062 98174.175	98177.568	98181.135	98184.412	98187.806	98190.958	98193.966	98196.821	98199.916	98202.635	98207.053											<sup>13</sup> C <sup>17</sup> O	$R_{ms}  (\mathrm{cm}^{-1})$															
$C^{1}\Sigma^{+}(v'=3$		$P_{ms}$ (nm)	101 87119	101.87502	101.87910	101.88313	101.88758	101.89200	101.89647	101.90136															$P_{ms}$ (nm)															
		$R_{ms}$ (nm)	101.86301	101.85626	101.85256	101.84916	101.84564	101.84237	101.83925	101.83629	101.83308	101.83026	101.82568												$R_{ms}$ (nm)															
		$\delta_P$	82	65	4	26	0	20	12	6-	56	37	ນ ເ	17-	5 64	f 5	5*	01	*	4	. 45				$\delta_P$	60	-31	33	-28	-50	8 G	77 ÷	19	10- 25	) *					
		$P_{ms} (\mathrm{cm}^{-1})$	98240 438	98236.778	98232.621	98228.577	98224.309	98219.985	98215.746	98211.110	98206.618	98201.956	98197.182	200726106	08187 747	98177188	001/1100	98166 618	98161 366	98156.578	98150.022	98144.419	98137.827		$P_{ms}  ({\rm cm}^{-1})$	08105 474	98101.567	98097.910	98093.782	98090.000	98085.959	98081./0/	980//.40/ 08073 367	98068 731	98063.961	98060.317				
	<sup>12</sup> C <sup>16</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	98248.469 98251 976	98255.483	98258.962	98262.276	98265.758	98268.790	98271.935	98275.081	98277.945	98280.744	98283.385	90200.009	08201144	98293 615	08205 861	100.00200	98299 643	98301.712				<sup>13</sup> C <sup>16</sup> O	$R_{ms} \ (\mathrm{cm}^{-1})$	98112.780 98116.226	98119.577	98123.023	98126.287	98129.465	98132.691	98135.532	5/5.85186	98144 229	98146.714	98149.517	98152.273			
		$P_{ms}$ (nm)	101 79108	101.79487	101.79918	101.80337	101.80779	101.81227	101.81667	101.82147	101.82613	101.83097	101.83592	20409101	101.85141	101 85666	101 86204	101 86762	101 87307	101.87804	101.88485	101.89066	101.89751		$P_{ms}$ (nm)	101 03111	101.93517	101.93897	101.94326	101.94719	101.95139	18669.101	101.06448	101 96930	101.97426	101.97805				
		$R_{ms}$ (nm)	101.78276	101.77549	101.77189	101.76846	101.76485	101.76171	101.75845	101.75520	101.75223	101.74933	101.74660	101.74360	101 73857	101 73601	101 73368	101 73165	77977 101	101.72763					$R_{ms}$ (nm)	101.92352	101.91646	101.91288	101.90949	101.90619	101.90284	101.89989	101.89094	66069701 101 89086	101.88828	101.88537	101.88251			
		J"	0 -	10	ŝ	4	ŝ	9	2	×	6	10	= 5	12	CI 71	1 2	12	51	18	16	20	21	22		J''	0 -	- 6	ŝ	4	S	91	- 0	×c	ر 10 م	11	12	13	4	15	16 17

# A114, page 34 of 62

Table A.18. Tern	n values (cm <sup>-1</sup> ) of	the $C^1 \Sigma^+ (v' = 3) l$	evels for <sup>12</sup> C <sup>16</sup>	$0, {}^{12}C^{17}O_{2}$	, <sup>12</sup> C <sup>18</sup> O	$^{13}C^{16}O$ and	<sup>13</sup> C <sup>18</sup> O.
------------------	---------------------------------	-------------------------------	-----------------------------------------	-------------------------	-----------------------------------	--------------------	----------------------------------

	$C^{1}\Sigma^{+}(v'=3)$											
J'	$^{12}C^{16}O$	$^{12}C^{17}O$	$^{12}C^{18}O$	<sup>13</sup> C <sup>16</sup> O	$^{13}C^{17}O$	<sup>13</sup> C <sup>18</sup> O						
0	98244.283	98166.927	98097.496	98109.150		97958.428						
1	98248.391 (78)	98170.897 (*)	98101.151 (8)	98112.687 (93)		97961.839 (14)						
2	98255.756 (65)	98177.984 (-61)	98108.361 (44)	98119.934 (-31)		97968.777 (-5)						
3	98267.022 (-4)	98188.982 (*)	98119.088 (27)	98130.572 (33)		97979.025 (-23)						
4	98282.005 (26)	98203.612 (10)	98133.397 (-13)	98145.106 (-28)		97992.660 (16)						
5	98300.722 (2)	98221.858 (31)	98151.258 (48)	98163.094 (-50)		98009.729 (56)						
6	98323.408 (20)	98243.884 (*)	98172.789 (55)	98184.608 (-8)		98030.266 (-43)						
7	98349.513 (12)	98269.333 (*)	98197.924 (-38)	98209.794 (82)		98054.206 (-7)						
8	98379.587 (-9)	98298.890	98226.549 (-70)	98238.590 (*)		98081.578 (30)						
9	98413.415 (56)	98331.716	98258.699 (-71)	98270.759 (-81)		98112.243 (44)						
10	98450.886 (37)	98368.526	98294.361 (*)	98306.531 (55)		98146.620 (6)						
11	98492.133 (15)	98408.701	98333.946	98346.621 (*)		98184.062 (46)						
12	98537.080 (-27)	98454.314	98377.064	98389.229		98225.166 (92)						
13	98585.779 (76)			98436.105		98269.547 (*)						
14	98638.200 (-43)			98486.598		98317.396 (58)						
15	98694.538 (67)					98368.494 (-65)						
16	98754.504 (*)					98422.903						
17	98818.246 (91)											
18	98885.902 (*)											
19	98956.419 (14)											
20	99031.355 (34)											
21	99109.060											

Notes. See note to Table A.11.



**Fig. A.12.** Transition wavelengths of the  $E^1\Pi(v'=0)-X^1\Sigma^+(v''=0)$  band for six CO isotopologues.



Fig. A.13. *e*-parity reduced term values  $(cm^{-1})$  of the  $E^{1}\Pi(v'=0)$  levels for six CO isotopologues. Data marked with a black center are kept to calculate molecular constants.

J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range



Fig. A.14. *f*-parity reduced term values (cm<sup>-1</sup>) of the  $E^1\Pi(v'=0)$  levels for six CO isotopologues (data marked with a black center are kept to calculate molecular constants).



Fig. A.15. Spectra of the  $E^1\Pi(v'=0)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{16}O$  and  ${}^{12}C^{16}O$ . The lower graph shows a ×10 expanded scale on the *Q*-branch between the red arrows).



A114, page 38 of 62

# J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range



**Fig. A.17.** Transition wavelengths of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for six CO isotopologues.



Fig. A.18. *e*-parity reduced term values (cm<sup>-1</sup>) of the  $E^1\Pi(v'=1)$  levels for six CO isotopologues (left). Data marked with a black center are kept to calculate molecular constants.



**Fig. A.19.** *f*-parity reduced term values (cm<sup>-1</sup>) of the  $E^1\Pi(v'=1)$  levels for six CO isotopologues (data marked with a black center are kept to calculate molecular constants).



Fig. A.20. Spectra of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{16}O$ . *Two upper panels*: RT spectra taken at different pressures. *Third panel*: comparison between 90 K (1 pressure) and room-temperature spectra (all pressures). *Lower panel*: ×5 expanded scale on the region indicated by black arrows on the above panel. This region contains among other lines those of the  $k^3\Pi(v'=5)$  perturbing band (around 105.205 nm), while  $k^3\Pi(v'=6)$  appears around 105.14 nm.



**Fig. A.21.** Spectra of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{17}O$  at 90 K and at room temperature (two pressures for the latter). Second panel: zoom of the central part of the *upper panel* (×3 zoom). *Third panel*: RT spectrum after weighted subtraction of  ${}^{12}C^{16}O$  and  ${}^{12}C^{18}O$  spectra (the signal in the *Q*-branch, in black, is divided by 7). *Lower panel*: simulated absorption spectrum of the *Q*-branch at room temperature.



J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

**Fig. A.22.** Spectra of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{18}O$  at 90 K and room temperature (both at two pressures).



**Fig. A.23.** Spectra of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{16}O$  at 90 K and room temperature.



**Fig. A.24.** *Upper panel*: spectra of the  $E^1\Pi(v'=1)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{18}O$  at 90 K and room temperature. *Lower panel*: ×4 expanded scale on the *Q*-branch between the black arrows.



**Fig. A.25.** Transition wavelengths of the  $E^1\Pi(v'=2)-X^1\Sigma^+(v''=0)$  band for five CO isotopologues.



Fig. A.26. Reduced term values (cm<sup>-1</sup>) of the  $E^1\Pi(v'=2)$  levels for five CO isotopologues (*left: e-parity and right: f-parity*). Data marked with a black center are kept to calculate molecular constants.





**Fig. A.27.** Spectra of the  $E^1\Pi(v'=2)-X^1\Sigma^+(v''=0)$  band. Upper panel: Simulated absorption spectra of the *Q*-branch of the for  ${}^{12}C^{16}O$  at 90 K and at room temperature. Lower panels: spectra of  ${}^{13}C^{16}O$  (*left*) and  ${}^{13}C^{18}O$  (*right*). Lowest panel: ×10 expanded scale on the *Q*-branch between the red arrows).



Fig. A.28. Transition wavelengths of the  $E^{1}\Pi(v'=3)-X^{1}\Sigma^{+}(v''=0)$  band for the five observed CO isotopologues.



Fig. A.29. Reduced term values (cm<sup>-1</sup>) of the  $E^1\Pi(v'=3)$  levels for the five observed CO isotopologues (*left: e-parity, and right: f-parity*).





**Fig. A.30.** Spectra of the  $E^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{16}O$  at room temperature (RT) and at ~90 K. Simulations below, in emission, of the upper experimental spectra (using classical Hönl–London factors).



**Fig. A.31.** Spectra of the  $E^1\Pi(v'=3) - X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{17}O$  at ~90 K. Traces of  ${}^{12}C^{18}O$  are present around 101.185 nm.



**Fig. A.32.** Spectra of the  $E^1 \Pi(v'=3) - X^1 \Sigma^+(v''=0)$  band for  ${}^{12}C^{18}O$  at ~90 K.

J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range



**Fig. A.33.** Spectra of the  $E^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ , and  ${}^{12}C^{18}O$  at ~90 K.  ${}^{12}C^{17}O$  is about equally mixed with  ${}^{12}C^{16}O$ , and traces of  ${}^{12}C^{18}O$  are present.



**Fig. A.34.** Spectrum of the  $E^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{16}O$  at ~90 K.





Fig. A.35. Spectra of the  $E^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{16}O$  at ~90 K (at two pressures) and  ${}^{13}C^{18}O$  at room temperature (in black) and ~90 K (with two different blues).



**Fig. A.36.** Spectra of the  $E^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band for  ${}^{13}C^{18}O$  at room temperature (RT) and at ~90 K. The asterisk shows an impurity line in the gas filter.

### J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

Table A.19. Measured transition wavelengths an	d wavenumbers of the $E^1\Pi(v' =$	$=0)-X^{1}\Sigma^{+}(v''=0)$ band for	$^{12}C^{16}O,  ^{12}C^{17}C$	), and <sup>12</sup> C <sup>18</sup> O.
0			,	/

