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1 The water vapor foreign continuum
2 in the 8100 - 8500 cm⁻¹ spectral range
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45 **Key words**

46 Water vapor; foreign continuum; MT_CKD model; CRDS; transparency window; atmosphere
47

Abstract

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In the Earth's atmosphere, the foreign absorption continuum of water vapor is due to the interaction of water molecules with other atmospheric gases (mostly N_2 and O_2). Following our study of the self-continuum in the high energy edge of the $1.25 \mu m$ transparency window (Korovela et al, J. Quant. Spectrosc. Radiat. Transfer 286 (2022) 108206), we report here the first room temperature measurements of water vapor foreign continuum in the same spectral region. Foreign continuum cross-sections, C_F , are derived at several selected spectral points between 8120 and 8500 cm^{-1} for humidified nitrogen, humidified oxygen and humidified air (10000 ppm of H_2O). The absorption signal is measured by cavity ring-down spectroscopy (CRDS) using pressure ramps up to 750 Torr. While the measured total continuum absorption follows nicely the expected quadratic dependence *versus* the total pressure, the uncertainty on the retrieved weak foreign continuum is strongly affected by other contributions which have to be subtracted from the measured absorption (far wings of the resonance lines, O_2 collision induced absorption, self-continuum, Rayleigh scattering). The obtained H_2O -air and H_2O - N_2 C_F cross-section values are found to be comparable while the H_2O - O_2 C_F value appears to be significantly smaller. Overall, the retrieved C_F values for H_2O -air mixture validate the MT_CKD model in the considered region.

65 **1. Introduction**

66 The absorption of light by water vapor includes two main contributions: the well-known narrow
67 rovibrational absorption lines (or resonance spectrum) and a broad-band contribution with weak
68 frequency dependence, the continuum. In the Earth's atmosphere, the continuum includes the self-
69 continuum and the foreign continuum related to water molecules in interaction with one another or
70 with other atmospheric species (mostly N₂ and O₂), respectively. As a result, the self-continuum varies
71 as the square of the water vapor partial pressure, P_{H_2O} , while the foreign continuum is proportional to
72 $P_{H_2O}P_F$ where P_F is the foreign gas pressure (dry air here) The water vapor absorption coefficient is
73 thus expressed as:

$$\begin{aligned} \alpha_W(\nu, T) &= \alpha_{WML} + \alpha_{WCS} + \alpha_{WCF} \\ &= \alpha_{WML} + \frac{1}{kT} C_S(\nu, T) P_{H_2O}^2 + \frac{1}{kT} C_F(\nu, T) P_{H_2O} P_F \end{aligned} \quad (1)$$

74 where α_{WML} , α_{WCS} and α_{WCF} are the contributions due to resonant lines (WML), the water vapor
75 self-continuum (WCS) and the foreign continuum (WCF), respectively. k is the Boltzmann constant,
76 P_{H_2O} and P_F are the water vapor and foreign gas partial pressures, respectively (thus $P = P_{H_2O} + P_F$
77 where P is the total pressure). C_S and C_F are the self- and foreign continuum cross-sections expressed
78 in cm²molecule⁻¹atm⁻¹.
79

80 Depending on the atmospheric conditions, the foreign continuum contribution to the absorption
81 by water vapor can be of the same order as the self-continuum contribution which makes the
82 characterization of both necessary. The semi-empirical MT_CKD (Mlawer–Tobin–Clough–Kneizys–
83 Davies) model [1,2,3] is the standard model implemented in climate and weather prediction models to
84 account for the water continuum. In the windows between absorption bands, this model is mostly a
85 far-wing line shape model with parameters empirically adjusted according to laboratory or
86 atmospheric data at disposal, mostly in the infrared (*e.g.* [3-5]). In near-infrared windows, the original
87 MT_CKD cross-sections (*i.e.* MT_CKD_1.0 through _3.0) thus resulted from long-range extrapolation
88 which had to be validated.

89 Since 2013, we are involved in a long-term experimental project aiming to characterize the
90 water vapor continuum mostly in the near-infrared windows where previous data were very scarce and
91 reported with large uncertainties. Due to the weakness of the continuum signal, the measurements are
92 performed using cavity enhanced absorption spectroscopy techniques (mostly cavity ring down
93 spectroscopy - CRDS- but also optical feedback cavity enhanced absorption spectroscopy - OFCEAS)
94 [7-17]. The cross-section derived at specific spectral point values are systematically used for
95 validation tests of the current version of the MT_CKD model. Although a number of significant
96 deviations were evidenced (*e.g.* the MT_CKD self-continuum in its 3.0 version was underestimated by
97 a factor 5 to 10 near the centre of the 2.3 μm window [11-13, 16]), the measurements roughly
98 validated the MT_CKD values up to 8000 cm⁻¹ [17]. Considering the long-range spectral extrapolation
99 of this semi-empirical model, this achievement deserves to be underlined. The most recent versions of

100 the MT_CKD self-continuum (from V3.2) were refined according to our CRDS and OFCEAS
101 experimental cross-sections in the 4.0, 2.1, 1.6 and 1.25 μm windows [3].

102 As concerns the foreign continuum absorption, experimental data are scarcer [18], in particular
103 at room temperature. In-band continuum measurements were reported in the 3500–4000 cm^{-1} spectral
104 range by direct absorption spectroscopy [6], between 1300 and 7500 cm^{-1} by Fourier transform
105 spectroscopy (FTS) [19] and in the 0.94 μm absorption band by CRDS [20]. Of interest for the present
106 investigation in the 1.25 μm transparency window are the high temperature (350-430 K) foreign
107 continuum FTS measurements by the CAVIAR consortium (Continuum Absorption at Visible and
108 Infrared wavelengths and its Atmospheric Relevance) over the wide 1.1 - 5.0 μm spectral range thus
109 including the 1.25 μm window of interest [21]. The comparison of our present room temperature
110 measurements to the CAVIAR high temperature measurements might give insights on the temperature
111 dependence of the foreign-continuum absorption which is known to be weak, much weaker than that
112 of the self-continuum; the latter is known to decrease sharply with temperature.

113 In the transparency windows, measurements of the water foreign continuum are limited, in
114 particular at room temperature, and spectrally dispersed. Cormier et al. [22] and Baranov&Lafferty
115 [23] reported measurements in the 10 μm window by CRDS and FTS, respectively. Water foreign
116 continuum was determined in the 4.0 μm window by FTS [23-25], in the 2.1 and 1.6 μm windows by
117 CRDS [9,14,15] and near 14400 cm^{-1} by photoacoustic spectroscopy [26]. On the basis Refs. [9,22],
118 the MT_CKD foreign continuum has been significantly increased starting with version 2.8 [3].

