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New measurements and validation of a previously  
proposed  $\chi$  factor**

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## Highlights

**The H<sub>2</sub>O – CO<sub>2</sub> continuum around 3.1, 5.2 and 8.0 μm: New measurements and validation of a previously proposed  $\chi$  factor**

Wissam Fakhardji, Ha Tran, Olivier Pirali, Jean-Michel Hartmann

- H<sub>2</sub>O – CO<sub>2</sub> continuum measurements at room temperature
- Confirmation of previous measurements for the 1400 – 1500 cm<sup>-1</sup> spectral region
- New measurements in the 1800 – 2000 and 3100 – 3300 cm<sup>-1</sup> regions
- Validation of a previous  $\chi$  factor model

1 The H<sub>2</sub>O – CO<sub>2</sub> continuum around 3.1, 5.2 and 8.0  
2 μm: New measurements and validation of a previously  
3 proposed  $\chi$  factor

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12 **Abstract**

13 The H<sub>2</sub>O – CO<sub>2</sub> continuum has been measured, at room temperature, at  
14 discrete spectral points in the 1100 – 1500, 1800 – 2000, and 3100 – 3300  
15 cm<sup>-1</sup> intervals. Our results are in good agreement with previous experimental  
16 values in the low frequency wing of the  $\nu_2$  band of H<sub>2</sub>O when the associated  
17 uncertainties are taken into account. Furthermore, they confirm the quality,  
18 in this region, of a  $\chi$  factor previously adjusted on measurements in the 100  
19 – 1500 cm<sup>-1</sup> range, and prove its validity in the blue side of the  $\nu_2$  band as  
20 well as in the region around 3.1 μm, which have been experimentally studied  
21 for the first time in this work. Together with recent measurements in the 1.6  
22 μm, 2.3 μm and far infrared regions, our results contribute to the progressive  
23 building-up of a data set for the modeling of the absorption by CO<sub>2</sub> + H<sub>2</sub>O  
24 mixtures throughout the infrared, which is needed for studies of CO<sub>2</sub>-rich  
25 planetary atmospheres.

26 *Keywords:* CO<sub>2</sub> – H<sub>2</sub>O continuum, measurements,  $\chi$ -factor model,  
27 CO<sub>2</sub>-rich atmospheres

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## 28 1. Introduction

29 The accurate knowledge and modeling of spectra of  $\text{H}_2\text{O} + \text{CO}_2$  mixtures  
30 for various temperature and pressure conditions is required for planetary  
31 science. In particular, the effect of  $\text{CO}_2$  on the water vapor greenhouse effect  
32 must be known to model the atmospheres of Venus and Early Mars and it  
33 will likely be soon needed for some exoplanets [see, e.g. (Lebonnois et al.,  
34 2015; Turbet et al., 2021; Turbet et al., 2020; Pluriel et al., 2019)].

35 The absorption by gas samples containing water vapor is generally split into  
36 several contributions, which, in the present case of  $\text{H}_2\text{O} + \text{CO}_2$  mixtures,  
37 are those of the local lines of the  $\text{H}_2\text{O}$  and  $\text{CO}_2$  monomers, and those  
38 of the so-called continua associated with intermolecular interactions within  
39  $\text{H}_2\text{O} - \text{H}_2\text{O}$ ,  $\text{CO}_2 - \text{CO}_2$  and  $\text{H}_2\text{O} - \text{CO}_2$  pairs. This separation, which was  
40 introduced many years ago [see, e.g. (Burch, 1982; Burch and Alt, 1984)]  
41 and kept since then (Mlawer et al., 2012), has a practical interest since the  
42 continua are proportional to the product of the densities of the molecules  
43 involved (provided that the local transitions contributions are computed up  
44 to a distant to the line centers significantly larger than the pressure broadened  
45 widths). Recall that the continua potentially include contributions of the  
46 far wings of the pressure-broadened absorption lines of the monomers, of  
47 collision-induced absorption, and of bound and quasi-bound bi-molecular  
48 complexes.