			$E^1\Pi(v'=0)$	$-X^1 \Sigma^+ (v^{\prime\prime} = 0)$			
		<b>D</b> ( )	<b>n</b> ( -1)	<sup>12</sup> C <sup>16</sup> O	<i>c</i>		o ( -1)
0	R <sub>ms</sub> (nm) 107.60335	$P_{ms}$ (nm)	92933.909	$P_{ms}$ (cm <sup>-1</sup> )	0 <sub>P</sub> 30	$Q_{ms}$ (nm)	$Q_{ms}$ (cm <sup>-1</sup> )
1	107.59867		92937.954		55	107.60789	92929.988 <sup>a</sup>
2	107.59401	107.61678	92941.976	92922.313	12	107.60775	92930.109 <sup>a</sup>
4	107.58424	107.62520	92950.416	92915.039	-1	107.60726	92930.291 92930.532 <sup>a</sup>
5	107.57921	107.62928	92954.762	92911.522	-6	107.60691	92930.832 <sup>a</sup>
6	107.57410	107.63321	92959.183	92908.131	4	107.60649	92931.194 <sup>a</sup> 92931.616 <sup>a</sup>
8	107.56354	107.64086	92968.305	92901.521	3	107.60545	92932.098 <sup>a</sup>
9	107.55815	107.64453	92972.961	92898.358	-6	107.60480	92932.656
10	107.55260	107.64809	92977.759 92982 554	92895.285 92892.285	-1 -19	107.60409	92933.268 92933.942
12	107.54134	107.65491	92987.495	92889.399	-7	107.60253	92934.616
13	107.53555	107.65820	92992.505	92886.561	5	107.60161	92935.417
15	107.52367	107.66449	93002.782	92885.814	-1	107.59959	92930.235
16	107.51763	107.66745	93008.004	92878.579	-5	107.59838	92938.207
17	107.51145	107.67031	93013.348 93018 740	92876.118	-3	107.59730	92939.134
19	107.49886	107.67578	93024.240	92871.397	18	107.59476	92941.330
20	107.49245	107.67842	93029.793	92869.116	-2	107.59329	92942.601
21	107.47935	107.68326	93041.133	92864.947	-13	107.59038	92945.111
23	107.47263	107.68556	93046.945	92862.960	-14	107.58869	92946.572
24	107.46583	107.68775	93052.831	92861.076	1	107.58711	92947.935
26	107.45898	107.69184	93064.814	92857.544	9	107.58363	92950.943
27	107.44493	107.69376	93070.932	92855.895	2	107.58177	92952.549
28	107.43781	107.69556	93077.101 93083 341	92854.336	8 _8	107.58000	92954.083
30	107.42264	107.69887	93090.243	92851.483	*	107.57762	72755.761
31	107.41584	107.70036	93096.144	92850.198	*		
32	107.40839	107.70427	93102.595	92846.831			
34	107.39310		93115.848	12 17			
	107.60271		02022 506	$^{12}C^{17}O$	21		
	107.59922		92935.390		19	107.60821	92929.714 <sup>e</sup>
2	107.59460	107.61678	92941.469	92922.310	40	107.60807	92929.831 <sup>e</sup>
3	107.58986	107.62096	92945.563	92918.701	8	107.60787	$92930.006^{e}$
5	107.58018	107.62893	92953.925	92911.820	2	107.60726	92930.241 92930.536 <sup>e</sup>
6	107.57519	107.63283	92958.234	92908.459	19	107.60684	92930.893 <sup>e</sup>
	107.57011	107.63659	92962.629	92905.211	1	107.60636	92931.311 <sup>e</sup> 02031.704 <sup>e</sup>
9	107.55967	107.64385	92971.654	92901.998 92898.942	-15	107.60517	92931.794 92932.341
10	107.55431	107.64733	92976.282	92895.938	-10	107.60448	92932.931
112	107.54886	107.65070	92980.997	92893.032	-11	107.60376	92933.555 92934 301
13	107.53763	107.65721	92990.702	92887.413	-1	107.60202	92935.060
14	107.53193	107.66031	92995.630	92884.743	2	107.60104	92935.906
16	107.52014	107.66625	93005.767	92879.615	-2	107.59917	92937.516
17	107.51422	107.66908	93010.952	92877.178	-2	107.59781	92938.691
18	107.50813	107.67178	93016.219 93021 547	928/4.846	-1 -8	107.59659	92939.747
20	107.49569	107.67694	93026.986	92870.397	12	107.59397	92942.010
21	107.48934	107.67937	93032.483	92868.300	21	107.59251	92943.269
22	107.48293	107.68173	93038.029 93043.670	92866.264 92864.314	-33	107.59105	92944.536 92946.109
24	107.46983	107.68613	93049.368	92862.473	21	107.58790	92947.259
25	107.46316	107.68810	93055.144	92860.773	*	107.58628	92948.659
27	107.44929	107.69267	93067.160	92856.831	*	107.58321	92951.304
28		107.69453		92855.225			
29		107.09038		<sup>12</sup> C <sup>18</sup> O			
0	107.60400		92933.352		27		
1	107.59955	107 (1/2)	92937.192	00000 010	55	107.60836	92929.585 <sup>e</sup>
$\frac{2}{3}$	107.59511	107.61678	92941.031 92944 996	92922.312 92918 772	17	107.60822	92929.706 <sup>e</sup> 92929.887 <sup>e</sup>
4	107.58584	107.62483	92949.035	92915.365	-2	107.60773	92930.126 <sup>e</sup>
5	107.58106	107.62868	92953.167	92912.037	0	107.60739	92930.419 <sup>e</sup>
7	107.57010	107.63247	92957.390 92961.697	92908.705	-3 5	107.60654	92930.764° 92931.157 <sup>e</sup>
8	107.56615	107.63974	92966.048	92902.491	õ	107.60602	92931.607 <sup>e</sup>
9	107.56100	107.64325	92970.497	92899.461	-9	107.60543	92932.116
11	107.55046	107.64997	92979.611	92893.665	-11	107.60397	92933.372
12	107.54503	107.65320	92984.303	92890.876	-2	107.60321	92934.028
13	107.53955	107.65634	92989.044 92993 904	92888.170 92885 544	-7/	107.60235	92934.775 92935 572
15	107.52828	107.66233	92998.790	92882.997	1	107.60042	92936.445
16	107.52252	107.66519	93003.776	92880.528	4	107.59934	92937.375
18	107.51070	107.67063	93013.963	92875.837	-9	107.59706	92939.341
19	107.50473	107.67321	93019.164	92873.614	1	107.59580	92940.430
20	107.49860	107.67569	93024.466 93029 814	928/1.4/0 92869 405	-4 -8	107.59443	92941.612 92942 772
22	107.48616	107.68035	93035.238	92867.451	-11	107.59162	92944.045
23	107.47978	107.68256	93040.760	92865.549	-3	107.58998	92945.456
25	107.46683	107.68669	93051.971	92861.983	-3	107.58688	92948.140
26	107.46014	107.68865	93057.762	92860.293	-8	107.58506	92949.710
27	107.45351	107.69048	93063.499 93069 388	92858.715 92857 294	0 _4	107.58360	92950.973 92951 910
29	107.43989	107.69387	93075.298	92855.794	-7	107.58105	92953.173
30	107.43292	107.69540	93081.335	92854.479	3	107.57945	92954.554
32	107.42591 107.41878	107.69826	93093.596	92852.013	-1/ 33	107.37778	72733.999
33	107.41161	107.69950	93099.802	92850.943			
34	107.40443	107.70077	93106.030	92849.846			

Notes. Column description (see also Sect. 2.2) for each isotopologue. Col. 1: J. Cols. 2 and 3:  $R_{ms}$  and  $P_{ms}$  wavelengths (nm). Cols. 4 and 5:  $R_{ms}$  and  $P_{ms}$  wavenumbers (cm<sup>-1</sup>). Col. 6:  $\delta_P$  wavenumber corrections applied to  $TV_P$  in units of the least significant digit ( $-\delta_P$  is applied to  $TV_R$ ). No value means no measurement for one of the branches, either *R* or *P*. An asterisk indicates, when both *R*- and *P*-branches are present at high *J'*, either the potential presence of a perturbing state or that one of the lines shows a larger uncertainty than the other. Cols. 7 and 8:  $Q_{ms}$  *Q*-branch wavelengths and wavenumbers. <sup>(a)</sup> Data from Cacciani & Ubachs (2004). <sup>(c)</sup> Data calculated from the *e*-parity levels.

Table A.20. Measured transition	wavelengths and wavenumbe	ers of the $E^1\Pi(v'=0)$	$X^{1}\Sigma^{+}(v''=0)$ band for <sup>13</sup> .	$C^{16}O$ , ${}^{13}C^{17}O$ , and	<sup>13</sup> C <sup>18</sup> O (same
column description as for Table A.	19).				

			$E^{1}\Pi(v'=0)$ -	$-X^{1}\Sigma^{+}(v''=0)$			
J	Rms (nm)	Pms (nm)	$R_{ms}$ (cm <sup>-1</sup> )	Pms (cm <sup>-1</sup> )	δρ	$O_{ms}$ (nm)	$Q_{ms}$ (cm <sup>-1</sup> )
0	107.60376	m3 ()	92933.553		23	107 (0010	00000.0017
2	107.59926	107.61659	92937.440 92941.275	92922.479	68 27	107.60810	92929.804 <sup>a</sup> 92929.918 <sup>a</sup>
3	107.59023	107.62070	92945.241	92918.925	-13	107.60777	92930.092 <sup>a</sup>
4 5	107.58552 107.58070	107.62468 107.62851	92949.311 92953.476	92915.492 92912.187	3	107.60750 107.60717	92930.323 <sup>a</sup> 92930.610 <sup>a</sup>
6	107.57584	107.63234	92957.679	92908.877	-3	107.60677	92930.956 <sup>a</sup>
7	107.57084	107.63602	92961.993	92905.701	-7	107.60630	92931.358 <sup>a</sup> 92931.763
9	107.56060	107.64316	92970.843	92899.543	-8	107.60518	92932.327
10 11	107.55535	107.64661 107.64991	92975.381 92980.029	92896.567 92893.715	-4 20	107.60447	92932.942 92933.557
12	107.54459	107.65316	92984.687	92890.910	-14	107.60299	92934.217
13 14	107.53905	107.65633	92989.481 92994.338	92888.178 92885.575	0	107.60209	92935.000 92935.794
15	107.52774	107.66231	92999.260	92883.016	-13	107.60018	92936.650
16 17	107.52191	107.66519	93004.302 93009 337	92880.535 92878 182	27	107.59905	92937.628 92938 514
18	107.51012	107.67064	93014.503	92875.829	23	107.59679	92939.579
19 20	107.50409	107.67323	93019.715 93025.050	92873.598 92871.427	23	107.59553	92940.661 92941 891
21	107.49172	107.67816	93030.424	92869.342	28	107.59282	92943.003
22	107.48546	107.68043	93035.838 93041 382	92867.385 92865.460	-5	107.59148	92944.160 92945 551
24	107.47261	107.68475	93046.965	92863.660	1	107.58820	92946.995
25 26	107.46605	107.68679	93052.640 93058.477	92861.903 92860.232	6	107.58637	92948.576
20	107.45267	107.69058	93064.230	92858.636	5		
28	107.44588	107.69221	93070.108	92857.231	0		
30	107.43201	107.69552	93082.124	92854.375	-2		
31 32	107.42497	107.69702	93088.224 93094 389	92853.084 92851.942	12		
33	107.41063	107.69967	93100.652	92850.799	-2		
34 35	107.40336	107.70084	93106.955	92849.785 92848.853	11		
36	107.38854	107.70298	93119.810	92847.940	-2		
37	107.38103	107.70392	93126.323	92847.136 92846.474	58		
39	107.36595	107.70557	93139.398	92845.709			
40	107.35877		93145.628	<sup>13</sup> c <sup>17</sup> o			
0	107 59949		92937 243				
2	107.59504		92941.084				
3	107.59047		92945.036		*		
5	107.58150		92952.785		*		
6	107.57715	107.63162	92956.546	92909.503 92906.536	-56		
8	107.56722	107.63901	92965.127	92903.125	-36		
9 10	107.56219	107.64246	92969.472	92900.146 92897.238	-12		
11	107.55184	107.64913	92978.418	92894.390	12		
12	107.54657	107.65230	92982.973	92891.654	-4		
13	107.53574	107.65832	92992.343	92886.459	3		
15	107.53022	107.66122	92997.115	92883.958	-2	107 50040	02027 247
10	107.51889	107.66672	93006.917	92881.555 92879.208	4	107.59832	92938.251
18	107.51307	107.66932	93011.949	92876.965	8	107.59717	92939.246
20	107.50127	107.67430	93022.154	92872.674	-16		
21	107.49522	107.67665	93027.391	92870.646	-22		
22 23	107.48910	107.68103	93032.080 93038.060	92868.720 92866.871			
24	107.47664		93043.472				
25 26	107.4/028 107.46373		93054.650	12 10			
0	107.60441		92932.991	<sup>13</sup> C <sup>18</sup> O	-19		
1	107.60012	107 61 650	92936.696	02022 550	26	107.60856	92929.407 <sup>a</sup>
3	107.59165	107.62041	92940.247 92944.020	92922.550 92919.180	*	107.60844	92929.516" 92929.681 <sup>a</sup>
4	107.58719	107.62438	92947.871	92915.754	*	107.60799	92929.902 <sup>a</sup>
5	107.58258	107.62854	92951.852 92955.869	92912.160 92908.903	*	107.60767	92930.175 <sup>a</sup> 92930.504 <sup>a</sup>
7	107.57319	107.63544	92959.963	92906.207	66	107.60685	92930.888 <sup>a</sup>
8	107.56841	107.63888	92964.094 92968.338	92903.230 92900.478	31	107.60638	92931.291 92931.809
10	107.55853	107.64539	92972.639	92897.613	16	107.60516	92932.348
11	107.55345	107.65151	92977.030 92981.424	92894.975	-3	107.60370	92932.917 92933.609
13	107.54305	107.65450	92986.015	92889.750	19	107.60286	92934.331
14	107.53234	107.66023	92990.620 92995.282	92887.223 92884.808	-1	107.60102	92935.925
16	107.52688	107.66297	93000.000	92882.449	6	107.60013	92936.688
17	107.51565	107.66817	93009.715	92800.203 92877.957	26	107.59892	92938.722
19	107.50994	107.67065	93014.658	92875.823	11	107.59665	92939.697
20	107.49825	107.67534	93024.768	92871.778	-10	107.59396	92940.780
22	107.49230	107.67755	93029.921	92869.868	-17	107.59262	92943.178
23	107.48010	107.68167	93040.480	92866.318	6	107.58943	92945.938
25 26	107.47394	107.68362	93045.815 93051 319	92864.633 92863.004	8	107.58782	92947.324 92949 017
27	107.46122	107.68733	93056.824	92861.432	-6	101.00000	22749.017
28 29	107.45480	107.68896	93062.384 93068.057	92860.027 92858 679	6		
30	107.44170	107.69209	93073.734	92857.331	-1		
31 32	107.43503	107.69348	93079.514 93085 459	92856.129 92854 951	11 58		
33	107.42148	107.69613	93091.251	92853.845	0		
34 35	107.41462	107.69730	93097.193 93103 107	92852.841 92851 904	-8		
36	107.40033	107.69940	93109.581	92851.025	91		
37 38	107.39327	107.70034	93115.701 93121.953	92850.214 92849.564	54 93		
39	107.37894	107.70181	93128.133	92848.949			
40	10737738	101/2/0254	93133 825	97848 319			

Notes.  $^{(a)}$  Data from Cacciani & Ubachs (2004) (same column description as for Table A.19).