119 To the best of our knowledge, no attempts were previously undertaken to measure the foreign
120 continuum in the 1.25 μm window at room temperature. Indeed, as described below the measurements
121 are particularly demanding in this region due to the weak absorption signal to be measured and to the
122 fact that the foreign contribution represents only a generally small fraction of the total measured
123 absorption. In this situation, the derived foreign cross-section values are directly impacted by the
124 evaluation of the other contributions (resonance lines broadened by N_2 , O_2 or dry air, O_2 collision
125 induced absorption band near 1.27 μm , self-continuum absorption, Rayleigh scattering) which have to
126 be subtracted from the measured CRDS absorption coefficient. In order to help disentangling the
127 different contributions, different series of measurements were performed using as foreign gas, pure N_2 ,
128 pure O_2 and dry air. These three sets of derived C_F values will allow to test their self-consistency and
129 discuss their uncertainties.

130 The remaining part of this paper is organized as follows: the data analysis is detailed in section
131 3 after the description of the data acquisition in the next experimental section. In section 4, we discuss
132 the consistency of our results and compare them to the MT_CKD model [2,3] and to CAVIAR high
133 temperature data [21].

134 **2. Experimental**

135 Water foreign continuum absorption measurements were performed by CRDS for a series of
136 spectral points of the high energy edge of the 1.25 μm window (8105 - 8480 cm^{-1}). The data

137 acquisition was performed at fixed frequency during pressure ramps of humidified gas (air, nitrogen
138 and oxygen). The experimental approach is mostly the same as described in Ref. [17] for the self-
139 continuum determination, except that the amplitude of the pressure ramps is much larger (up to 1 atm).
140 The spectrometer uses an external cavity diode laser (ECDL, Toptica fiber-connected DL pro, 1200
141 nm) as a light source. About 10% of the light intensity is sent to a wavelength meter (HighFinesse
142 WSU7-IR, 5 MHz resolution, 20 MHz accuracy over 10 hours) which provides the laser frequency.
143 The main part of the radiation is injected into the 1.4 m long CRDS cavity using a single mode fiber.
144 The coincidence between the laser frequency and that of one mode of the CRDS cavity is achieved by
145 modulating the rear mirror of the cavity mounted on a piezoelectric transducer (PZT), over about half
146 the wavelength, over about half the wavelength, corresponding to the free spectral range of the cavity.
147 At resonance, the cavity is filled with photons and then the injection of the laser light is interrupted by
148 an acousto-optic modulator. An InGaAs PIN photodiode is used to measure the purely exponential
149 decay time of photons leaking from the cavity. The absorption coefficient, $\alpha(\nu)$, is determined directly
150 from fitted RD time, τ :

$$\alpha(\nu) = \frac{1}{c\tau(\nu)} - \frac{1}{c\tau_0} \quad (1)$$

152 where c is the speed of light. τ_0 and τ correspond to the ring down time of the cavity empty
153 and filled with gas, respectively.

154 In the present experiments, Rayleigh scattering has a non-negligible contribution to the increase
155 of the loss rate, $\frac{1}{c\tau(\nu)}$. (For convenience, “absorption coefficient” will be used in the following to name
156 the increase of the loss rates due to both absorption and Rayleigh scattering).

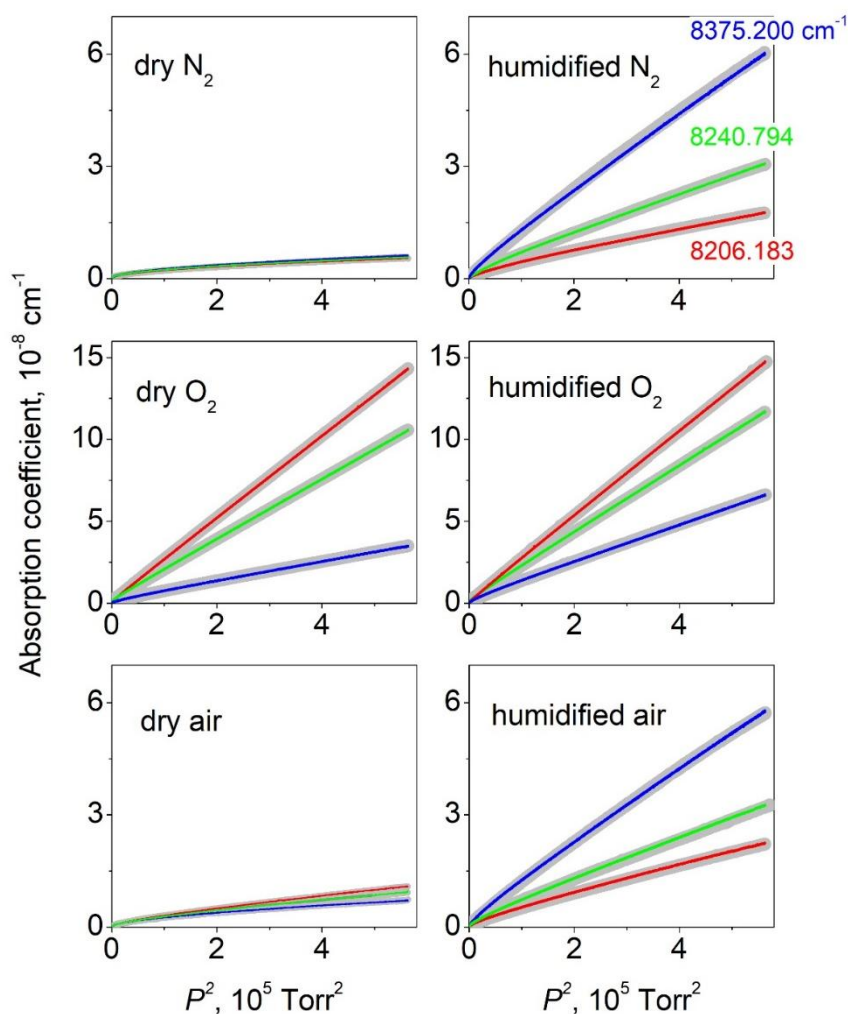
157 As in Ref. [17], the CRDS absorption signal is measured for series of pressure ramps at several
158 fixed spectral points (from 5 to 8 depending on the gas mixture) selected in spectral microwindows
159 minimizing the resonance line contribution (in fact, in the considered spectra region, the resonance
160 line contribution is always large and remains the dominant contribution of the water-related absorption
161 - see below). The chosen spectral points are part of the 29 spectral points used in Ref. [17] for the
162 retrieval of the self-continuum absorption in the same region.