49 In a pioneer study carried three decades ago, a quasistatic theoretical  
50 approach was developed (Ma and Tipping, 1992; Pollack et al., 1993) for  
51 the prediction of the  $\text{H}_2\text{O} - \text{CO}_2$  continuum due to the far wings of the  
52  $\text{CO}_2$ -broadened lines of  $\text{H}_2\text{O}$ . In the absence of any experimental results,  
53 the associated calculated spectra and line-shape correction-factor  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$   
54 provided the very first data throughout the infrared. Twenty five years  
55 later came the first measurements of the  $\text{H}_2\text{O} - \text{CO}_2$  continuum, which  
56 investigated the  $1100\text{--}1300\text{ cm}^{-1}$  region (Baranov, 2016). Then, Tran et  
57 al. (2019) produced new data from  $100$  to  $1500\text{ cm}^{-1}$ , which confirmed  
58 the results of Baranov (2016) and extended the investigated spectral range.  
59 Note that this latter study also provided a line-shape factor  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  for  
60  $\text{CO}_2$ -broadened  $\text{H}_2\text{O}$  transitions, obtained by adjusting the measured values  
61 between  $100$  and  $1500\text{ cm}^{-1}$ , with which the calculated continuum agrees  
62 well with the experiments. For the  $\text{H}_2\text{O}$ -broadened wings of  $\text{CO}_2$  lines,  
63 the situation is somehow similar, with first results and data obtained only  
64 recently. These include measurements in the high frequency wing of the  $\text{CO}_2$

65  $\nu_3$  band (Baranov, 2016; Tran et al., 2018) from which a  $\chi_{\text{CO}_2-\text{H}_2\text{O}}$  absorption  
66 factor was deduced (Tran et al., 2018), and direct predictions using molecular  
67 dynamics simulations (Hartmann et al., 2018a). Finally, recall that another  
68 process participating to the continua is collision-induced absorption (CIA)  
69 (Frommhold, 1993). In the particular case of  $\text{H}_2\text{O} + \text{CO}_2$  mixtures such a  
70 contribution was pointed out recently by a cavity ring down spectroscopy  
71 study (Fleurbaey et al., 2022a). This investigation, which provided values of  
72 the continuum of  $\text{H}_2\text{O} + \text{CO}_2$  mixtures at some points around 1.60, 2.3 and  
73 3.5  $\mu\text{m}$ , also evidenced the presence of a CIA peak around  $6000 \text{ cm}^{-1}$ . The  
74 latter was soon after attributed (Fleurbaey et al., 2022b) to the simultaneous  
75 transitions involving the  $\nu_3$ -band dipole of  $\text{CO}_2$  and the  $\nu_1$ -band polarizability  
76 of  $\text{H}_2\text{O}$ .

77 In the present work, we continue the efforts made to build up a  $\text{H}_2\text{O} +$   
78  $\text{CO}_2$  continuum throughout the infrared by measuring the absorption, at  
79 room temperature, on both sides of the  $\nu_2$  band as well as around 3.1  $\mu\text{m}$ .  
80 The experimental procedure is presented in Section 2 and the data analysis  
81 is described in Section 3. Finally, the results are shown in Section 4 and  
82 compared to previous experiments and predictions based on the line-shape  
83 factor  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  proposed in Tran et al. (2019).

## 84 2. Measurements

85 The spectra were measured using the facilities at the AILES beam line  
86 of the SOLEIL synchrotron, previously used for similar experiments (Tran  
87 et al., 2019; Fakhardji et al., 2022). A high resolution Fourier transform  
88 spectrometer (FTS, Bruker IFS 125 HR) was used, equipped with a global  
89 source and a KBr beam splitter. The light exiting the FTS passed through  
90 a 2.5 m long multi-pass cell with diamond windows, set for an optical path  
91 of 101.3 m. The transmitted intensity was then measured with a liquid  
92 nitrogen-cooled HgCdTe detector. For each spectrum, whose usable part lies  
93 between about 700 and  $4600 \text{ cm}^{-1}$ , an average of 1000 scans was made with  
94 an unapodized resolution of  $0.5 \text{ cm}^{-1}$ . In the measurements of the absorption  
95 by  $\text{H}_2\text{O} + \text{CO}_2$  mixtures, all carried at 295 K, the cell was first filled with  
96 purified water vapor at a pressure of  $\sim 15 \text{ mb}$  (measured using a 0-1000  
97 mb Pfeiffer model CMR361 capacitive gauge which has a stated accuracy  
98 of 0.2%). Then  $\text{CO}_2$  was introduced step by step, progressively increasing  
99 the total pressure from  $\sim 500 \text{ mb}$  to  $\sim 1000 \text{ mb}$  (measured using the same  
100 capacitive gauge) and a spectrum was recorded after each step (awaiting