Ī	~	PV1	0.110	0.066	-0.066	-0.043	0.271	0.406	0.674	0.788	1.051	1.312	1.523	1.733	2.079	2.348	2.793	2.980	3.340	3.768	4.166	4.503	4.973	5.292	5.679	6.144	6.332													
18O	f nor (0)	-par. (2)	92932.900 00020.0044	92939.994	92964.828 <sup>a</sup>	92982.563 <sup>a</sup>	$93003.844^{a}$	93028.671 <sup>a</sup>	93057.006	93088.945	93124.392	93163.355	93205.926	93252.010	93301.595	93354.773	93411.338	93471.663	93535.404	93602.603	93673.387	93747.784	93825.568	93907.037	93991.966	94080.358	94172.509													
13 C	A more (D.9.D)	e-pai. (Nor ) J	92933.010 (-19) 010.65229	(07) C01.04626	92964.762 (*)	92982.520 (*)	93004.115 (125)	93029.077 (*)	93057.680 (66)	93089.733 (76)	93125.443 (31)	93164.667 (16)	93207.449 (19)	93253.743 (-3)	93303.675 (19)	93357.121 (22)	93414.130 (-1)	93474.644 (6)	93538.743 (15)	93606.371 (26)	93677.553 (11)	93752.286 (27)	93830.541 (-10)	93912.329 (-17)	93997.645 (-21)	94086.502 (6)	94178.841 (8)	942/4./98 (14)	94374.230 (-0) 04477134 (6)	01583 607 (6)	94693 532 (-1)	94806.976 (11)	94923.983 (58)	95044.372 (0)	95168.285 (-8)	95295.635 (-60)	95426.758 (91)	95561.129 (54)	95698.962 (93)	95840.259 0508/1 375
	V	$p_{VI}$															2.695	3.007	3.373																				_	
0	f nor (0)	/ -par. (2)															93423.571	93485.311	93550.600																					
130	a more (D.P. D)	e-pai. (Novr)	100.01000	120-04626	92966.508	92984.470 (*)	93006.594 (*)	93031.813 (121)	93061.093 (-56)	93093.972 (-36)	93130.487 (-12)	93170.667 (-4)	93214.514 (12)	93261.994 (-4)	93313.108 (1)	93367.880 (3)	93426.266 (-2)	93488.318 (-1)	93553.973 (4)	93623.295 (8)	93696.218 (2)	93772.782 (-16)	93852.983 (-22)	93936.765	94024.193	94115.203	94209.849	161.80646												
		PV 050	0.001.0	0.102	0.229	0.321	0.469	0.600	0.840	0.981	1.171	1.422	1.719	1.964	2.285	2.617	2.922	3.379	3.715	4.130	4.461	5.036	5.603	6.018	6.465	6.839														
~16O	f nor (0)	J-pai. (2)	72933.480	046.04626	92967.080	92985.744 <sup>a</sup>	93008.141 <sup>a</sup>	93034.267 <sup>a</sup>	93064.068	93097.699	93135.052	93176.072	93220.805	93269.325	93321.522	93377.441	93437.142	93500.410	93567.511	93638.282	93712.853	93790.953	93872.742	93958.408	94047.766	94140.896														
2) 13(	(D & D)	e-pai. (Nocr)	(07) 000 000 000	(00) 040.14670	92967.309 (-13)	92986.065 (3)	93008.610 (0)	93034.867 (-3)	93064.908 (-7)	93098.680 (4)	93136.223 (-8)	93177.494 (4)	93222.524 (20)	93271.289 (-14)	93323.807 (0)	93380.058 (8)	93440.065 (-13)	93503.789 (27)	93571.227 (7)	93642.412 (23)	93717.314 (23)	93795.989 (22)	93878.345 (28)	93964.425 (-5)	94054.231 (8)	94147.735 (1)	94244.954 (6)	(0) 6/ 6.04000 (0) (0) (0) (0) (0) (0) (0) (0) (0)	(C) / CC.0C446 (0) 228 855 (0)	(0) CC0.0CCFC	94786 606 (-2)	94905.981 (12)	95029.057 (-2)	95155.825 (-2)	95286.218 (11)	95420.319 (38)	95558.078 (-2)	95699.410 (58)	95844.488	95993.041 96144 880
	, v	PV -	0.06	0110	0.221	0.311	0.435	0.616	0.800	166.0	1.186	1.403	1.688	1.973	2.272	2.595	2.914	3.326	3.690	4.105	4.490	5.002	5.450	5.838	6.470	6.969	7.441	105.8	10 563	107.01	12 473									
	f nor (D)	J-par. (2)	74725247	260.04626	92966.743°	92985.343 <sup>e</sup>	$93007.656^{e}$	93033.675 <sup>e</sup>	93063.409 <sup>e</sup>	93096.859	93134.063	93174.965	93219.526	93267.830	93319.833	93375.560	93434.991	93498.062	93564.887	93635.401	93709.645	93787.501	93869.101	93954.467	94043.304	94135.934	94232.325	94552.024	010.02449	07525700	94766 874									
12	a nov (DP. D)	e-pai. (ACC)	(17) 070.0000	(CC) 067.04676 (T1) 000 C20C0	92966.964 (3)	92985.655 (-2)	93008.091 (0)	93034.290 (-3)	93064.209 (5)	93097.850 (0)	93135.249 (-9)	93176.368 (-7)	93221.214 (-11)	93269.803 (-2)	93322.106 (-7)	93378.155 (11)	93437.905 (1)	93501.388 (4)	93568.577 (-9)	93639.506 (3)	93714.135 (1)	93792.503 (-4)	93874.551 (-8)	93960.305 (-11)	94049.774(-3)	94142.903 (-5)	94239.766(-1)	(2-) (227) (-2) (-2) (-2) (-2) (-2) (-2) (-2) (-2	(U) 000000000000000000000000000000000000	(1-) 1517774 04664 061 (-7)	94779 347 (3)	94898.307 (-17)	95020,894 (33)	95147.182	95277.045					
		PV1	CI1.0	761.0	0.324	0.406	0.547	0.677	0.863	1.054	1.282	1.540	1.773	2.087	2.391	2.707	3.260	3.479	3.880	4.261	4.773	5.214	5.719	5.997	6.816	7.353		\$.125												
с17 <b>О</b>	f nor (D)	J-pai. (2)	7204.02626	92041.015	92967.718	92986.750 <sup>e</sup>	93009.589 <sup>e</sup>	93036.235 <sup>e</sup>	93066.689 <sup>e</sup>	93100.951	93138.997	93180.817	93226.498	93275.929	93329.181	93386.198	93446.804	93511.579	93579.962	93652.174	93728.049	93807.799	93891.273	93978.765	94069.544	94164.280	00717010	94.004.098												
12	1 more (D.9. D)	e-pai. (Nocr)	(17) C/C.66676	07057 672 (40)	92968.042 (8)	92987.156 (1)	93010.137 (2)	93036.912 (19)	93067.553 (1)	93102.005 (1)	93140.279 (-15)	93182.357 (-10)	93228.270 (-11)	93278.016 (-3)	93331.572 (-1)	93388.904 (2)	93450.064 (-2)	93515.058 (-3)	93583.842 (-2)	93656.435 (-1)	93732.822 (-8)	93813.013 (12)	93896.992 (21)	93984.762 (3)	940/6.360 (-33)	94171.633 (21)	94270.495 (*)	() 777777777777777777777777777777777777	( ) 600.08446											
		0.045	0.0100	0.120	0.229	0.363	0.508	0.657	0.851	1.058	1.274	1.555	1.858	2.154	2.504	2.839	3.156	3.629	4.050	4.507	4.916	5.496	5.993	6.435	180.7	1.678	8.282	176.0	771.6	777.01										
	f nor (0)	1-par. (2)	2020.000	92941.044	92968.980"	92988.5024	$93011.929^{a}$	$93039.258^{a}$	$93070.488^{a}$	93105.634	93144.672	93187.609	93234.382	93285.114	93339.694	93398.212	93460.682	93526.855	93597.021	93671.007	93748.983	93830.681	93916.344	94005.944	94099.250	94196.467	94297.544	C84:20446	94511.144 04673 037	700007040										
12	0 P. (D.P.D)	e-par. (Nor.)	(DC) 8/ 8.22220	92941.744 (JJ) 02052 400717)	92969.209 (17)	92988.865 (-1)	93012.438 (-6)	93039.915 (4)	93071.339 (3)	93106.692 (3)	93145.946 (-6)	93189.164 (-1)	93236.240 (-19)	93287.268 (-7)	93342.198 (5)	93401.050 (-4)	93463.838 (-1)	93530.484 (-5)	93601.072 (-3)	93675.514 (15)	93753.899 (18)	93836.178 (-2)	93922.337 (6)	94012.379 (-13)	94106.331 (-14)	94204.145(1)	94305.826 (-5)	94411.400 (9)	94520.800 (2) 94634 154 (8)	0/751 320 (-8)	94872 072 (*)	94996.743 (*)	95125.965	95258.538	95395.000					
t		, -	- (	4 0	0 <del>4</del>	5	9	2	~	6	10	Ξ	12	13	4	15	16	17	18	19	50	51	ន	3	51	<u>ค</u>	88	26	8 P	1 F	3 ल	32	33	2	35	36	37	38	<u> </u>	<del>9</del>

**Notes.** The  $\delta_P$  value in parentheses (in units of the least significant digit) corresponds to the wavenumber correction applied to TV<sub>P</sub> and TV<sub>P</sub>. There is no value when the term value is derived from a single transition, either *R* or *P*. An asterisk indicates when both *R*- and *P*-branches are present at high *J'*, either the potential presence of a perturbing state or that one of the lines shows a larger uncertainty than the other (see also Sect. 2.2.2). Each third column is the  $\Lambda$ -type doubling (cm<sup>-1</sup>) of the <sup>1</sup> $\Pi$  state:  $\Lambda_d = TV_{R\&P}-TV_Q$ . <sup>(a)</sup> Data from Cacciani & Ubachs (2004). <sup>(\*)</sup> Data calculated from the *e*-parity levels.

**Table A.22.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v'=1)-X^{1}\Sigma^{+}(v''=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ , and  ${}^{12}C^{18}O$  (same column description as for Table A.19).

**Table A.23.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v'=1)-X^{1}\Sigma^{+}(v''=0)$  band for  ${}^{13}C^{16}O$ ,  ${}^{13}C^{17}O$ , and  ${}^{13}C^{18}O$  (same column description as for Table A.19).