163 All the recordings are performed with a gas flow produced by a commercial humidity generator
164 (from Omicron Technologies) (see Ref. [27] for a detailed description). The gas sample used for the
165 recordings is a mixture of water vapor with 10,000 ppm molar fraction (*i.e.* 1%) in either synthetic air,
166 N₂, or O₂ (Alphagaz 2, 99,9995 % purity). Water vapor is produced from deionized liquid water in a
167 temperature-regulated membrane system and then mixed with the carrier gas. The pressure and the gas
168 flow in the gas line are controlled by a pressure controller (Model IQP-700C from Bronkhorst) and a
169 mass flow controller (Area model, FC-R7800 series from Hitachi Metals Ltd.), respectively. The water
170 concentration of the humidified gas is controlled by using the dew point temperature measured directly
171 by the remote head of a precision chilled mirror hygrometer (Model S8000 from Mitchell). A small

172 part of the generated gas flow (typ. few tens of sccm) is directed inside the cavity where the pressure is
173 varied between 0 and 750 Torr during the pressure ramps.

174 Two pressure gauges (10 and 1000 Torr full scale, from MKS Instruments, 0.25% of reading
175 accuracy) are used to monitor continuously the total pressure in the cavity. A temperature sensor (TSic
176 501 from IST, ± 0.1 K accuracy) fixed on the external wall of the cavity and enveloped by thermal
177 insulation foam measure the temperature during the recordings. The temperature remains in the
178 294 ± 1 K range during the whole measurement campaign.

179 The humidified gas recordings include three steps: (i) increasing pressure ramp with a typical
180 speed of 1 Torr/s (*i.e.* total duration of about 12 minutes), (ii) checking that the water partial pressure
181 in the cell is constant by repetitive scan of a water line during about 1 hour and, (iii) decreasing
182 pressure ramp (about 12 minutes). In addition, just after or just before this recording sequence, an
183 additional recording is performed with the corresponding dry gas sample for an increasing and a
184 decreasing pressure ramp. The dry gas pressure ramps measurements are used as baselines to be
185 subtracted from humidified gas signal (see below).



186

187 **Fig. 1.**

188 Variation of the absorption coefficient *versus* the squared total pressure, P , during pressure
189 ramps up to 750 Torr for three spectral points of the 1.25 μm window (8206.183, 8240.794 and

190 8375.200 cm^{-1} - red, green and blue curves, respectively). For each spectral point, measurements were
191 performed during increasing and decreasing pressure ramps (grey and colored lines, respectively) for
192 dry and humidified gas samples of synthetic air, N_2 and O_2 (left and right panels, respectively).

193 The variation of the absorption signal during increasing and decreasing pressure ramps with dry
 194 and humidified samples are compared on **Fig. 1** for three spectral points. This figure deserves several
 195 comments: (i) a nearly perfect superposition is observed for increasing and decreasing pressure
 196 measurements, illustrating the stability of the experimental setup and allowing to use the averaged data
 197 for further analysis, (ii) in the case of the O₂ measurements, the absorption signal is much larger than
 198 for air and N₂ (note the different scales used in **Fig. 1**) as a result of the impact of the broad collision-
 199 induced absorption (CIA) of the $a^1\Delta_g - X^3\Sigma_g^-(0-0)$ band centered near 7900 cm⁻¹ [28]. This CIA
 200 contribution is smaller at high energy which makes the absorption at 8375.200 cm⁻¹ smaller than those
 201 at 8206.183 and 8240.794 cm⁻¹ in the case of O₂ while it is the opposite in the case of air and N₂.

202 3. Cross-section retrieval

203 On the left panels of **Fig. 2**, the pressure ramps with humidified and dry gas are superimposed
 204 for the 8240.794 cm⁻¹ spectral point. The water-related absorption presented on the right panels is
 205 obtained by difference. It is important to mention, that the subtraction applies to absorption
 206 coefficients corresponding to the same dry gas pressure and not to the same total pressure value. In
 207 other words, the water-related absorption measured at a total pressure of $P = P_{H_2O} + P_F$ was
 208 decreased by the dry gas absorption at P_F . Ignoring the 1% difference between P and P_F in the
 209 humidified gas sample would lead to negative water-related absorption in the case of humidified
 210 oxygen as 1% of the O₂ CIA is larger than the O₂ foreign continuum absorption of water vapor. This
 211 small contribution of the foreign continuum absorption to the measured absorption makes the accurate
 212 retrieval of the water foreign continuum absorption particularly challenging in the region.

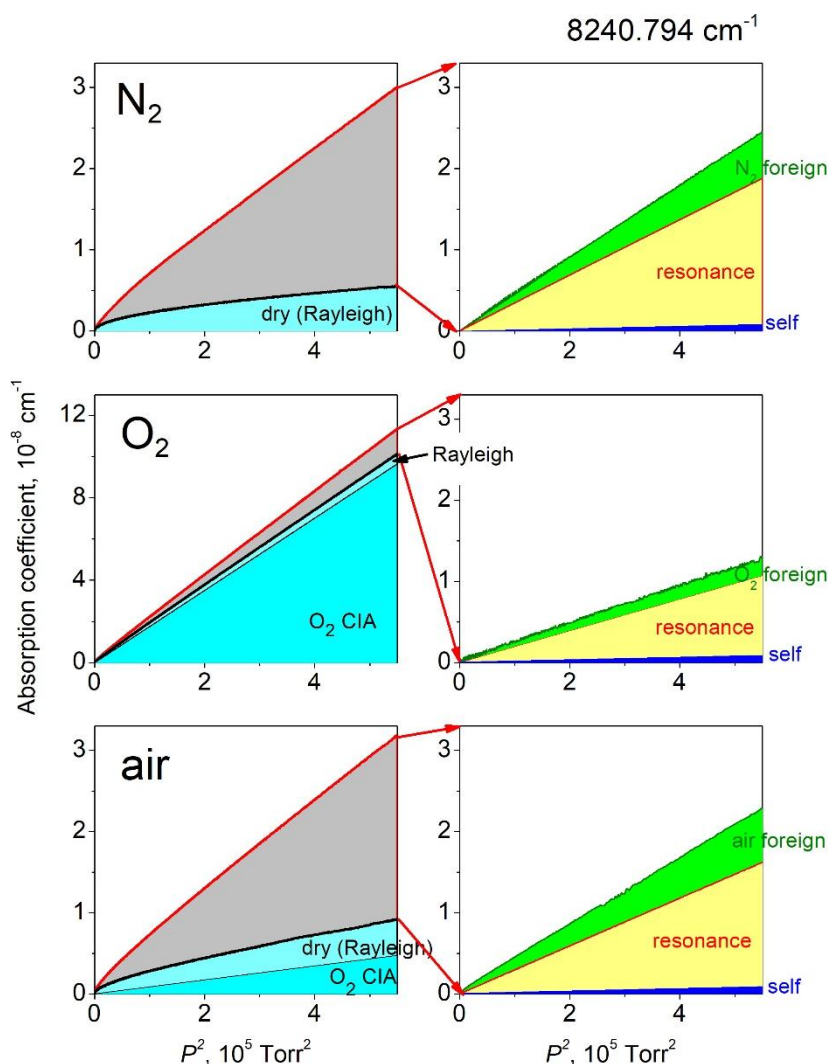
213 Let us first consider the dry gas recordings.