101 about 10 to 15 min each time to allow the gas mixture to reach equilibrium).  
 102 In addition to this "ascendant" procedure, we also recorded spectra using a  
 103 "descendant" procedure, i.e. starting from the highest pressure of  $\sim 1000$  mb  
 104 and progressively reducing it down to  $\sim 500$  mb. Note that these two ways of  
 105 collecting data are not equivalent since the mole fractions of  $H_2O$  ( $\sim 1.5\%$ )  
 106 and  $CO_2$  ( $\sim 98.5\%$ ) are kept constant in the descendant procedure while they  
 107 vary in the ascendant one (the proportion of water vapor then decreasing from  
 108  $\sim 3\%$  down to  $\sim 1.5\%$ ). In order to obtain the 100% transmittance levels,  
 109 reference spectra were also recorded with the cell filled with pure argon at  $\sim$   
 110 1 bar, before and after each of the series with  $H_2O + CO_2$  mixtures described  
 111 above.

### 112 3. Data analysis

113 In a first step, the transmission associated with each  $H_2O + CO_2$  sample  
 114 was obtained by dividing the corresponding recording by the reference  
 115 spectrum (recorded with argon). Then, various contributions to the  
 116 absorption needed to be removed in order to obtain the targeted continuum  
 117 due to the  $CO_2$ -broadened far wings of the  $H_2O$  lines. Indeed, for a  $CO_2+H_2O$   
 118 mixture at temperature  $T$  with densities  $d_{CO_2}$  and  $d_{H_2O}$ , the total absorption  
 119 coefficient  $\alpha_{tot}$  at wavenumber  $\sigma$  can be written as:

$$\begin{aligned}
 \alpha_{tot}(\sigma, d_{CO_2}, d_{H_2O}, T) = & \alpha_{loc}^{CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T) + \alpha_{loc}^{H_2O}(\sigma, d_{CO_2}, d_{H_2O}, T) \\
 & + \alpha_{CA}^{CO_2-CO_2}(\sigma, d_{CO_2}, T) + \alpha_{CA}^{H_2O-H_2O}(\sigma, d_{H_2O}, T) \\
 & + \alpha_{CA}^{H_2O-CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T)
 \end{aligned}
 \tag{1}$$

120 where  $\alpha_{loc}^{CO_2}$  and  $\alpha_{loc}^{H_2O}$  are the contributions of local lines of the two molecules,  
 121 computed including all transitions within a given interval (see below) around  
 122 the current wavenumber. The coefficient  $\alpha_{CA}^{CO_2-CO_2}$  and  $\alpha_{CA}^{H_2O-H_2O}$  denote  
 123 the continuum absorptions by pure  $CO_2$  and  $H_2O$  respectively. Finally  
 124  $\alpha_{CA}^{H_2O-CO_2}$  is the continuum absorption due to interacting  $H_2O + CO_2$  pairs.  
 125 In order to deduce  $\alpha_{CA}^{H_2O-CO_2}$  we have computed all the other contributions  
 126 as described below.

127

128 *1 - Computation of the local lines absorption ( $\alpha_{loc}^{CO_2}$ ,  $\alpha_{loc}^{H_2O}$ )* - The  
 129 calculation of the associated absorption coefficients was carried using Voigt  
 130 profiles [truncated  $\pm 5$   $cm^{-1}$  for  $CO_2$ , for consistency with Perrin and