	1		$E^1\Pi(v'=1)$	$-X^{1}\Sigma^{+}(v''=0)$							$E^1 \Pi(v'=1)$	$X^{1}\Sigma^{+}(v''=0)$ $X^{13}C^{16}O$			
J	R <sub>ms</sub> (nm)	$P_{ms}$ (nm)	$R_{ms} ({ m cm}^{-1})$	$P_{ms}$ (cm <sup>-1</sup> )	$\delta_P$	Q <sub>ms</sub> (nm)	$Q_{ms}$ (cm <sup>-1</sup> )	J	R <sub>ms</sub> (nm)	P <sub>ms</sub> (nm)	$R_{ms} (\text{cm}^{-1})$	Pms (cm <sup>-1</sup> )	$\delta_P$	Qms (nm)	$Q_{ms} (cm^{-1})$
0	105.16712		95086.757		-11	105 17156	05082 741b	0	105.21928		95039.616 95043 351		-2	105 22332	95035 969b
2	105.15842	105.17985	95094.620	95075.244	-5	105.17145	95082.841 <sup>b</sup>	2	105.21101	105.23149	95045.086	95028.592	12	105.22332	95035.958 <sup>b</sup>
3	105.15401	105.18408	95098.607	95071.424	26	105.17129	95082.987 <sup>b</sup>	3	105.20672	105.23551	95050.961	95024.962	2	105.22333	95035.961 <sup>b</sup>
4	105.14960	105.18818	95102.595	95067.718 95063 954	2	105.17138	95082.898 <sup>o</sup> 95083.036 <sup>b</sup>	4	105.20255	105.23953	95054.730	95021.333	1	105.22320	95036.078 <sup>b</sup>
6	105.14016	105.19638	95111.132	95060.305	69	105.17133	95082.951 <sup>b</sup>	5	105.19838	105.24335	95058.502	95017.877	-2	105.22326	95036.021 <sup>b</sup> 95036.180 <sup>b</sup>
7	105.13607	105.20042	95114.839	95056.654	19	105.17065	95083.564 <sup>b</sup>	7	105.18922	105.25127	95066.774	95010.732	-9	105.22244	95036.763 <sup>b,u</sup>
8	105.13178	105.20409	95118.714	95053.340	-1 37	105.17100	95083.249 <sup>b,u</sup> 95083.108 <sup>b</sup>	8	105.18501		95070.579		15	105.22255	95036.662 <sup>b,u</sup>
10	105.12216	105.20858	95125.488	95049.405	-8	105.17048	95083.718 <sup>b,u</sup>	9	105.18037	105.25836	95074.771	95004.330	-28	105.22265	95036.575 <sup>D,U</sup>
11	105.11726	105.21584	95131.857	95042.726	-80	105.17060	95083.607 <sup>b,u</sup>	10	105.17161	105.26233	95078.656	95000.745	-2 16	105.22222	95036.836 <sup>b,u</sup>
12	105.11267	105.21988	95136.013	95039.074	-9	105.17018	95083.991 <sup>10</sup> 95083.938 <sup>b,u</sup>	12	105.16712	105.26961	95086.751	94994.181	8	105.22220	95036.978 <sup>b,u</sup>
14	105.10324	105.22734	95144.549	95032.335	-2	105.17012	95084.042 <sup>b,u</sup>	13	105.16257	105.27330	95090.869	94990.850	20	105.22204	95037.126 <sup>b,u</sup>
15	105.09840	105.23114	95148.930	95028.909	19	105.17004	95084.116 <sup>b,u</sup>	14	105.15799	105.27690	95095.006	94987.595	-4	105.22187	95037.276 <sup>D,U</sup>
16	105.09356	105.23487	95153.311 95157.692	95025.540 95022.226	14 -16	105.16980	95084.331 <sup>b,u</sup> 95084.442 <sup>b,u</sup>	16	105.14874	105.28396	95103.377	94981.227	-2	105.22105	95037.640 <sup>b,u</sup>
18	105.08382	105.24214	95162.129	95018.968	-15	105.16943	95084.664 <sup>b,u</sup>	17	105.14408	105.28746	95107.593	94978.069	-6	105.22124	95037.849 <sup>b,u</sup>
19	105.07886	105.24569	95166.622	95015.767	16	105.16922	95084.853 <sup>b,u</sup> 95085.018 <sup>b,u</sup>	18	105.13937	105.29091	95111.847	94974.964	-1	105.22106	95038.011 <sup>b,u</sup>
20	105.06894	105.25278	95175.608	95009.364	-24	105.16886	95085.176 <sup>b,u</sup>	20	105.12988	105.29433	95120.433	94968.820	-7	105.22081	95038.441 <sup>b,u</sup>
22	105.06392	105.25621	95180.157	95006.275	-11			21	105.12510	105.30105	95124.765	94965.811	-6	105.22021	95038.775 <sup>b,u</sup>
23	105.05883	105.25963	95184.762 95189.311	95003.186	-31			22	105.12027	105.30436	95129.135	94962.826	* 5	105.22014	95038.842 <sup>b,u</sup>
25	105.04867	105.26641	95193.973	94997.064	77			23	105.110542	105.31010	95135.520	94957.656	-23	105.21979	95059.100
26	105.04358	105.26971	95198.579	94994.087	*			25	105.10568	105.31410 105.31724	95142.338 95146.831	94954.048 94951.216	-18 8		
28	105.03317	105.27687	95208.014	94990.942	*			27	105.09575	105.32038	95151.324	94948.381	-26		
29	105.02804	105.28042	95212.665	94984.427	*			29	105.08578	105.32648	95160.353	94945.509	63		
30	105.02280	105.28396	95217.416	94981.226 94978.081	*			30	105.08074 105.07567	105.32955 105.33272	95164.920 95169.508	94940.122 94937.264			
32		105.29094		94974.936				32	105.07059		95174.114				
33		105.29437		94971.836				34	105.06558		95178.646				
35		105.30108		94965.791				0	105 25000		05011 872	<sup>13</sup> C <sup>17</sup> O	2		
36		105.30449		94962.708				1	105.24604		95015.447		3	105.25399	95008.279 <sup>u</sup>
0	105 19698		95059 762	<sup>12</sup> C <sup>17</sup> O	-1			2	105.24203	105.26189	95019.067	95001.140 94997 548	-1	105.25399	95008.279 <sup>u</sup> 95008.246 <sup>u</sup>
1	105.19279		95063.545		-11	105.20115	95055.999 <sup>u</sup>	4	105.25010	105.26978	95022.502	94994.020		105.25402	95008.095 <sup>u</sup>
2	105.18855	105.20942	95067.381	95048.522	-2	105.20111	95056.030 <sup>u</sup>	5	105.22903	105.27384	95030.806 95034.455	94990.356	0	105.25212 105.25321	95009.966 <sup>u</sup> 95008.983 <sup>u</sup>
4	105.18425	105.21551	95075.037	95044.828 95041.151	-4	105.20094	95055.989 <sup>e</sup> 95056.184 <sup>e</sup>	7	105.22120	105.28056	95037.878	94984.293	-1	105.25330	95008.896 <sup>u</sup>
5	105.17557	105.22160	95079.115	95037.518	-1	105.20094	95056.188 <sup>e</sup>	8	105.21645	105.28444 105.28857	95042.168 95046.007	94980.792 94977.067	0	105.25354	95008.681 <sup>u</sup> 95009.127 <sup>u</sup>
6	105.17126	105.22569	95083.007	95033.825 95030.408	2	105.20128	95055.882 <sup>e</sup> 95056 754 <sup>e</sup>	10	105.20789	105.29174	95049.901	94974.207	-3	105.25296	95009.203 <sup>u</sup>
8	105.16198	105.23347	95091.405	95026.804	-7	105.20031	95056.693 <sup>e</sup>	11	105.20351	105.29540 105.29900	95053.858 95057.843	94970.906 94967.659	-2 -4	105.25284 105.25269	95009.312 <sup>n</sup> 95009.447 <sup>u</sup>
9	105.15765	105.23793	95095.312	95022.772	7	105.19994	95057.086 <sup>e</sup>	13	105.19468	105.30253	95061.837	94964.476	-4	105.25254	95009.581 <sup>x</sup>
10	105.14848	105.24075	95103.611	95016.645	3	105.19988	95057.147 <sup>e</sup>	14	105.19019	105.30602	95065.895 95069.935	94961.328 94958.190	-3	105.25236 105.25216	95009.746 <sup>x</sup> 95009.924 <sup>x</sup>
12	105.14389	105.24826	95107.760	95013.447	17	105.19971	95057.297 <sup>e</sup>	16	105.18119	105.31292	95074.029	94955.107	-2	105.25195	95010.114 <sup>x</sup>
13	105.13929	105.25208	95111.926 95116.128	95009.998 95006.647	-19	105.19953	95057.640 <sup>e</sup>	18	105.17204	105.31969	95082.301	94949.003	-1	105.25149	95010.529 <sup>x</sup>
15	105.12994	105.25944	95120.384	95003.353	40	105.19912	95057.828 <sup>e</sup>	19	105.16747	105.32300	95086.432	94946.019	-1	105.25125	95010.753 <sup>x</sup> 95010.988 <sup>x</sup>
16	105.12522	105.26299	95124.654	95000.155 94996 833	15 *	105.19890	95058.026 <sup>e</sup> 95058.232 <sup>e</sup>	20	105.15806	105.32960	95094.941	94940.069	~	105.25070	95011.233 <sup>x</sup>
18	105.11566	105.27014	95133.302	94993.697	-20	105.19844	95058.445 <sup>e</sup>	22	105.15337	105.33272	95099.183	94937.257		105.25043 105.25014	95011.488 <sup>x</sup> 95011.754 <sup>x</sup>
19	105.11079	105.27376	95137.713	94990.432	25			24						105.24983	95012.029 <sup>x</sup>
20 21	105.10590	105.27699	95142.141	94987.519 94984.400	90			25				<sup>13</sup> C <sup>18</sup> O		105.24952	95012.313 <sup>x</sup>
22	105.09636	105.28392	95150.777	94981.263				0	105.27550		94988.861	00	35		
23	105.09106		95155.568 95159.911					1	105.27239	105 28719	94991.669	0/078 312	58	105.27943	94985.317 <sup>a</sup> 94984 570 <sup>b</sup> ,u
25	105.08194		95163.833					3	105.26511	105.29187	94994.815	94974.090	10	105.28020	94984.220 <sup>b,u</sup>
26	105.07707		95168.244					4	105.26112	105.29598	95001.835	94970.383	57	105.28082	94984.067 <sup>b,u</sup>
	100.071/4		,5115.015	<sup>12</sup> C <sup>18</sup> O				5	105.25720	105.29997	95005.373	94966.789	*	105.28079	94984.086 <sup>b,u</sup>
0	105.22385		95035.489		-15	105 00000	05021 0524	7	105.23285	105.30585	95009.505	94959.712	41 6	105.28064	94984.227 <sup>b,u</sup>
	105.21971	105 23598	95039.225	95024 533	12	105.22776	95031.953 <sup>o</sup> 95031.929 <sup>b</sup>	8	105.24464	105.31099	95016.718	94956.848	56	105.28062	94984.240 <sup>b,u</sup>
3	105.211340	105.24001	95046.773	95020.893	2	105.22764	95032.064 <sup>b</sup>	9	105.24047	105.31461	95020.481	94953.590	52	105.28049	94984.358 <sup>b,u</sup>
4	105.20718	105.24389	95050.548	95017.388	15	105.22775	95031.968 <sup>b</sup>	10	105.23630	105.31828	95024.246	94950.277	-7	105.28040	94984.441 <sup>b</sup> ,u
5	105.20308	105.24785	95054.254	95013.817 95010.244	28 17	105.22789	95031.841 <sup>b</sup> 95031.804 <sup>b</sup>	12	105.22778	105.32526	95031.938	94943.986	-10	105.28010	94984.710 <sup>b,u</sup>
7	105.19390	105.25584	95062.545	95006.605	25	105.22666	95032.947 <sup>b</sup>	13	105.22337	105.32875	95035.926	94940.841	19	105.27994	94984.853 <sup>b,u</sup>
8	105.18973	105.25840	95066.319	95004.297	8	105.22726	95032.407 <sup>b,u</sup>	14	105.21901	105.33218	95039.858	94937.752	22	105.27973	94985.049 <sup>b,u</sup>
10	105.18510	105.26286	95074.406	94996.765	11	105.22728	95032.784 <sup>b</sup>	15	105.21400	105.33334	95043.789	94934.719	6	105.27933	94985.459 <sup>b,u</sup>
11	105.17638	105.27025	95078.383	94993.597	-36	105.22685	95032.775 <sup>b,u</sup>	17	105.20577	105.34221	95051.820	94928.710	-14	105.27908	94985.634 <sup>b,u</sup>
12	105.17183	105.27399	95082.494	94990.227	20	105.22668	95032.932 <sup>b,u</sup> 95033.041 <sup>b,u</sup>	18	105.20129	105.34545	95055.864	94925.789	-2	105.27881	94985.874 <sup>b,u</sup>
13	105.16728	105.28123	95090.717	94983.690	4	105.22630	95033.284 <sup>b</sup>	19	105.19676	105.34869	95059.964	94922.869	11 _1	105.27884	94985.849 <sup>0</sup> 94986 161b
15	105.15812	105.28474	95094.895	94980.523	32	105.22604	95033.509 <sup>b</sup>	20	105.19222	105.355195	95068.220	94917.084	18	105.27816	94986.462 <sup>b</sup>
16	105.15357	105.28826	95099.006	94977.354	-39 -6	105.22596	95033.579 <sup>b</sup> 95033.835 <sup>b</sup>	22	105.18302	105.35823	95072.376	94914.276	11	105.27790	94986.695 <sup>b</sup>
18	105.14418	105.29513	95107.498	94971.154	-11	105.22554	95033.959 <sup>b</sup>	23	105.17843 105.17377	105.36135 105.36440	95076.532 95080.744	94911.468 94908.716	6		
19	105.13950	105.29857	95111.731	94968.054	-41	105.22533	95034.154 <sup>b</sup>	25 26	105.16911 105.16439	105.36746 105.37045	95084.957 95089.225	94905.964 94903.268	-20 14		
20 21	105.13479	105.30192 105.30522	95115.994 95120 386	94965.033 94962.055	-14	105.22512 105.22482	95034.342 <sup>o</sup> 95034.616 <sup>b</sup>	27	105.15960	105.37338	95093.550	94900.629	23		
22	105.12524	105.30867	95124.632	94958.942	*	105.22465	95034.769 <sup>b</sup>	28	105.15488 105.15010	105.37637 105.37924	95097.818 95102.143	94897.932 94895.349	-22		
23	105.12047	105.31179	95128.953	94956.132	-8 *			30 31	105.14526 105.14043	105.38205 105.38493	95106.522 95110.887	94892.822 94890.225	2 0		
24 25	105.11541	105.31491	95135.534 95137.938	94955.520	*			32	105.13554	105.38770	95115.311	94887.732	-73		
26		105.32201		94946.914				33 34	105.13070	105.39047	95119.094 95124.053	94882.956			
27		105.32201		94946.914				_							

**Notes.** <sup>(b)</sup>Data from Baker et al. (1993). <sup>(a)</sup>Data from Ubachs et al. (2000). <sup>(e)</sup>Data calculated from the *e*-parity levels.

**Notes.** <sup>(b)</sup>Data from Baker et al. (1993). <sup>(u)</sup>Data from Ubachs et al. (2000). <sup>(e)</sup>Data calculated from the *e*-parity levels. <sup>(x)</sup>Data calculated from the *e*-parity levels using the deperturbation described in Ubachs et al. (2000).