214 Rayleigh scattering is responsible of the variation of the loss rate during the dry N₂ pressure
 215 ramps. Rayleigh scattering being proportional to pressure, it leads to a clear curvature for low pressure
 216 values when plotted *versus* pressure squared both for dry and humidified N₂ (**Fig. 1** upper panels). As
 217 Rayleigh scattering is mostly identical in the dry and humidified N₂ samples, the curvature nicely
 218 vanishes in the water-related contribution obtained by difference and a nearly perfect quadratic
 219 dependence *versus* the total pressure is achieved (**Fig. 2** right upper panel). Indeed, following **Eq. 1**,
 220 the three contributions to the water-related absorption, $\alpha_W(\nu, T)$, have a pressure squared dependence
 221 (the foreign contribution, proportional to $P_{H_2O}P_F$ leads to a P^2 dependence as the mixing ratio of water
 222 in the dry gas is fixed to 1%).

223 Rayleigh scattering contribution of N₂ can be calculated from the refractive index coefficients
 224 given in Ref. [29]. The measured losses induced by dry N₂ in our recordings are found about 50%
 225 larger than expected from calculations. As a check of the calculated values obtained from Ref. [29],
 226 we evaluated experimentally the refractive index from the variation of the frequency of the CRDS
 227 cavity modes during an increasing pressure ramp of dry N₂ up to 1 atm. 643 modes were counted to
 228 scroll during the filling and the evacuating of the cell at a fixed frequency of 8240.794 cm⁻¹. It leads to

229 a refractive index of 1.000279 in perfect agreement with that used in Ref. [29]. The difference between
 230 our observations and the calculated Rayleigh scattering losses could be related to mechanical changes
 231 in the alignment of the CRDS cell induced by the change of pressure. This effect is believed to have
 232 no impact on the retrieval of the water-related continuum absorption as, being reversible (as checked
 233 by the consistency of the results obtained with increasing and decreasing pressure ramps), it is
 234 cancelled in the subtraction of the humidified N_2 and dry N_2 signals.

235 In the case of oxygen (**Figs. 1 and 2**, middle panels), the absorption signal is largely dominated
 236 by the CIA. The measured dry O_2 absorption can be compared to calculated values obtained using the
 237 CIA binary coefficients of Ref. [28] and the Rayleigh scattering coefficients of Ref. [29]. An excellent
 238 agreement (better than 1%) is achieved.

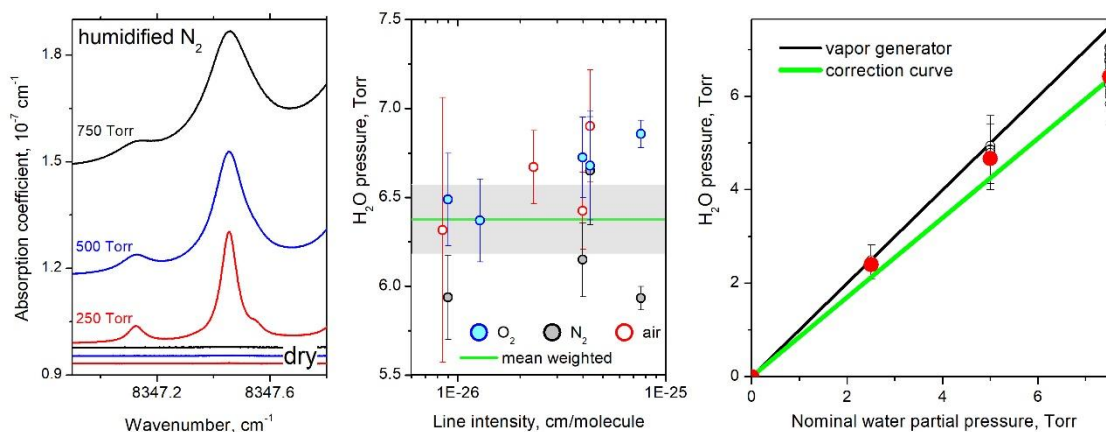


239
 240 **Fig. 2.**
 241 *Left panels:* Variation of the absorption coefficient *versus* the squared total pressure, P , for
 242 humidified (red line) and dry (black line) gas samples during pressure ramps up to 750 Torr at the
 243 8240.794 cm^{-1} spectral point. The dry gas “absorption” (cyan background) includes a Rayleigh
 244 scattering contribution and a contribution of the CIA of the $1.27 \mu\text{m}$ oxygen band (for O_2 and air).
 245 *Right panels:* The water-related absorption is obtained by difference of the humidified and dry
 246 absorption and includes contributions of the water vapor self-continuum absorption (blue area), of the
 247 resonance lines, (yellow area) and of the foreign continuum absorption (green area).

248 In the case of dry air, the calculated Rayleigh and CIA contributions, highlighted on the lower
 249 panel of **Fig. 2**, have similar amplitude and our measurements are slightly larger than their predicted
 250 sum. As for nitrogen, due to Rayleigh scattering losses, a nonlinear dependence on total pressure
 251 squared is clearly observed (**Fig. 1** lower panels), but after subtraction of the dry part, the water-related
 252 absorption pressure dependence becomes nicely linear *versus* the squared pressure (lower right panel
 253 of **Fig. 2**).