131 Hartmann (1989) and  $\pm 25 \text{ cm}^{-1}$  for  $\text{H}_2\text{O}$ , for consistency with Mlawer et  
 132 al. (2012) and Clough et al. (1989), away from their centers] with line  
 133 positions and intensities taken from the HITRAN database (Gordon et al.,  
 134 2022). Since the latter provides only self- and air-broadening coefficients,  
 135 the needed values of the broadenings of  $\text{H}_2\text{O}$  lines by  $\text{CO}_2$  were taken from  
 136 Brown et al. (2007), while we used the data of Sung et al. (2009) for the  $\text{H}_2\text{O}$   
 137 broadenings of  $\text{CO}_2$  transitions, as done in Tran et al. (2019). The pressure  
 138 shifts of the  $\text{CO}_2$  lines induced by collisions with  $\text{H}_2\text{O}$  and those of  $\text{H}_2\text{O}$  lines  
 139 by  $\text{CO}_2$  being not available, they are considered to be the same as the ones  
 140 with air. The impact of this approximation is expected to be negligible given  
 141 the small value of the line shift in comparison to the spectral resolution of  
 142 the recorded spectra. The partial pressure of  $\text{H}_2\text{O}$  for each recording was  
 143 also determined by fitting some absorption lines. The obtained results are  
 144 consistent (with a difference around only  $\sim 2\%$ ) with the values deduced  
 145 from the  $\text{H}_2\text{O}$  mole fraction and the total pressure of the mixture (both a  
 146 priori known through the pressure readings during the making of the mixture  
 147 and the successive recordings).

148 *2 – Computation of the pure  $\text{CO}_2$  continuum* ( $\alpha_{CA}^{CO_2-CO_2}$ ) –  $\alpha_{CA}^{CO_2-CO_2}$  was  
 149 computed taking into account two contributions. The first, due to the wings  
 150 of  $\text{CO}_2$  lines broadened by collisions with  $\text{CO}_2$ , was computed using the  
 151  $\chi_{\text{CO}_2-\text{CO}_2}$  factor from Perrin and Hartmann (1989). Note that this model was  
 152 preferred to a line-mixing model because it leads to much better agreement  
 153 with the measurements in the line-wings (Tran et al., 2011). The second,  
 154 due to two collision-induced absorption bands around  $1350 \text{ cm}^{-1}$  (Baranov  
 155 and Vigasin, 1999) was taken from Karman et al. (2019).

156 *3 – Computation of the pure  $\text{H}_2\text{O}$  continuum* – Finally, the contribution  
 157 of the  $\text{H}_2\text{O}$  self-continuum was computed using the version v3.2 (available  
 158 at [http://rtweb.aer.com/continuum\\_frame.html](http://rtweb.aer.com/continuum_frame.html)) of the MT\_CKD model  
 159 (Mlawer et al., 2012).

160 Note that, since data are available for its computation, the contribution of  
 161 the  $\text{H}_2\text{O}$ -broadened wings of  $\text{CO}_2$  lines were computed using the  $\chi_{\text{CO}_2-\text{H}_2\text{O}}$   
 162 from Tran et al. (2018), and removed from  $\alpha_{CA}^{H_2O-CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T)$ . Note  
 163 that it makes a practically negligible contribution in the investigated spectral  
 164 regions.

165 Once all these contributions have been calculated, the associated spectral  
 166 transmission  $\tau_{Calc}(\sigma)$  is predicted and convolved by the FTS instrument  
 167 function  $F_{inst}(\sigma)$ . The targetted continuum due to the far wings of the  
 168  $\text{CO}_2$ -broadened  $\text{H}_2\text{O}$  monomer lines was then obtained from the measured

169 transmission  $\tau_{Meas}(\sigma)$  by using:

$$\alpha_{CA}^{H_2O-CO_2}(\sigma) = -\ln [\tau_{Meas}(\sigma)/(\tau_{Calc}(\sigma) * F_{inst}(\sigma))] / L \quad (2)$$

170 where  $L$  is the optical path in cm and  $*$  denotes a convolution. Note that  
 171 for consistency with the usual definition of the H<sub>2</sub>O continua (Mlawer et al.  
 172 2012; Clough et al., 1989), the values of  $\alpha_{CA}^{H_2O-CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T)$  provided  
 173 by this procedure are corrected by adding the "pedestal" (since it was not  
 174 subtracted from  $\alpha_{loc}^{H_2O}$ ) defined by:

$$P(\sigma, d_{CO_2}, d_{H_2O}, T) = \frac{d_{CO_2} d_{H_2O}}{\pi} \sum_{l \text{ if } |\sigma - \sigma_l| < 25} \frac{S_l(T) \gamma_l(T)}{(25)^2} \quad (3)$$