5
2
-
Ĕ
ä
F
5
e
õ
5
ğ
S
es
E
õ
0
do
ot
is
0
Ũ
×
SI.
G
£
S
×
le
N
÷
parit
f-parit
d <i>f</i> -parit
and <i>f</i> -parit
- and <i>f</i> -parit
e- and f-parit
1) $e$ - and $f$ -parit
= 1) $e$ - and $f$ -parit
v' = 1) $e$ - and $f$ -parit
$\Pi(v' = 1) e$ - and $f$ -parit
$\mathcal{E}^{1} \prod (v' = 1) e^{-}$ and $f$ -parit
$E^{1}\Pi(v'=1) e^{-}$ and $f^{-}$ parit
he $E^1 \Pi(v' = 1)$ <i>e</i> - and <i>f</i> -parit
f the $E^1 \Pi(v' = 1)$ e- and f-parit
of the $E^1 \Pi(v' = 1)$ <i>e</i> - and <i>f</i> -parit
<sup>1</sup> ) of the $E^1 \Pi(v' = 1)$ <i>e</i> - and <i>f</i> -parit
$n^{-1}$ ) of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit
$\operatorname{cm}^{-1}$ ) of the $E^1 \Pi(v' = 1)$ <i>e</i> - and <i>f</i> -parit
$(\text{cm}^{-1})$ of the $E^1 \Pi(v' = 1)$ <i>e</i> - and <i>f</i> -parit
les (cm <sup>-1</sup> ) of the $E^1 \Pi(v' = 1)$ e- and f-parit
lues (cm <sup>-1</sup> ) of the $E^1\Pi(v' = 1) e^-$ and $f$ -parit
values (cm <sup>-1</sup> ) of the $E^{1}\Pi(v' = 1) e^{-1}$ and $f^{-1}$
n values (cm <sup>-1</sup> ) of the $E^1\Pi(v'=1) e^-$ and $f$ -parit
trm values (cm <sup>-1</sup> ) of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit
Term values (cm <sup>-1</sup> ) of the $E^{1}\Pi(v' = 1) e^{-1}$ and $f$ -parit
<b>I.</b> Term values $(\text{cm}^{-1})$ of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit
<b>24.</b> Term values $(\text{cm}^{-1})$ of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit
<b>A.24.</b> Term values $(\text{cm}^{-1})$ of the $E^{1}\Pi(v' = 1) e^{-1}$ and $f$ -parit
e A.24. Term values (cm <sup>-1</sup> ) of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit
<b>ble A.24.</b> Term values $(\text{cm}^{-1})$ of the $E^1\Pi(v' = 1) e^-$ and $f$ -parit
<b>able A.24.</b> Term values $(\text{cm}^{-1})$ of the $E^1 \Pi(v' = 1) e^-$ and $f$ -parit

_	_	_																								_										
		$\Lambda_d$	0.016	0.056	0.125	0.193	0.230	0.428	0.594	0.777	0.883	1.080	1.294	1.512	1.733	2.014	2.287	2.528	2.914	3.207	3.792	3.793	4.440	4.880												
<sup>3</sup> C <sup>18</sup> O	(O) /	J-par. (Q)	94988.809"	94995.048 <sup>b,µ</sup>	95005.176 <sup>b,µ</sup>	95018.993 <sup>b,µ</sup>	95036.474 <sup>b.u</sup>	95057.200 <sup>b</sup> #	95082.010 <sup>b</sup> #	95109.955 <sup>b,µ</sup>	95141.494 <sup>b.u</sup>	95176.485 <sup>b,u</sup>	95215.002 <sup>b.u</sup>	95257.027 <sup>b.u</sup>	95302.532 <sup>b,u</sup>	95351.572 <sup>b,u</sup>	95404.072 <sup>b,u</sup>	95460.109 <sup>b,µ</sup>	95519.563 <sup>b,u</sup>	95582.555 <sup>b,u</sup>	$95648.756^{b}$	$95719.066^{b}$	$95792.226^{b}$	$95869.086^{b}$												
	/D 0 D/	e-par. (K&P)	94988.826 (35)	94995.104 (58)	95005.301 (-8)	95019.186 (10)	95036.704 (57)	95057.628 (*)	95082.604 (41)	95110.732 (6)	95142.377 (56)	95177.565 (52)	95216.296 (-7)	95258.539(19)	95304.265 (-10)	95353.586(19)	95406.358 (22)	95462.637 (-1)	95522.476 (6)	95585.762 (-14)	95652.547 (-2)	95722.859 (11)	95796.666 (-1)	95873.966 (18)	95954.755 (11)	96039.005 (7)	96126.766 (6)	96218.010 (-20)	96312./03 (14)	96410.928 (23)	96512.597 (-22)	96617.699 (1)	96726.316 (2)	96838.360 (0)	(5/-) 006.55606	9/0/2.814 97195 137
		$\Lambda_d$	0.017	0.008	0.087	0.153	1.859	0.355	0.516	0.579	0.848	1.040	1.254	1.505	1.789	2.051	2.359	2.651	2.980	3.339	3.697	4.039	4.534	4.946	5.375											
C <sup>17</sup> O	· · · · / ·	J-par. (U)	95011.857"	95019.015"	95029.718"	95043.880"	95063.643"	95084.128"	95109.085"	95137.490"	95170.129"	95205.972"	95245.420"	95288.464"	95335.075 <sup>x</sup>	95385.285 <sup>x</sup>	95439.074 <sup>x</sup>	95496.438 <sup>x</sup>	95557.375 <sup>x</sup>	95621.883 <sup>x</sup>	95689.958 <sup>x</sup>	95761.600 <sup>x</sup>	95836.803 <sup>x</sup>	95915.566 <sup>x</sup>	95997.887 <sup>x</sup>	96083.760 <sup>x</sup>	96173.183 <sup>x</sup>									
13	(D.0.D)	e-par. (K&P)	95011.874 (-2)	95019.023 (3)	95029.804 (-1)	95044.034	95065.501	95084.483 (0)	95109.601 (-1)	95138.068 (-1)	95170.977 (0)	95207.012 (-2)	95246.673 (-3)	95289.968 (-2)	95336.864 (-4)	95387.336 (-4)	95441.433 (2)	95499.088 (-3)	95560.355 (-2)	95625.222 (-2)	95693.656 (-1)	95765.639 (-1)	95841.338 (2)	95920.512	96003.261											
		$\Lambda_d$	-0.028	0.037	0.086	0.178	0.331	0.273	-1.376	0.726	0.922	1.101	1.416	1.626	1.879	2.171	2.474	2.805	3.149	3.551	3.924	4.359	4.677	5.295	6.056											
3C160	· · · · · · · ·	$f$ -par. ( $\mathcal{U}$ )	$95039.645^{b}$	$95046.985^{b}$	$95058.015^{b}$	$95072.835^{b}$	$95091.155^{b}$	$95113.365^{b}$	95139.672 <sup>b.u</sup>	95168.967 <sup>b.u</sup>	95201.948 <sup>b,µ</sup>	95239.071 <sup>b,µ</sup>	95279.350 <sup>b,u</sup>	95323.565 <sup>b.u</sup>	95371.452 <sup>b,u</sup>	95423.004 <sup>b,u</sup>	95478.264 <sup>b,u</sup>	95537.154 <sup>b,u</sup>	95599.745 <sup>b µ</sup>	95665.943 <sup>b,u</sup>	95735.856 <sup>b,u</sup>	$95809.403^{b,u}$	95886.725 <sup>b,u</sup>	95967.425 <sup>b.u</sup>	96052.017"											
	/D 0 D/	e-par. (K&P)	95039.617 (-2)	95047.022 (5)	95058.102 (12)	95073.014 (2)	95091.486(1)	95113.638 (-2)	95138.296	95169.692 (-9)	95202.869 (15)	95240.172 (-28)	95280.767 (-2)	95325.191 (16)	95373.330 (8)	95425.175 (20)	95480.738 (-4)	95539.959 (-6)	95602.894 (-2)	95669.495 (-6)	95739.780 (-1)	95813.762 (1)	95891.402 (-7)	95972.720 (-6)	96058.072 (*)	96146.373 (5)	96238.694 (-23)	96334.675 (-18)	90434.323 (8)	96537.662 (-26)	96644.586 (-16)	96755.095 (63)	96869.400	96987.277	9/108./81	97255.816 97357 920
	-	$\Lambda_d$	-0.111	-0.039	-0.006	0.158	0.386	0.455	0.651	0.829	0.978	1.090	1.368	1.581	1.876	2.104	2.349	2.784	3.066	3.514	3.930	4.368	4.668	5.304												
<sup>2</sup> C <sup>18</sup> O	0 0 0	$f$ -par. ( $\mathcal{U}$ )	$95035.615^{b}$	$95042.915^{b}$	$95054.035^{b}$	$95068.585^{b}$	$95086.765^{b}$	$95108.695^{b}$	$95135.465^{b}$	95164.209 <sup>b.u</sup>	95197.135 <sup>b.u</sup>	$95234.125^{b}$	95274.368 <sup>b,#</sup>	95318.430 <sup>b,µ</sup>	95366.096 <sup>b.u</sup>	95417.545 <sup>b</sup>	$95472.625^{b}$	$95531.195^{b}$	$95593.595^{b}$	$95659.505^{b}$	$95729.125^{b}$	$95802.375^{b}$	$95879.345^{b}$	$95959.825^{b}$												
	/D 0 D/	e-par. (K&P)	95035.504 (-15)	95042.876 (12)	95054.029 (24)	95068.743 (2)	95087.151 (15)	95109.150 (28)	95136.116 (17)	95165.038 (25)	95198.113 (8)	95235.215 (25)	95275.736 (11)	95320.011 (-36)	95367.972 (20)	95419.649 (11)	95474.974 (4)	95533.979 (32)	95596.661 (-39)	95663.019 (-6)	95733.055 (-11)	95806.743 (-41)	95884.013 (15)	95965.129 (-14)	96049.800 (112)	96137.973 (-8)	96229.827 (*)	96326.848 (*)								
		$\Lambda_d$	0.017	0.031	0.151	0.084	0.116	0.752	0.024	-0.202	0.612	0.826	1.246	1.376	1.609	1.867	2.180	2.448	2.807	3.149																
C <sup>17</sup> O	· · · · /0/	f-par. (Q)	95059.746"	95067.273"	95078.475 <sup>e</sup>	95093.661°	95112.401 <sup>e</sup>	95134.578 <sup>e</sup>	95161.677 <sup>e</sup>	95191.588 <sup>e</sup>	95225.695 <sup>e</sup>	95263.088 <sup>e</sup>	$95304.408^{e}$	95349.493 <sup>e</sup>	95398.331°	95450.915 <sup>e</sup>	95507.244 <sup>e</sup>	95567.313 <sup>e</sup>	$95631.120^{e}$	$95698.660^{e}$																
12	/D 0 D/	e-par. (K&P)	95059.764 (-1)	95067.304 (-11)	95078.626 (-2)	95093.745 (13)	95112.518 (-4)	95135.330 (-1)	95161.701 (2)	95191.386 (4)	95226.307 (-7)	95263.914 (7)	95305.654 (10)	95350.870 (3)	95399.940 (17)	95452.782 (13)	95509.424 (-19)	95569.761 (40)	95633.927 (15)	95701.809 (111)	95773.538 (-20)	95848.955 (25)	95928.090 (90)	96011.085	96097.514	96188.225	96282.196	96379.454	96480.902	96586.468						
	-	$\Lambda_d$	0.182	0.137	0.104	0.305	0.335	0.617	0.592	0.823	1.019	1.307	1.557	1.847	2.152	2.468	2.842	3.159	3.609	3.975	4.402	4.883	5.424													
C l6 O	· · · · / ·	$f$ -par. ( $\mathcal{U}$ )	$95086.586^{b}$	$95094.376^{b}$	$95106.056^{b}$	$95121.346^{b}$	$95140.706^{b}$	$95163.686^{b}$	$95191.206^{b}$	95221.640 <sup>b.u</sup>	$95256.086^{b}$	95295.122 <sup>b.u</sup>	95337.275 <sup>b,u</sup>	$95383.756^{b}$	95433.635 <sup>b,µ</sup>	95487.503 <sup>b,u</sup>	95545.171 <sup>b,µ</sup>	95606.806 <sup>b,u</sup>	95672.162 <sup>b,u</sup>	95741.453 <sup>b,u</sup>	95814.531 <sup>b,µ</sup>	95891.400 <sup>b,u</sup>	95972.079 <sup>b,u</sup>													
12	/ D 0- D/	?-par. (K&P)	95086.768 (-11)	15094.514 (20)	P5106.160 (−5)	05121.651 (26)	05141.042 (2)	P3164.303 (6)	(69) 661:16150	5222.462 (19)	95257.105 (-1)	15296.429 (37)	15338.832 (-8)	95385.603 (-80)	05435.787 (-9)	05489.971 (8)	95548.013 (-2)	15609.965 (19)	0 3675.772 (14)	95745.428 (-16)	15818.933 (-15)	15896.283 (16)	15977.503 (-5)	36062.534 (-24)	06151.401 (-11)	96244.129 (5)	96340.657 (-31)	96440.956 (77)	( ) 9544.954 ( )	96652.787 (*)	96764.482 (* )	96879.924 (*)	96999.193 (*)	77121.216	1/24/.894	1/3/8.4/1 17512 670
1	1	۲	~	5	5	5	5	5	5	5,	5	5	5										5			_		_	_	_	_	_	_		_	

Data calculated from the e-parity levels using the deperturbation described Data calculated from the e-parity levels. **Notes.** <sup>(b)</sup> Data from Baker et al. (1993). <sup>(u)</sup> Data from Ubachs et al. (2000). <sup>(\*)</sup> in Ubachs et al. (2000). **Table A.25.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v'=2)-X^{1}\Sigma^{+}(v''=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ , and  ${}^{12}C^{18}O$  (same column description as for Table A.19).

**Table A.26.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v'=2)-X^{1}\Sigma^{+}(v''=0)$  band for  ${}^{13}C^{16}O$ ,  ${}^{13}C^{17}O$ , and  ${}^{13}C^{18}O$  (same column description as for Table A.19).