254 Let us now considered the water-related absorption.

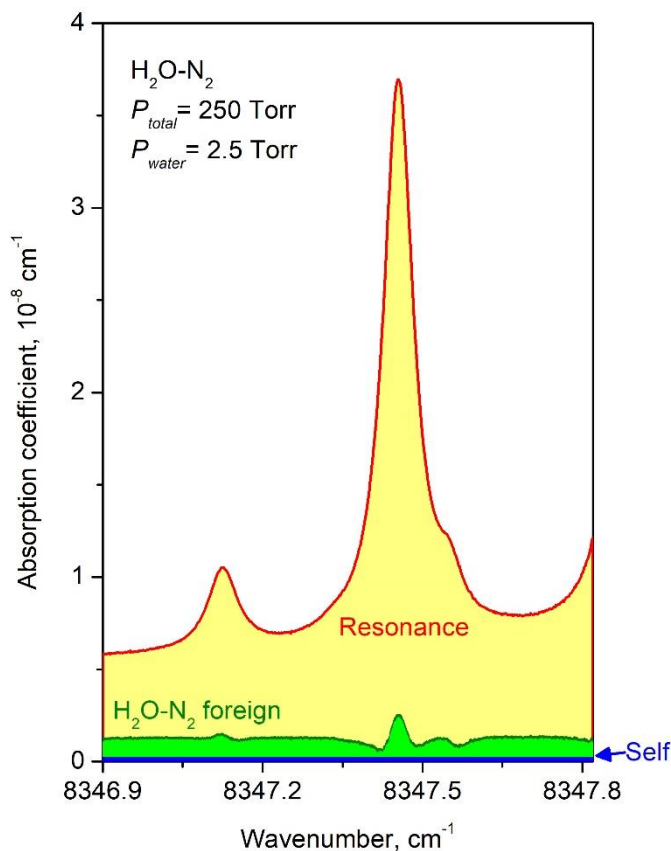
255 In the considered region corresponding to the high energy edge of the 1.25 μm transparency
 256 window, the resonance line contribution is the dominant part of the water-related absorption. We used
 257 the same convention as adopted for the MT_CKD model to simulate the resonance spectrum: line
 258 profile was assumed to be of Voigt type and the line wings were truncated at $\pm 25\text{ cm}^{-1}$ frequency
 259 detuning from the line center, the underlying pedestal being considered as part of the continuum
 260 absorption.



261
 262 **Fig. 3.**
 263 *Left panel:* CRDS spectra of 1% humidified N_2 recorded at 250, 500 and 750 Torr total
 264 pressures near 8347 cm^{-1} . The three baselines at the bottom of the plot are the corresponding dry N_2
 265 spectra with level increasing linearly with pressure as a consequence of Rayleigh scattering losses,
 266 *Middle panel:* Water vapor partial pressure values retrieved from a series of recordings of eight
 267 lines of water broadened by N_2 , O_2 or air at a total pressure of 750 Torr, *versus* their HITRAN line
 268 intensities [30],
 269 *Right panel:* Water vapor partial pressures retrieved from the line profile analysis *versus* the
 270 nominal partial pressure (1% of the total pressure). The red dots correspond to the line at 8347.46 cm^{-1}
 271 presented on the left panel. The pressure values presented corresponding to the nominal value of 7.5
 272 Torr are those plotted on the middle panel. The linear fit of the experimental partial pressures *versus*
 273 their nominal values gives a slope of 0.85 (green straight line). This factor was used to correct all the
 274 water partial pressure values (see text).

275 A major issue of the current analysis is related to the knowledge of the real water vapor partial
 276 pressure in the CRDS cell. Indeed, on the basis of spectra recorded over intervals corresponding to
 277 mostly isolated water lines, it appeared that the simulation of the resonance line spectrum calculated
 278 using the 10000 ppm relative concentration (corresponding to the set point of the humidity generator)

279 leads to an overestimation of the resonance line absorption. In other words, probably due to adsorption
 280 effects, the real water pressure value in the cell is lower than its nominal value. In order to determine
 281 its value, eight mostly isolated (broadened) water lines were selected and recorded for total pressure
 282 values of humidified gas of 250, 500 and 750 Torr. **Fig. 3** shows an example of recorded line (left
 283 panel), together with the different retrieved pressure values obtained from the eight lines broadened by
 284 O₂, N₂ or air *versus* their intensities (central panel) and the comparison with the nominal pressure
 285 values (right panel). A weighted linear fit of the obtained P_{H_2O} values *versus* their nominal values (*i.e.*
 286 1.00 % of the total pressure) was performed. The weight attached to each pressure value was fixed
 287 according to its uncertainty resulting from the experimental noise, the fit uncertainty and the HITRAN
 288 intensity uncertainty. As a result, the obtained partial pressure in the cell differs from its nominal value
 289 in the gas by about 15% (green line **Fig. 3**, right panel). In the following analysis of the recorded
 290 pressure ramps, this correction will be applied to all the (nominal) water vapor partial pressures. In
 291 spite of the high signal-to-noise level of the recorded spectra and our careful analysis of about twenty
 292 water line recordings, the large broadening of the line profile makes an accurate determination of the
 293 line area difficult (due to baseline uncertainty). As a result, the uncertainty on the amplitude of the
 294 pressure correction remains a potential source of uncertainty on the derived foreign cross-section
 295 values (see below).



296
 297 **Fig. 4.**

298 The different contributions to the water-related absorption in humidified (1%) N₂ at a total
 299 pressure of 250 Torr, near 8347 cm⁻¹: self-continuum (blue), H₂O-N₂ foreign continuum (green) and
 300 resonance line contribution (yellow).

301
 302 As mentioned above, the water resonance line contribution was simulated as a sum of Voigt line
 303 profiles with the standard ± 25 cm⁻¹ wing cut-off. Line intensities, self- and air-broadening coefficients
 304 were taken from the HITRAN2020 database [30]. N₂- and O₂-broadening coefficients of water lines
 305 are not provided in the HITRAN lists. The water line broadening parameters by N₂ (γ_{N_2}) were
 306 calculated in [31] in the frame of MCRB formalism and the ‘‘HITRAN’’ list attached to this work as
 307 supplementary material, including γ_{N_2} , was adopted. Oxygen-broadening coefficients of each water
 308 line, γ_{O_2} , were calculated using the equation $\gamma_{air} = 0.79\gamma_{N_2} + 0.21\gamma_{O_2}$, using γ_{air} , and γ_{N_2} from
 309 HITRAN2020 and Ref. [31], respectively.