175 where the sum extends over all H<sub>2</sub>O lines centered within  $\pm 25 \text{ cm}^{-1}$   
 176 around the current wavenumber.  $S_l(T)$  is the the integrated intensity of  
 177 line  $l$  in  $\text{cm}^{-2}/\text{amagat}$ , and  $\gamma_l(T)$  (in  $\text{cm}^{-1}.\text{amagat}^{-1}$ ) is the CO<sub>2</sub>-broadening  
 178 coefficient of the line. Note that the amagat density unit is used here as in  
 179 previous studies, 1 amagat corresponding to  $2.687 \times 10^{19} \text{ molec}/\text{cm}^3$ .

180 Using the above described procedure, the  $\alpha_{CA}^{H_2O-CO_2}$  continuum can  
 181 potentially be retrieved for each wavenumber where the absorption by H<sub>2</sub>O  
 182 is measurable under our experimental conditions. However, the values  
 183 obtained are very uncertain when the computed absorption that has been  
 184 removed represents a very large part of the total absorption. Hence, as  
 185 done in Tran et al. (2019), we selected only the spectral points located  
 186 in troughs between lines and sufficiently distant from the latter. In order  
 187 to determine the density-normalized  $CA^{H_2O-CO_2}(\sigma, T)$  continuum from the  
 188 values of  $\alpha_{CA}^{H_2O-CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T)$ , we used the fact that, for binary  
 189 collisions (an assumption valid at the pressures of our measurements), they  
 190 are related through:

$$\alpha_{CA}^{H_2O-CO_2}(\sigma, d_{CO_2}, d_{H_2O}, T) = d_{CO_2} d_{H_2O} CA^{H_2O-CO_2}(\sigma, T) \quad (4)$$

191 We thus performed a linear fit of  $\alpha_{CA}^{H_2O-CO_2}$  versus the product of the densities  
 192  $d_{CO_2} d_{H_2O}$  for each retained spectral point. Some examples of this exercise  
 193 are displayed in Fig. 1, which shows that our measured values do quite well  
 194 follow the proportionality law of Eq. (4). Note that, in order to obtain  
 195 these results, the level of the reference spectrum (corresponding to the 100%  
 196 transmittance recorded with the cell filled with argon) was also adjusted by  
 197 multiplying it by a linear function of wavenumber assumed independent of  
 198 the pressure.