			$E^1 \Pi(v' = 2)$ -	$-X^1\Sigma^+(v^{\prime\prime}=0)$			
				${}^{12}C^{16}O$			
J	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} (cm^{-1})$	$P_{ms} (cm^{-1})$	$\delta_P$	$Q_{ms}$ (nm)	$Q_{ms}$ (cm <sup>-1</sup> )
0	102.92548		97157.676		-6	2000	2
1	102.92149		97161.438		0	102.92955	97153.831
2	102.91750	102.93769	97165.201	97146.152	9	102.92968	97153.712
3	102.91364	102,94186	97168.852	97142.214	-30	102.92987	97153.531
4	102.90977	102.94604	97172.503	97138.271	2	102.93012	97153.288
5	102.90596	102.95023	97176.098	97134.311	-21	102,93045	97152.979
6	102,90216	102.95458	97179.692	97130.212	13	102.93085	97152.604
7	102.89847	102.95887	97183.174	97126.168	-9	102.93132	97152.156
8	102.89478	102.96327	97186.656	97122.012	-1	102,93189	97151.626
9	102.89116	102.96768	97190.082	97117.856	9	102,93249	97151.060
10	102.88759	102.97214	97193.452	97113.644	-8	102.93315	97150.430
11	102.88402	102.97667	97196.821	97109.375	4	102,93387	97149.752
12	102.88058	102.98120	97200.079	97105.106	_9	102.93447	97149.189
13	102 87707	102 98578	97203 392	97100 782	35	102 93557	97148 150
14	102 87374	102 99043	97206 538	97096 401	8	102 93653	97147 243
15	102 87041	102 99514	97209 684	97091 965	20	102 93757	97146 265
16	102 86714	102 99986	97212 772	97087 508	23	102 93865	97145 240
17	102.86394	103.00467	97215.802	97082.977	-1	102.93981	97144.145
18	102.86080	103.00951	97218 770	97078 413	0	102 94111	97142 922
19	102.85773	103 01436	97221 671	97073 848		102 94247	97141 638
20	102.85469	103.01933	97224 538	97069158		102.94386	97140 325
21	102.85173	105.01755	97227 342	77007.150		102.94540	97138 875
22	102.84890		97230.019			102.94540	97137 393
23	102.84597		97232 789			102.94867	97135 788
2.5	102.04377		71252.107	<sup>12</sup> C <sup>17</sup> O		102.74007	71155.700
	102 07070		07107.292	0	25		
0	102.97878		9/10/.382		33	102 08274	07102 654
	102.97490	102 00078	97111.040	07006.067	-0	102.98274	97103.034
2	102.97103	102.99078	07118 266	07002 324	-20	102.98287	07103.331
1	102.90724	102.99475	07121 202	07092.324	20	102.98505	07102.140
5	102.90340	102.99885	97121.092	97088.479	12	102.96326	97103.140
6	102.93973	103.00300	97123.334	97084.550	-12	102.96336	97102.805
	102.95002	103.00718	07122.830	97030.012	-40	102.98595	97102.511
s s	102.93230	103.01153	07135 732	97070.047	-17	102.98444	97102.052
o o	102.94675	103.01355	97135.752	97072.747	36	102.96497	97101.555
10	102.94324	103.02424	07142 346	97068.037	50	102.98550	97100.995
10	102.94172	103.02424	07145.607	97060 302		102.98008	07000.498
12	102.95017	105.02075	57145.057	27000.502		102.98762	97099.052
12						102.08830	07008 400
14						102.98030	97097 534
14				<sup>12</sup> C <sup>18</sup> O		102.70725	71071.554
	103 02681		07062 114	0	8		
	103.02001		97065 713		2	103 03074	97058 409
	103.02299	103 03849	97069.246	97051 112	_0	103.03074	97058 302
	103.01524	103.03049	07072 780	07047 401	- 2	103.03102	07058 141
	103.01348	103.04243	97076.267	97047.401	ŝ	103.03103	97050.141
5	103.00800	103.05049	97079 754	07030 820	17	103.03154	97057.658
6	103.00446	103.05454	97083 175	97035.007	8	103.03189	97057.336
7	103.000440	103.05454	97086 540	97032 127	1	103.03108	97056.950
	102.00008	103.05005	07080.049	07028 249	-6	103.03228	07056 519
ů	102.99751	103.06277	97009.914	97026.248	21	103.03273	97056.518
10	102.99579	103.00094	97095.255	97024.322	41	103.03328	97050.019
11	102.99050	103.07542	97090.400	97016 340	3	103.033440	97055.511
12	102.98095	103.07970	97102 866	97012 227	78	103.03440	97054.904
12	102.98557	103.07979	07102.000	07008 200	70	103.03522	07053 502
13	102.9601/	103.06400	97100.070	97008.209		103.03595	97055.502
14	102.97550	103.06639	3/110.4/9	97003.940		103.03070	97052.741
1 12 1	1					103.03739	2/031.93/

			$E^1\Pi(v'=2)$	$-X^{1}\Sigma^{+}(v''=0)$			
I	D (nm)	D (nm)	<b>P</b> (am <sup>-1</sup> )	P (am <sup>-1</sup> )	8	0 (nm)	0 (cm <sup>-1</sup> )
J 0	K <sub>ms</sub> (nm) 103.01876	r'ms (nm)	97060 703	$r'_{ms}$ (cm <sup>-1</sup> )	0P 22	$Q_{ms}$ (nm)	$Q_{ms}$ (cm )
1	103.01491		97073 325		13	103 02267	97066.018
2	103.01111	103.03051	97076.906	97058.631	3	103.02278	97065.907
3	103.00738	103.03445	97080.427	97054,919	-6	103.02296	97065.740
4	103.00364	103.03843	97083.951	97051.171	10	103.02320	97065.518
5	102.99998	103.04248	97087.394	97047.358	-1	103.02349	97065.241
6	102.99633	103.04657	97090.837	97043.502	-3	103.02384	97064.911
7	102.99272	103.05069	97094.242	97039.620	6	103.02420	97064.573
8	102.98915	103.05483	97097.605	97035.724	4	103.02468	97064.124
9	102.98565	103.05903	97100.908	97031.767	-6	103.02532	97063.518
10	102.98217	103.06325	97104.192	97027.792	-4	103.02581	97063.059
11	102.97870	103.06752	97107.459	97023.776	10	103.02644	97062.463
12	102.97533	103.07183	97110.642	97019.722	3	103.02715	97061.790
13	102.97195	103.07618	97113.828	97015.629	-1	103.02791	97061.079
14	102.96865	103.08057	9/116.936	97011.496	-1	103.028/2	97060.313
15	102.96538	103.08496	9/120.023	97007.364	11	103.02965	97059.438
10	102.96217	103.08945	97125.050	97003.132	1 40	102.02058	97058.559
19	102.95905	103.09390	07120.01/	06004 630	-49	103.03104	97057.508
10	102.95388	103.09849	97120.903	96994.030	∠1 *	103.03275	97050.522
20	102.95282	103 10776	97134 730	96985 913	*	103.03508	97054 320
21	102.94691	103.11073	97137.450	96983.118	*	103.03646	97053.028
22	102,94389	103.11393	97140.297	96980.108		103.03784	97051.724
23	102.94110	103.11717	97142.928	96977.056		103.03936	97050.297
24	102.93836		97145.520			103.04087	97048.873
				<sup>13</sup> C <sup>17</sup> O			
0	103.07389		97017.780		*		
1	103.06991		97021.526		*	103.07767	97014.220
2		103.08426		97008.020			
3		103.08762		97004.859			
4		103.09098		97001.697			
5		103.09442		96998.460			
6		103.09783		96995.252			
7		103.10130		96991.987			
8		103.10479		96988.704			
9		103.10830		96985.403			
10		103.11187		90982.045			
12		103.11344		90978.087			
12		105.11900		<sup>13</sup> C <sup>18</sup> O			
0	103 12332		96971 277	0	12		
1	103.11968		96974 703		2	103 12705	96967 768
2	103.11603	103.13449	96978.129	96960.774	20	103.12715	96967.673
3	103.11245	103.13825	96981.499	96957.237	10	103.12730	96967.530
4	103.10887	103.14208	96984.868	96953.642	1	103.12751	96967.341
5	103.10535	103.14590	96988.182	96950.047	21	103.12776	96967.104
6	103.10188	103.14973	96991.440	96946.453	-15	103.12806	96966.822
7	103.09842	103.15367	96994.697	96942.746	-22	103.12841	96966.495
8	103.09496	103.15755	96997.955	96939.096	0	103.12880	96966.123
9	103.09156	103.16150	97001.156	96935.389	-4	103.12923	96965.717
10	103.08821	103.16550	97004.302	96931.626	-8	103.12977	96965.212
11	103.08487	103.16951	97007.446	96927.863	-19	103.13031	96964.706
12	103.08153	103.17357	97010.591	96924.044	14	103.13091	96964.145
1.5	103.07831	103.17/62	9/013.625	96920.243	-8	103.13156	96963.531
14	103.07506	103.181/0	97010.079	90910.358	-40	105.13228	96962.853
15	103.0/188	103.18389	97019.0/1	90912.473	-30	103.13304	90902.141
17	103.06568	103.19417	97025 511	96904 702	-30	103.13468	96960 592
18	103.06260	103.19849	97028 409	96900 645	_9	103.13568	96959 659
19	103.05955	103,20280	97031.282	96896.593	13	103.13669	96958.706
20	103.05660	103.20716	97034.059	96892.506	5	103.13770	96957.754
21	103.05368	103.21153	97036.804	96888.399	56	103.13883	96956.691
22	103.05083	103.21594	97039.488	96884.260	-23		
23	103.04801	103.22051	97042.147	96879.976	68		
24	103.04519	103.22485	97044.804	96875.897	-5		
25	103.04237	103.22958	97047.462	96871.456			
26	103.03987	103.23396	97049.812	96867.351			
27	1 103.03702		97052.493				

**Table A.27.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v'=3)-X^{1}\Sigma^{+}(v''=0)$  band for  ${}^{12}C^{16}O$ ,  ${}^{12}C^{17}O$ , and  ${}^{12}C^{18}O$  (same column description as for Table A.19).

V D+

**Table A.28.** Measured transition wavelengths and wavenumbers of the  $E^{1}\Pi(v' = 3)-X^{1}\Sigma^{+}(v'' = 0)$  band for  ${}^{13}C^{16}O$ ,  ${}^{13}C^{17}O$ , and  ${}^{13}C^{18}O$  (same column description as for Table A.19).

	1		$E \Pi(v = 5)$	$-X \ge (v = 0)$			
	_		. <u></u> .	<u>C</u> 0			
J	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms} (cm^{-1})$	$P_{ms} (cm^{-1})$	$\delta_P$	$Q_{ms}$ (nm)	$Q_{ms}$ (cm <sup>-1</sup> )
0	101.08858		98923.141		-59		
1	101.08548		98926.174		-34	101.09248	98919.326
2	101.08256	101.10025	98929.039	98911.724	53	101.09335	98918.475
3	101.08020	101.10506	98931.341	98907.018	26	101.09455	98917.301
4	101.07825	101.11017	98933.250	98902.019	3	101.09616	98915.725
5	101.07665	101.11562	98934.815	98896.689	33	101.09822	98913.710
6	101 07544	101 12148	98936.003	98890 958	41	101 10069	98911 293
7	101.07469	101 12780	98936 739	98884 777	40	101 10362	98908 427
l é l	101.07459	101 13446	08036 838	08878 266	-60	101.10502	08005 160
	101.07439	101.13440	00026 670	00071.205	-00	101.10095	98905.109
9	101.07475	101.14158	98930.079	988/1.505	-48	101.11074	98901.462
10	101.07544	101.14911	98936.003	98863.945	-94	101.11499	98897.305
11	101.07630	101.15/15	98935.160	98856.087	-22	101.11970	98892.698
12	101.07785	101.16560	98933.644	98847.830	-36	101.12492	98887.594
13	101.07978	101.17446	98931.754	98839.173	47	101.13067	98881.971
14	101.08211	101.18383	98929.473	98830.021	*	101.13687	98875.909
15	101.08552	101.19378	98926.134	98820.303	0	101.14365	98869.281
16	101.08923	101.20415	98922.503	98810.177	31	101.15095	98862.146
17	101.09327	101.21512	98918.550	98799.468	*	101.15888	98854.396
18	101.09779	101.22674	98914.131	98788.127	*	101.16739	98846.081
19	101.10357	101.23877	98908.472	98776.388		101.17658	98837.102
20	101 10950	101 25154	98902 677	98763 930		101 18636	98827 549
21	101 11626	101.20101	98896.065	201021220		101 19684	98817 315
22	101.11020		70070.005			101.20805	08806 370
22						101.20803	98800.570
25						101.22003	98/94.6/4
24						101.23283	98/82.180
25						101.24633	98769.012
				${}^{12}C^{17}O$			
0	101.13600		98876.756		2		
1	101.13290		98879.787		-16	101.13989	98872.957
2	101.13009	101.14751	98882.538	98865.508	-8	101.14060	98872.263
3	101.12768	101.15204	98884.898	98861.081	-20	101.14169	98871.197
4	101.12550	101.15691	98887.031	98856.321	-17	101.14313	98869.790
5	101 12383	101 16214	98888 661	98851 211	17	101 14497	98867 991
6	101 12245	101 16763	08800.008	08845 846	_25	101 14724	08865 772
7	101.12245	101.17270	00001 010	08820.016	-25	101.14724	08863.772
6	101.12142	101.17570	96691.019	96639.910	-30	101.14978	96605.290
	101.12078	101.17990	96691.039	90033.039	65	101.15275	90000.307
9	101.12077	101.18052	98891.048	98827.595		101.15692	98850.512
10	101.12142	101.19378	98891.019	98820.505		101.16215	98851.201
11	101.12294		98889.535			101.16773	98845.749
12	101.12494		98887.576			101.17359	98840.023
13	101.12675		98885.803			101.17997	98833.791
14	101.12915		98883.455			101.18654	98827.374
15	101.13187		98880.802			101.19376	98820.323
16	101.13448		98878.242			101.20130	98812.960
				<sup>12</sup> C <sup>18</sup> O			
0	101.18111		98832.677		1		
	101.17796		98835.754		-81	101.18489	98828,985
2	101.17514	101.19236	98838.509	98821.690	3	101.18551	98828.380
3	101.17264	101.19654	98840.951	98817.608	4	101.18649	98827.423
4	101 17044	101 20130	98843 101	98812 872	0	101 18782	98826 124
5	101.17044	101.20139	08844 029	08807.000		101.10702	08824 522
5	101.10057	101.20039	20044.928	20007.220	-0	101.10940	20024.322
	101.16702	101.21108	98846.442	98802.820	24	101.19144	98822.588
	101.16582	101.21/29	98847.015	98/9/.550	2	101.19379	98820.295
8	101.16497	101.22330	98848.445	98/91.484	-4	101.19656	98817.588
9	101.16445	101.22955	98848.953	98785.384	14	101.19953	98814.688
10	101.16440	101.23618	98849.002	98778.915	-25	101.20292	98811.378
11	101.16463	101.24319	98848.777	98772.075	-73	101.20678	98807.610
12	101.16505	101.25055	98848.367	98764.896		101.21085	98803.636
13	101.16650	101.25817	98846.950	98757.462		101.21547	98799.126
14	101.16820		98845.289			101.22059	98794.127
15	101.16989		98843.638				
16	101.17207		98841.508				
17	101.17424		98839.388				
18	101.17702		98836.673				
19	101 17967		98834 084				
20	101 18946		98824 522				
21	101 18255		98831 271				
41	101.10233		20031.271				