310 The last contribution which has to be subtracted is the water self-continuum (see Eq. 1). It was
 311 calculated using the self-continuum cross-section values derived by CRDS of pure water vapor [17].
 312 The different contributions to the water-related absorption are separated on **Fig. 4** in a small spectral
 313 interval around 8347 cm⁻¹. After the subtraction of the resonance line contribution, significant
 314 residuals are obtained near the line centres as a result of some inaccuracies of the line parameters used
 315 to compute the resonance line spectrum. The foreign continuum absorption represents less than 20%
 316 of the water-related absorption illustrating the difficulty of an accurate evaluation.

317 On the right panels of **Fig. 2**, the different contributions are presented during the pressure ramp
 318 at 8240.794 cm⁻¹. The self-continuum contribution is small (a few %) while the resonance line
 319 contribution represents about 70% of the total absorption. This is a typical situation for all the
 320 measurement points listed in **Table 1**: in spite of a careful selection of microwindows minimizing the
 321 resonance line contribution, the latter represents most of the water-related absorption at all
 322 measurement points. The relative contribution of the resonance line to the water-related absorption
 323 (ranging between 61 and 83%) is given in **Table 1** for each spectral point.

324 **Table 1**
 325 Foreign gas cross-sections of water vapor (C_F) derived at nine spectral points between 8100 and
 326 8500 cm⁻¹.

| Wavenumber, cm ⁻¹ | C_F 10 ⁻²⁷ cm ² molecule ⁻¹ atm ⁻¹ | | | Resonance absorption % | | | Uncertainty due to resonance spectrum 10 ⁻²⁷ cm ² molecule ⁻¹ atm ⁻¹ | | |
|------------------------------|---|----------------|------------|---------------------------|----------------|------|---|----------------|------|
| | N ₂ | O ₂ | air | N ₂ | O ₂ | air | N ₂ | O ₂ | air |
| 8105.865 | - | 5.3(3) | - | - | 49.6 | - | - | 2.1 | - |
| 8123.155 | 7.6(1.1) | 0.3(2) | 3.8(9) | 68.6 | 82.6 | 77.0 | 2.3 | 3.8 | 4.4 |
| 8206.183 | 19(2) | 7.7(8) | 19.1(1.9) | 63.1 | 67.2 | 61.3 | 4.1 | 6.3 | 7.6 |
| 8240.794 | 33(4) | 10.1(1.9) | 33.0(3.7) | 69.8 | 77.7 | 67.6 | 8.8 | 14.2 | 16.9 |
| 8279.585 | - | - | 53.5(7.0) | - | - | 72.4 | - | - | 34.3 |
| 8317.615 | - | 26.7(4.7) | - | - | 76.1 | - | - | 32.3 | - |
| 8375.200 | 68.2(8.5) | 25.9(5.1) | 62.0(8.0) | 71.4 | 78.0 | 71.8 | 14.3 | 33.8 | 32.3 |
| 8434.240 | - | 52.1(6.9) | - | - | 68.8 | - | - | 40.2 | - |
| 8480.505 | 104(11) | 33.3(6) | 88.4(10.0) | 66.5 | 74.2 | 67.8 | 12.9 | 37.5 | 42.0 |

327
 328 *Notes*

329 Columns 2-4: C_F values for N_2 , O_2 and air, respectively, with corresponding experimental
330 uncertainty given between parenthesis. The uncertainty value is limited to the statistical fit uncertainty
331 and water partial pressure uncertainty,

332 Columns 5-7: Corresponding fraction (in %) of the resonance absorption contribution to the
333 water-related absorption,

334 Columns 8-10: Uncertainty related to the subtraction of the resonance absorption contribution
335 evaluated on the basis of the errors on the HITRAN line parameters.

336
337 The pressure dependence of the water-related absorption after subtraction of the self-continuum
338 and resonance lines contributions is presented in **Fig. 5** for air, N_2 and O_2 pressure ramps at three
339 measurement points. A good pressure squared dependence is achieved as expected from Eq. 1 (recall
340 that P_{H_2O} and P are proportional). Note that the plotted ramps are in fact the superposition of the
341 increasing and decreasing pressure ramp signals. The foreign continuum cross-sections listed in **Table**
342 **1** were obtained from a linear fit of the pressure dependences using Eq. 1.

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356 **Fig. 5.**

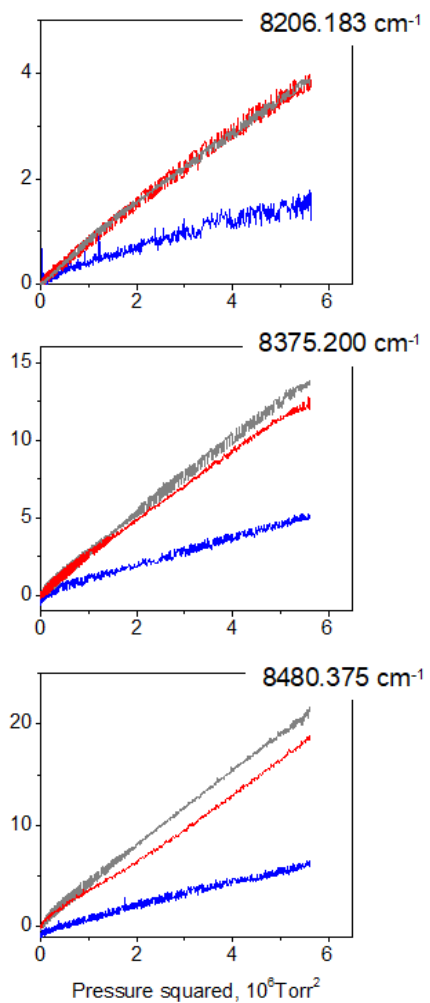
357 Variation of the absorption coefficient corresponding to
358 the foreign gas contribution *versus* the squared total pressure,
359 P , during pressure ramps up to 750 Torr for three spectral
360 points of the 1.25 μm window (8206.183, 8375.200 and
361 8480.375 cm^{-1}). Traces in grey, blue and red correspond to gas
362 samples of humidified (10000 ppm) N_2 , O_2 and synthetic air,
363 respectively. Each curve corresponds to the measured
364 absorption signal decreased by the dry gas contribution, the
365 resonance gas contribution and the water self-continuum and is
366 the superposition of the increasing and decreasing pressure
367 ramps.

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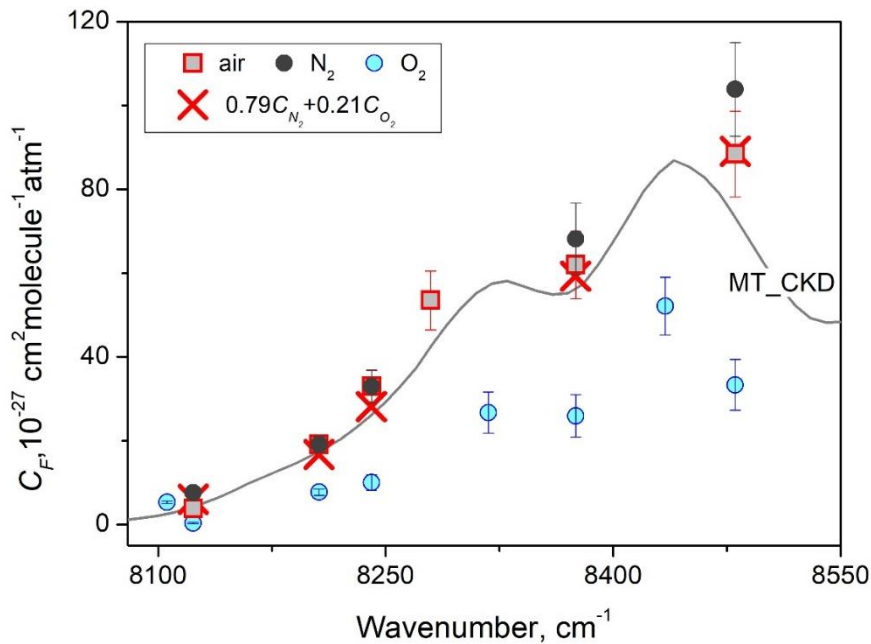
4. Discussion and concluding remarks

370 **Fig. 6** shows an overview of the retrieved foreign cross-sections. The plotted error bars are
371 limited to the experimental uncertainties on the (corrected) value of the water partial pressure (about
372 3%), and on the linear coefficient of the pressure ramp fit (on the order of 1 % for N_2 and O_2 and up to



373 15% for air). It should be pointed that the above 15 % correction of the partial pressure of water in the
 374 cell has an important impact on the obtained C_F values. In absence of correction, C_{N_2} and C_{air} values
 375 would have been smaller by a factor 2-3 while the C_{O_2} cross-sections would have been decreased to a
 376 level too weak to be evaluated.

377 As in the retrieval of the water self-continuum cross-sections in the same region [17], an
 378 additional important error source should be considered. It is related to the evaluation of the resonance
 379 line contribution which represents 60-80% of the water-related absorption and has thus a direct impact
 380 on the retrieved C_F values. In other words, the obtained C_F values cannot be dissociated from the
 381 resonance line databases we used for their retrieval. Based on the error codes attached to the HITRAN
 382 line parameters [30], we evaluated the uncertainty on the resonance line contribution. The obtained
 383 error bars included in **Table 1** are sometimes comparable to our absolute C_F values. This problematic
 384 situation may indicate that our obtained C_F values should be used with much caution or/and that the
 385 HITRAN error bars are overestimated. There is some indication that HITRAN uncertainties on the
 386 broadening parameters are indeed overestimated: in the case of N_2 , the uncertainties on the resonance
 387 line contribution included in **Table 1** were obtained from the ‘‘HITRAN’’ list produced by Vispoel et
 388 al. [31] (where error values are attached to each N_2 -broadening coefficient instead of error codes given
 389 in HITRAN for air-broadening coefficients). As a result, the obtained resonance line uncertainties are
 390 2-3 times smaller for N_2 than for air (see **Table 1**).



391 **Fig. 6.**
 392 Overview of the foreign continuum cross-sections, C_F , retrieved for N_2 (black dots), O_2 (blue
 393 dots) and dry air (red squares) between 8100 and 8500 cm^{-1} and comparison to the values provided for
 394 air by the MT_CKD_V3.5. The red crosses correspond to the calculated values of C_{air} obtained from
 395 $C_{air}=0.79C_{N_2}+0.21C_{O_2}$. The plotted error bars are those given in Columns 2-4 of Table 1 and are
 396 limited to the combined impact of the uncertainty on the water partial pressure (about 3%) and on the
 397 linear coefficient of the pressure ramp fit (see Text).
 398

399 In spite of the doubts on the estimation of the error bars, a number of observations give some
400 confidence to our results:

401 (i) The overall consistency between the C_{N_2} and C_{air} values, determined independently, is very
402 good, the C_{N_2} values being generally larger than C_{air} values,

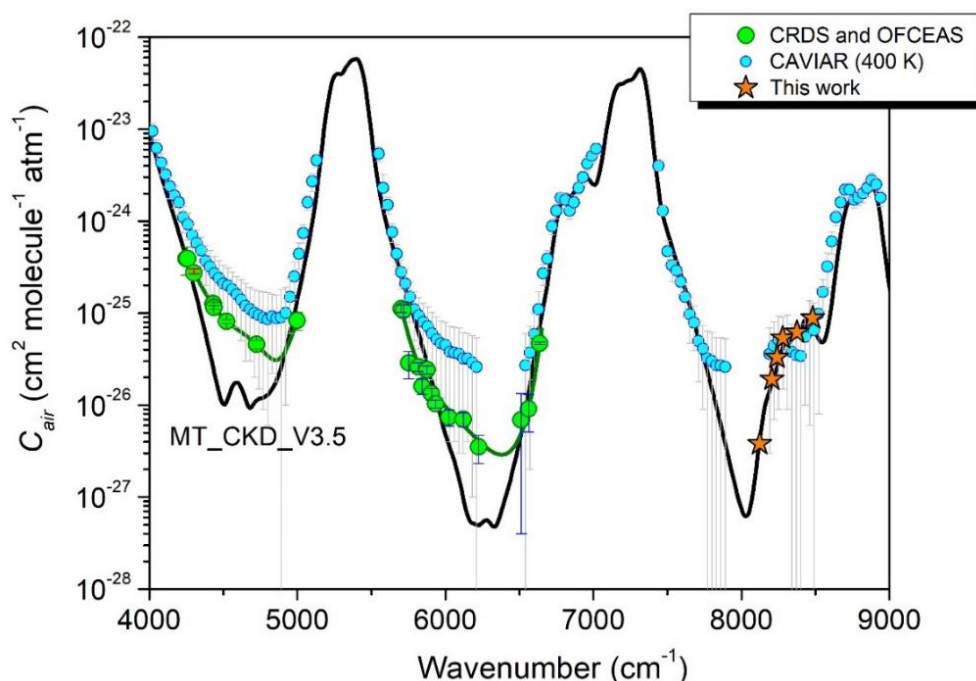
403 (ii) Air foreign continuum cross-sections calculated as $C_{air}=0.79C_{N_2}+0.21C_{O_2}$ (red crosses in
404 **Fig. 6**) nicely agree with the direct experimental determinations of C_{air} (red squares) illustrating the
405 self-consistency of three sets of measurements: C_{O_2} values being smaller than C_{N_2} and C_{air} values, the
406 differences between C_{N_2} and C_{air} values are close to the calculated impact of the O_2 contribution on
407 C_{air} values,

408 (iii) The comparison of experimental and calculated C_{air} values with the MT_CKD model
409 shows an overall good agreement. We also note that C_{O_2} frequency dependence is consistent with the
410 two maxima of the MT_CKD model.