			$E^1 \Pi(v'=3)$ -	$-X^{1}\Sigma^{+}(v''=0)$			
				<sup>13</sup> C <sup>16</sup> O			
J	$R_{ms}$ (nm)	$P_{ms}$ (nm)	$R_{ms}$ (cm <sup>-1</sup> )	$P_{ms}$ (cm <sup>-1</sup> )	$\delta_P$	$Q_{ms}$ (nm)	$Q_{ms} (cm^{-1})$
0	101.17336		98840.250		1	2	2
1	101.17017		98843.366		13	101.17705	98836.643
2	101.16738	101.18465	98846.091	98829.220	-14	101.17774	98835.969
3	101.16489	101.18901	98848.525	98824.961	8	101.17884	98834.895
4	101.16270	101.19369	98850.667	98820.391	-13	101.18003	98833.732
5	101.16080	101.19877	98852.516	98815.430	11	101.18183	98831.974
6	101.15927	101.20406	98854.014	98810.265	11	101.18372	98830.128
7	101.15821	101.20974	98855.048	98804.720	-30	101.18621	98827.696
8	101.15725	101.21573	98855.992	98798.872	31	101.18885	98825.118
9	101.15683	101.22211	98856.401	98792.645	16	101.19200	98822.041
10	101.15720	101.22879	98856.039	98786.126	*	101.19548	98818.643
11	101.15795	101.23586	98855.302	98779.227	*	101.19927	98814.942
12	101.15914	101.24320	98854.145	98772.066		101.20345	98810.861
13	101.16051	101.24981	98852.807	98765.617		101.20825	98806.174
14	101.16179		98851.554			101.21322	98801.323
15	101.16382		98849.572			101.21881	98795.866
16	101.16664		98846.813			101.22533	98/89.503
1/	101.16932		98844.197			101.23138	98/83.599
18	101.17231		98841.274			101.24046	98774.739
19	101.17528		98838.371	130170			
0				10			
1						101.13448	98878.242 <sup>1</sup>
				<sup>13</sup> C <sup>18</sup> O			
0	101.27772		98738.403		41		
1	101.27466		98741.379		1	101.28135	98734.861
2	101.27178	101.28855	98744.187	98727.842	18	101.28187	98734.354
3	101.26925	101.29258	98746.658	98723.914	-17	101.28267	98733.574
4	101.26689	101.29690	98748.961	98719.704	1	101.28377	98732.502
5	101.26482	101.30146	98750.983	98715.260	-8	101.28509	98731.215
6	101.26297	101.30630	98752.780	98710.544	11	101.28665	98729.694
7	101.26142	101.31137	98754.297	98705.604	8	101.28855	98727.842
8	101.26015	101.31673	98755.532	98700.382	2	101.29074	98725.708
9	101.25917	101.32233	98756.487	98694.927	-3	101.29322	98723.291
10	101.25848	101.32821	98757.161	98689.200	-11	101.29592	98720.659
11	101.25801	101.33438	98757.615	98683.191	3	101.29898	98717.677
12	101.25813	101.34083	98757.499	98676.910	*	101.30244	98714.305
13	101.25864	101.34755	98757.004	98670.367	*	101.30596	98710.875
14	101.25951	101.35460	98/56.160	98663.504	*	101.31006	98706.881
15	101.260/8	101.36193	98/54.922	98656.369	*	101.31444	98/02.613
16	101.26242	101.36964	98753.321	98648.866	*	101.31912	98698.054
1/	101.26433	101.37/66	98/51.456	98641.062	*	101.32420	98693.106
18	101.26639	101.38603	98/49.448	98632.918	*	101.32965	98687.798
19		101.394/8		98024.407		101.53550	98082.101
20		101.40394		98615.498		101.34180	980/5.900
21		101.41328		98006.415		101.34846	98009.482
22						101.33301	96002.321
23						101.30318	90033.133
24	1					101.37144	20047.114

**Notes.** <sup>(*t*)</sup> A small signal for  ${}^{13}C{}^{17}O$  may be indicative of the *Q*-branch position.

	$\Lambda_d$	0.004	0.043	0.102	0.179	0.302	0.387	0.518	0.664	0.817	1.040	1.209	1.442	1.685	1.936	2.253	2.539	2.776	3.129	3.486	3.821	4.201							
<sup>13</sup> C <sup>18</sup> O	f-par. ( $Q$ )	96971.261	96978.151	96988.486	97002.267	97019.492	97040.162	97064.278	97091.838	97122.853	97157.256	97195.144	97236.462	97281.210	97329.376	97380.988	97436.035	97494.520	97556.341	97621.612	97690.355	97762.455							
	e-par. (R&P)	96971.265 (12)	96978.195 (2)	96988.588 (20)	97002.445 (10)	97019.794 (1)	97040.549 (21)	97064.796 (-15)	97092.502 (-22)	97123.670(0)	97158.296 (-4)	97196.353 (-8)	97237.903 (-19)	97282.895 (14)	97331.312 (-8)	97383.242 (-40)	97438.574 (-56)	97497.296 (-30)	97559.469 (-30)	97625.099 (-9)	97694.176 (13)	97766.655 (5)	97842.511 (56)	97921.902 (-23)	98004.558 (68)	98090.838 (-5)	98180.495	98273.304 08360 804	1-20.20206
	$\Lambda_d$	0.469																											_
<sup>13</sup> C <sup>17</sup> O	f-par. (Q)	97017.799																											
	e-par. (R&P)	97018.268 (*)	97025.718 (*)	97037.483	97052.137	97070.397	97092.177	97117.514	97146.406	97178.814	97214.795	97254.300																	
	$\Lambda_d$	-0.013	0.053	0.136	0.212	0.322	0.432	0.543	0.716	1.016	1.117	1.328	1.586	1.822	2.114	2.436	2.730	3.100	3.507	3.834	4.998	6.218	7.350	5.726	6.142	_			-
C <sup>16</sup> O	f-par. (Q)	97069.694	97076.934	97087.795	97102.275	97120.376	97142.096	97167.482	97196.429	97228.890	97265.168	97304.978	97348.378	97395.405	97446.040	97500.229	97558.074	97619.464	97684.455	97753.063	97825.282	97900.978	97980.306	98063.154	98149.643				
(2) 13,	e-par. (R&P)	97069.681 (22)	97076.987 (13)	97087.931 (3)	97102.487 (-6)	97120.697 (10)	97142.528 (-1)	97168.025 (-3)	97197.145 (6)	97229.906 (4)	97266.286 (-6)	97306.305 (-4)	97349.964 (10)	97397.226 (3)	97448.154 (-1)	97502.665 (-1)	97560.803 (11)	97622.564 (1)	97687.962 (-49)	97756.896 (21)	97830.280 (*)	97907.196 (*)	97987.656 (*)	98068.880	98155.785	98246.290			
$E^{\text{III}(V)} =$	$\Lambda_d$	0.035	0.086	0.129	0.208	0.304	0.434	0.582	0.746	0.960	1.103	1.209	1.575	1.729	2.122	3.668													
C <sup>18</sup> 0	f-par. ( $Q$ )	97062.071	97069.288	97080.112	97094.544	97112.582	97134.227	97159.476	97188.320	97220.762	97256.851	97296.557	97339.692	97386.557	97437.002	97491.072													
12	e-par. (R&P)	97062.106 (8)	97069.373 (2)	97080.242 (-9)	97094.752 (8)	97112.886 (-2)	97134.661 (17)	97160.058 (8)	97189.066 (1)	97221.722 (-6)	97257.954 (21)	97297.766 (41)	97341.267 (3)	97388.286 (78)	97439.125	97494.740													
	$\Lambda_d$	-0.055	0.028	0.069	0.142	0.262	0.352	0.618	0.802	1.011	1.036	1.198	1.709																
C <sup>17</sup> 0	f-par. (Q)	97107.402	97114.775	97125.866	97140.617	97159.076	97181.208	97206.976	97236.448	97269.605	97306.563	97347.213	97391.250	97439.278	97490.810														
	e-par. (R&P)	97107.346 (35)	97114.802 (-8)	97125.935 (-20)	97140.758 (-5)	97159.339 (30)	97181.559 (-12)	97207.594 (-48)	97237.250 (-17)	97270.616 (11)	97307.599 (36)	97348.412	97392.959																
	$\Lambda_d$	0.005	0.037	0.127	0.216	0.300	0.450	0.617	0.809	1.009	1.217	1.445	1.530	2.006	2.350	2.671	3.002	3.359	3.813	4.234	4.641	5.143	5.618	6.092					
C <sup>16</sup> 0	f-par. (Q)	97157.676	97165.246	97176.600	97191.736	97210.650	97233.339	97259.798	97290.016	97324.038	97361.834	97403.419	97448.955	97497.848	97550.704	97607.320	97667.716	97731.866	97799.711	97871.316	97946.708	98025.778	98108.626	98195.160					
12	e-par. (R&P)	97157.681 (-6)	97165.283 (0)	97176.728 (9)	97191.952 (-30)	97210.949 (2)	97233.789 (-21)	97260.415 (13)	97290.825 (-9)	97325.047 (-1)	97363.051 (9)	97404.864 (-8)	97450.484 (4)	97499.853 (-9)	97553.054 (35)	97609.991 (8)	97670.718 (20)	97735.224 (23)	97803.524 (-1)	97875.550 (9)	97951.348	98030.921	98114.244	98201.252	98292.161				
	J'		6	ŝ	4	5	9	7	~	6	10	Π	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	1 07

**Table A.30.** Term values (cm<sup>-1</sup>) of the  $E^{1}\Pi(v' = 3)$  e- and f-parity levels for six CO isotopologues (see note to Table A.21).

	_	_	_																_						
	$\Lambda_d$	0.008	0.039	0.118	0.203	0.283	0.344	0.484	0.648	0.819	0.923	1.101	1.428	1.367	1.546	1.639	1.676	1.869	2.107	3.612					
<sup>3</sup> C <sup>I8</sup> O	f-par. (Q)	98738.354	98744.832	98754.530	98767.428	98783.603	98803.035	98825.625	98851.423	98880.427	98912.703	98948.115	98986.622	99028.555	99073.404	99121.461	99172.704	99284.479	99345.007	99408.567	99475.245	99544.912	99617.632	99693.142	
-	e-par. (R&P)	98738.362 (41)	98744.871 (1)	98754.648 (18)	98767.631 (-17)	98783.886 (1)	98803.379 (-8)	98826.109 (11)	98852.071 (8)	98881.246 (2)	98913.626 (-3)	98949.216 (-11)	98988.050 (3)	99029.922 (106)	99074.950 (*)	99123.099 (*)	99174.379 (*)	99286.348 (*)	99347.114 (*)	99412.179					
	$\Lambda_d$							_				_	_												
<sup>13</sup> C <sup>17</sup> O	f-par. ( $Q$ )	98881.821																							
	e-par. ( $R&P$ )																								
	$\Lambda_d$	-0.071	0.032	0.184	0.083	0.329	0.326	0.583	0.565	0.853	1.006	0.944	1.432	0.233	0.083	0.624	1.346	3.422							
<sup>13</sup> C <sup>16</sup> O	f-par. ( $Q$ )	98840.319	98846.997	98856.950	98870.490	98887.108	98907.313	98930.605	98957.423	98987.413	99020.752	99057.457	99097.448	99140.500	99187.050	99236.657	99289.017	99402.671							
	e-par. (R&P)	98840.249 (1)	98847.029 (13)	98857.134 (-14)	98870.572 (8)	98887.437 (-13)	98907.639 (11)	98931.188 (11)	98957.987 (-30)	98988.266 (31)	99021.758 (16)	99058.401 (*)	99098.880 (*)	99140.733	99187.133	99237.281	99290.363	99406.093	99469.206	99535.993					
$E^{-11}(v) = c$	$\Lambda_d$	0.029	0.132	0.099	0.178	0.271	0.380	0.499	0.740	0.820	0.964	1.166	1.309	1.684	1.617										
C <sup>18</sup> 0	f-par. (Q)	98832.647	98839.365	98849.393	98862.741	98879.446	98899.480	98922.811	98949.390	98979.431	99012.719	99049.202	99089.134	99132.181	99178.388										
12	e-par. (R&P)	98832.676 (1)	98839.498 (-81)	98849.492 (3)	98862.919 (4)	98879.718 (0)	98899.860 (-8)	98923.310 (24)	98950.130 (2)	98980.251 (-4)	99013.682 (14)	99050.368 (-25)	99090.444 (-73)	99133.865	99180.005	99229.551	99282.754	99399.149	99462.219	99529.055	99592.555	99676.000			
	$\Lambda_d$	0.049	0.045	0.106	0.138	0.321	0.388	0.516	0.691	1.530	2.991	4.075	4.577	5.113	6.022	6.992	7.970								
C <sup>17</sup> 0	f-par. ( $Q$ )	98876.705	98883.507	98893.684	98907.267	98924.205	98944.468	98968.213	98995.282	99024.921	99057.266	99093.010	99132.220	99174.660	99220.649	99269.739	99322.248								
12	e-par. (R&P)	98876.754 (2)	98883.551 (-16)	98893.790 (-8)	98907.404 (-20)	98924.525 (-17)	98944.857 (17)	98968.729 (-25)	98995.973 (-30)	99026.452 (83)	99060.258	99097.085	99136.797	99179.773	99226.672	99276.730	99330.218								
	$\Lambda_d$	0.029	0.044	0.150	0.211	0.316	0.424	0.628	0.772	0.848	0.996	1.135	1.490	1.777	2.034	2.458	2.567	3.298	3.836	4.217	4.842	5.364			
C <sup>16</sup> 0	f-par. (Q)	98923.171	98930.010	98940.370	98954.174	98971.380	98992.029	99016.069	99043.560	99074.440	99108.709	99146.366	99187.359	99231.669	99279.371	99330.336	99384.621	99502.870	99566.780	99633.932	99704.217	99777.603	99854.046	99933.495	100016.071
12,	e-par. (R&P)	98923.200 (-59)	98930.053 (-34)	98940.521 (53)	98954.385 (26)	98971.696 (3)	98992.453 (33)	99016.697 (41)	99044.332 (49)	99075.288 (-60)	99109.706 (-48)	99147.501 (-94)	99188.849 (-22)	99233.446 (-36)	99281.404 (47)	99332.793 (*)	99387.189 (0)	99444.947 (31)	99570.616 (103)	99638.149	090.00766	99782.967			
╪	J'	_	61	ŝ	4	5	9	7	~	6	10	Ξ	12	13	4	15	16	17	19	20	21	22	23	24	25

**Table A.29.** Term values (cm<sup>-1</sup>) of the  $E^{1}\Pi(v' = 2) e^{-}$  and *f*-parity levels for six CO isotopologues (see note to Table A.21).