411 From **Table 1** and **Fig. 6**, it appears that the foreign cross-sections are significantly smaller for
412 O_2 than for N_2 . In the literature, the dependence of the water foreign continuum upon the nature of the
413 foreign gas has been rarely discussed. In several experimental studies using N_2 as foreign gas, the
414 obtained water- N_2 cross-sections are compared to the MT_CKD model (thus for air) with the implicit
415 assumption that water- O_2 and water- N_2 cross-sections are close. In fact, little is known on the water- O_2
416 foreign continuum. To the best of our knowledge, the only previous study which reported water
417 foreign cross-section for O_2 , N_2 and air was performed in the far infrared (FIR) [32]. Although the
418 strong resonance line contribution was a limiting factor of the analysis (as in the present study), the
419 water- O_2 continuum in the rotational region ($50-700\text{ cm}^{-1}$) was found largely smaller than the water- N_2
420 and water-air continua (in fact, C_{O_2} appeared to be too weak to be experimentally determined *i.e.* more
421 than five times smaller than, C_{N_2} and C_{air} – see Fig. 6 of Ref. [32]). Here, the measurement of the
422 water- O_2 continuum is made even more challenging due to the overlapping with the CIA band of O_2
423 near $1.27\text{ }\mu\text{m}$. At the 8240.794 cm^{-1} spectral point of **Fig. 2**, the water-related absorption represents
424 about 10% of the measured absorption and the O_2 -foreign itself no more than 1.6 % which obliges to
425 some caution when considering the derived C_{O_2} values. Nevertheless, the obtained frequency
426 dependence of C_{O_2} appears to be reasonable which gives some credit to the evidenced smaller
427 amplitude of the water- O_2 continuum compared to the water- N_2 continuum. Although the oxygen
428 concentration in air is only 21%, the resulting decrease of the water-air continuum compared to the
429 water- N_2 continuum is consistent with the observations (see **Fig. 6**).

430 Note that in the frame of the far wings interpretation of the water foreign continuum, the water-
431 O_2 and the water- N_2 continua are expected to scale according to the corresponding water broadening
432 coefficients. Roughly, the broadening coefficients of water lines by O_2 are on average 30% smaller
433 than those by N_2 . This factor appears to be not far from the scaling factor of the C_{O_2} and C_{N_2} cross-
434 sections determined in the present work but disagrees with the FIR observations [32].

435 We have gathered in **Fig. 7**, the room temperature water-air foreign cross-sections derived in
 436 this work and in our previous CRDS studies in the 2.3 and 1.6 μm windows [9,14,15], and compared
 437 them to the MT_CKD_V3.5 foreign continuum. A clear underestimation of the MT_CKD model was
 438 evidenced in the 2.3 and 1.6 μm windows, which is not the case in the presently studied 1.25 μm
 439 where the MT_CKD model is validated. The foreign (air) cross-sections reported by the CAVIAR
 440 consortium [21] have been superimposed on the plot. The CAVIAR measurements by FTS were
 441 performed at 350, 372, 402 and 431 K (which allowed to increase the absorption signal by increasing
 442 the water partial pressure to a few hundreds of mbar). In the 1.25 μm window, the large (1σ) error bars
 443 of the CAVIAR measurements (on the order of 100%) do not allow a sound comparison. Nevertheless,
 444 the order of magnitude of CAVIAR C_{air} values at 400 K is reasonable compared to our room
 445 temperature measurements (let us recall that the temperature dependence of the foreign continuum is
 446 known to be very weak).



447 **Fig. 7.**
 448 Overview of the water foreign continuum cross-sections, C_{air} between 4000 and 9000 cm^{-1}
 449 obtained in this work and found in the literature [9,14,15, 21], and comparison to the MT_CKD_V3.5
 450 model. The CAVIAR experimental values [21] were obtained at 400 K while the other displayed
 451 values correspond to the room temperature.
 452

453
 454 As a final conclusion, the first (challenging) measurements of the air-, O_2 -, and N_2 -water
 455 continua at room temperature have been performed in the 1.25 μm window for a series of pressure
 456 ramps at fixed spectral points. The humidity rate was fixed to 1% and the measured total continuum
 457 absorption were found to follow satisfactorily the expected quadratic dependence *versus* the total
 458 pressure up to 1 atm. In spite of the sensitivity and stability of the used CRDS setup (illustrated by the
 459 obtained pressure squared dependences), the accuracy of our final cross-section values is limited. As

460 the foreign continuum represents of small fraction of the measured absorption signal and as some of
461 the other contributions (far wings of the resonance lines, O₂ collision induced absorption, self-
462 continuum, Rayleigh scattering) are known with large uncertainties (*e.g.* resonance line absorption),
463 we cannot claim a high accuracy on the reported cross-section values. In addition, the real humidity
464 rate in the CRDS cell had to be estimated from a line profile analysis which led to a correction of 15%
465 compared to its nominal value. Altogether, we roughly estimate as 50% the overall error bars on our
466 cross-section values. The agreement with the MT_CKD model, unexpectedly better than this error bar,
467 might be coincidental. We thus conclude that in the 1.27 μm transparency window, the MT_CKD
468 model is validated within our uncertainties, which was not the case in the 2.3 and 1.6 μm windows,
469 where an underestimation of the MT_CKD values by up to a factor 10 were measured in the centers of
470 the windows [9,14,15].

471 The question of the relative amplitude of the O₂-, and N₂-water continua deserves further
472 investigation in more favorable spectral ranges. The 1.6 μm window is considered for dedicated study
473 of this issue.

474

475 **CRedit authorship contribution statement**

476 **A. O. Koroleva:** Investigation. **S. Kassi:** Investigation. **D. Mondelain:** Investigation. **A. Campargue:**
477 Investigation.

478

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