# A&A 614, A114 (2018)

**Table A.31.** Molecular constants  $T_v$ ,  $B_v$ , and  $D_v$  of the six CO isotopologues for each state,  $B^1\Sigma^+$ ,  $C^1\Sigma^+$ , and  $E^1\Pi$  for e- and f-parity ( $D_v$  is always kept as a free parameter in the fitting process).

																						1						_
	$-D_v (\times 10^{-6})$		-6.454(62)	-6.801(82)	-5.752(69)	-5.676(84)		-4.245(105)		-8.616(523)	-13.559(1204)	-7.989(453)	-7.970(242)	-5.009(136)	-0.856(856)		-9.328(113)	-6.806(1930)	-9.835(410)	-8.390(90)	-6.896(82)		-58.382(246)	-37.152(19329)	-43.920(6431)	-45.754(17962)	-38.301(3880)	-
	$B_v$	$E00_{f}$	1.95270 (4)	1.90387 (5)	1.85972 (4)	1.86675 (5)		1.77352 (6)	$E10_{f}$	1.92879 (24)	1.88372 (40)	1.83783 (23)	1.84490 (12)	1.79498 (10)	1.75065 (20)	$E20_{f}$	1.89151 (6)	1.84493(36)	1.80427 (6)	1.81106 (4)	1.72321 (4)	$E30_e$	1.72512 (12)	1.69637 (144)	1.67165 (85)	1.67623 (199)	1.61846 (60)	
	$T_v$		92929.9317 (54)	92929.6481 (53)	92929.5452 (45)	92929.7481 (43)		92929.3602 (56)		95082.8140 (227)	95055.9701 (259)	95031.9316 (228)	95035.9422 (127)	95008.5805 (140)	94983.9515 (176)		97153.8983 (54)	97103.7201 (88)	97058.4630 (18)	97066.0601 (37)	96967.8062 (26)		98919.6726 (103)	98873.3289 (198)	98829.3276 (205)	98836.9281 (406)	98735.1064 (170)	
	$-D_v (\times 10^{-6})$		-6.516(19)	-6.304(108)	-5.871(55)	-5.918(13)	-5.989(78)	-5.516(22)		-9.042(190)	-7.715(522)	-6.089(480)	-9.292(1008)	-4.433(413)	-3.196(715)		-9.413(114)	-12.927(10413)	-6.456(3105)	-8.275(237)	-7.524(132)		-55.337(1319)	-22.505(28193)	-44.847(4302)	-72.393(8489)	-35.294(1614)	
	$B_v$	$E00_e$	1.96456 (2)	1.91479 (6)	1.87052 (4)	1.87768 (2)	1.82811 (6)	1.78395 (3)	$E10_e$	1.94090(20)	1.89129 (24)	1.84697(33)	1.85712 (121)	1.80440 (24)	1.75965 (93)	$E20_e$	1.90270 (5)	1.85644 (95)	1.81424 (34)	1.82118 (9)	1.73261 (5)	$E30_e$	1.73377 (48)	1.70479 (209)	1.68059(66)	1.68816 (112)	1.62678 (25)	
	$T_v$		92929.9358 (40)	92929.7231 (53)	92929.5590 (44)	92929.7536 (39)	92929.4750 (87)	92929.2758 (76)		95082.7605 (454)	95055.9480 (237)	95032.0645 (469)	95035.6846 (2739)	95008.6131 (296)	94984.1816 (2353)		97153.8834 (48)	97103.6477 (162)	97058.4759 (70)	97066.0611 (57)	96967.7962 (33)		98919.7206 (317)	98873.3367 (289)	98829.3477 (188)	98836.8720 (271)	98735.1160 (71)	
	$-D_v (\times 10^{-6})$		-6.363(16)	-5.914(40)	-5.641(8)	-5.690(10)	-5.404(27)	-5.130(5)		-6.337(24)	-5.761(162)	-5.644(88)	-5.051(72)	-4.405(130)	-5.280(38)		-5.197(343)		32.499(*)	-1.736(*)	43.594(9531)		-1.933(*)	8.705(*)	9.638(*)	4.310(*)	-8.017(2855)	
	$B_v$	C00	1.94336 (2)	1.89464 (4)	1.85142 (1)	1.85845(1)	1.80969 (3)	1.76641 (1)	C10	1.92385 (3)	1.87569 (8)	1.83317 (6)	1.83959 (9)	1.79134 (12)	1.74951 (4)	C20	1.90283 (19)		1.80991 (190)	1.81989 (92)	1.72615 (143)	C30	1.87571 (72)	1.82668 (813)	1.78947 (161)	1.79608 (198)	1.71070 (65)	
	$T_v$		91919.0328 (53)	91918.9284 (85)	91918.8543 (25)	91919.0551 (37)	91918.8853 (80)	91918.7947 (23)		94065.5649 (47)	94038.5061 (64)	94014.3118 (77)	94018.5116 (213)	93990.4543 (194)	93965.8762 (64)		96176.9248 (190)		96076.3267 (238)	96084.2280 (245)	95981.2762 (379)		98244.5110 (415)	98167.0437 (798)	98097.5876 (428)	98109.1420 (705)	97958.4479 (263)	
-6.121 (0) -5.815 (0) -5.551 (0) -5.593 (0) -5.301 (0) -5.049 (0)	$-D_v (\times 10^{-6})$		-6.739(11)	-6.584(117)	-6.196(28)	-6.191(44)	-5.437(356)	-5.639(46)		-7.408(41)	-4.528(371)	-6.593(24)	-6.715(35)	-5.212(352)	-5.975(27)		9.682(3169)		39.098(*)	12.410(3659)	37.719(8152)							-
<b>X0</b> 1.92253 (0) 1.87396 (0) 1.83098 (0) 1.83797 (0) 1.78940 (0) 1.74641 (0)	$B_v$	B00	1.94814(1)	1.89904 (8)	1.85548 (3)	1.86254 (5)	1.81312 (18)	1.76980 (4)	B10	1.92199 (5)	1.87334 (19)	1.83120 (2)	1.83818 (3)	1.78966 (17)	1.74738 (2)	B20	1.87355 (47)		1.78362 (155)	1.79341 (47)	1.69520 (235)							
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000	$T_v$		86916.1484 (32)	86916.4584 (102)	86916.7386 (54)	86916.8158 (83)	86917.1248 (168)	86917.3644 (69)		88998.3150 (97)	88972.9899 (174)	88950.2474 (34)	88954.0973 (40)	88928.1002 (139)	88904.7410 (31)		90988.2294 (126)		90899.3726 (195)	90906.3225 (105)	90815.2393 (1206)							
1216 1217 1217 1218 1316 1316 1317 1318			1216	1217	1218	1316	1317	1318		1216	1217	1218	1316	1317	1318		1216	1217	1218	1316	1318		1216	1217	1218	1316	1317 1318	

**Notes.** Standard errors are given in parentheses in units of the least significant digit, and for  $D_v$ , an asterisk indicates that the standard error is higher than 50% of the value. A ninth-order polynomial is used for the ground state X0.

# J. L. Lemaire et al.: Atlas of new and revised high-resolution spectroscopy of six CO isotopologues in the 101-115 nm range

**Table A.32.** Molecular constants  $T_v(1)$ ,  $q_v$ , and  $q_{Dv}$  of the six CO isotopologues for the  $E^1\Pi$  state, calculated from the previous table:  $T_v(J=1)$  is the average of  $T_v$  for *e*- and *f*-parity,  $q_v = B_e - B_f$ , and  $q_{Dv} = D_e - D_f$ .

Species	$T_v(1)$	$q_v$	$q_{Dv} (\times 10^{-6})$
		E00	
1216	92929.9338(47)	0.01186(3)	-0.06(4)
1217	92929.6856(53)	0.01092(5)	0.50(10)
1218	92929.5521(44)	0.01080(4)	-0.12(6)
1316	92929.7509(41)	0.01093(3)	-0.24(5)
1317	92929.4750(87)		
1318	92929.3180(66)	0.01043(4)	-1.27(6)
		E10	
1216	95082.7873(341)	0.01211(22)	-0.43(36)
1217	95055.9591(248)	0.00757(32)	5.84(86)
1218	95031.9981(348)	0.00914(28)	1.90(47)
1316	95035.8134(1433)	0.01222(67)	-1.32(63)
1317	95008.5968(218)	0.00942(17)	0.58(27)
1318	94984.0666(1264)	0.00900(57)	-2.34(79)
		E20	
1216	97153.8909(51)	0.01119(6)	-0.09(11)
1217	97103.6839(125)	0.01151(65)	-6.12(617)
1218	97058.4695(44)	0.00997(20)	3.38(176)
1316	97066.0606(47)	0.01012(6)	0.12(16)
1317			
1318	96967.8012(29)	0.00940(4)	-0.63(11)
		E30	
1216	98919.6966(210)	0.00865(30)	3.04(78)
1217	98873.3328(243)	0.00842(177)	14.65(2376)
1218	98829.3377(197)	0.00894(75)	-0.93(537)
1316	98836.9001(338)	0.01193(156)	-26.64(1323)
1317			
1318	98735.1112(120)	0.00832(42)	3.01(275)

**Table A.33.** Molecular constants  $q_v$  and  $q_{Dv}$  of the six CO isotopologues for the  $E^1\Pi$  state, obtained from a second-order regression through the data.

	Species	N	$q_v$	$q_{Dv} (\times 10^{-6})$
		E00		
1	1216	29	0.01173(9)	0.10(12)
	1217	26	0.01082(21)	0.61(31)
	1218	26	0.01084(10)	-0.27(15)
	1316	25	0.01107(19)	-0.54(32)
1	1317			
	1318	26	0.01112(35)	-2.41(53)
		E10		
	1216	21	0.01133(29)	0.55(67)
1	1217	18	0.00848(60)	2.75(183)
	1218	22	0.01025(37)	0.23(76)
	1316	22	0.01140(208)	-1.13(434)
	1317	22	0.00996(15)	-0.21(32)
	1318	22	0.00943(36)	0.13(74)
1			E20	
	1216	23	0.01108(20)	0.09(38)
	1217	12	0.01128(185)	-4.08(1198)
	1218	14	0.00967(67)	0.33(328)
1	1316	21	0.00998(14)	0.51(25)
	1317			
	1318	21	0.00947(10)	-0.80(23)
		E30		
	1216	22	0.00832(38)	4.11(79)
	1217	8	0.00842(183)	14.69(2463)
	1218	11	0.00958(104)	-6.38(793)
	1316	13	0.00792(96)	5.96(279)
	1317			
	1318	12	0.00832(76)	3.05(494)

**Notes.** The standard errors, in parentheses, are expressed in units of the least significant digit. N is the number of data.

**Notes.** The standard errors, in parentheses, are expressed in units of the least significant digit.



**Fig. A.37.** A-type doubling (in cm<sup>-1</sup>) vs.  $J \times (J + 1)$  of E00, E10, and E20 for the six isotopologues and of E30 for five isotopologues. For E10, we combined our dataset for the *R*- and *P*-branches and the *Q*-branch of Ubachs et al. (2000). A polynomial fit is also drawn; it is linear in most cases.



**Fig. A.38.** Trend comparison for the six CO isotopologues. *Left*: term value differences between <sup>16</sup>O- and <sup>18</sup>O-bearing isotopologues for <sup>12</sup>C and <sup>13</sup>C (dotted and solid lines, respectively) versus the *B*, *C*, and *E* states. *Right*:  $T_v$  versus v' for the *B*, *C*, and *E* states (each datapoint contains up to six isotopologues). For each state, a linear fit is drawn through all isotopologues.



Fig. A.39. Molecular constants for the six CO isotopologues. Top row:  $B_0$  and  $D_0$  for v'' = 0 of the  $X^1\Sigma^+$  ground state ( $T_0 = 0$  for all). The standard deviation (at  $2\sigma$ ) is shown between two short horizontal bars. For  $T_V$ , all values are in cm<sup>-1</sup>, with  $\delta$  values indicating the local spacing between ticks.

A114, page 62 of 62