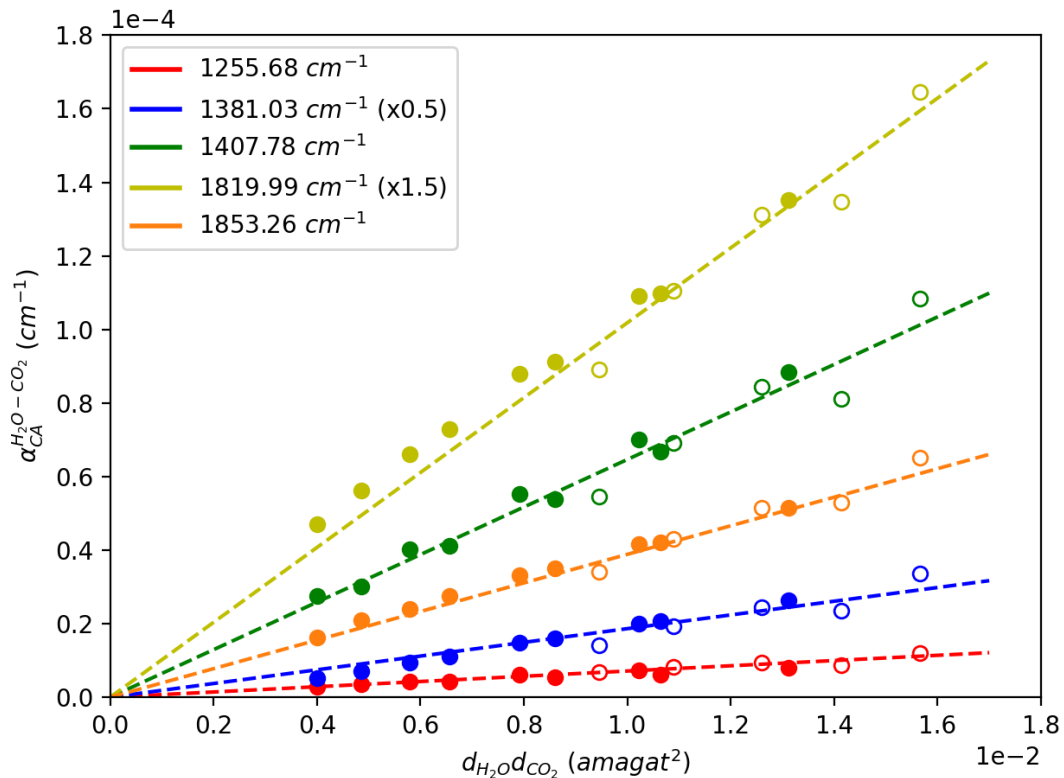


Figure 1: Examples of linear fits (dashed lines) of the measurements (represented with filled and empty dots respectively for increasing and decreasing pressure ramps) for fixed values of the wavenumber. The value of the  $\text{H}_2\text{O} - \text{CO}_2$  continuum  $C A^{\text{H}_2\text{O}-\text{CO}_2}(\sigma)$  is directly given by the slope of the line.

#### 199 4. Results and discussion

200 Figure 2 displays a comparison of our experimental values (provided in  
 201 the supplementary material) for the  $\text{H}_2\text{O} - \text{CO}_2$  continuum with the other  
 202 measurements available in the considered spectral region (Baranov, 2016;  
 203 Tran et al., 2019). The uncertainties on our determinations, shown by the  
 204 error bars in Fig. 2, were obtained taking into account three major sources  
 205 of error. The first one comes from the dispersion of the measurements and  
 206 it was obtained from the  $1\sigma$  statistical error in the linear fits exemplified  
 207 in Fig. 1. In addition, the calculations of the other contributions to the  
 208 absorption (presented in Sec. 3) that have been removed propagate errors

209 due to uncertainties on the spectroscopic parameters used (in particular  
 210 for the contribution of the H<sub>2</sub>O local lines). This additional source of  
 211 errors was computed using the uncertainties on the H<sub>2</sub>O line intensities  
 212 and air-broadening coefficients provided, for each line, by the HITRAN  
 213 database (Gordon et al., 2022) [we thus assumed the same values for the  
 214 CO<sub>2</sub>-broadening coefficients of Brown et al. (2007)]. Even though they  
 215 are not expected to play a major role, the uncertainties on the intensities  
 216 and self-broadening coefficient for CO<sub>2</sub> are also taken in account. For both  
 217 H<sub>2</sub>O and CO<sub>2</sub> lines, we disregarded the uncertainties on their positions since  
 218 the associated uncertainties are negligible. The third source of error is the  
 219 uncertainty on the self H<sub>2</sub>O continuum that we estimated by comparing the  
 220 MT\_CKD model with the measurements made by Ptashnik et al., (2019).  
 221 The difference observed was on average about  $\sim 10\%$  and we then supposed  
 222 this level for the uncertainties and added them to the error bars. Note  
 223 that the first and the two other sources of error mentioned above behave  
 224 differently according to the spectral region of interest. Indeed, the dispersion  
 225 of the measurements becomes less important as the absorption increases,  
 226 and the associated statistical error decreases. In contrast, the uncertainties  
 227 on the spectral parameters and those on the self H<sub>2</sub>O continuum naturally  
 228 play a larger role near the center of the  $\nu_2$  band, while their impact is less  
 229 pronounced in the far wings regions. Hence the first source of error dominates  
 230 in the weak absorption regions, while the uncertainty associated with the  
 231 calculation of the removed absorption is predominant near the band center.  
 232 Finally, in our results we have selected only the values of the continuum  
 233 which are larger than their associated uncertainty.

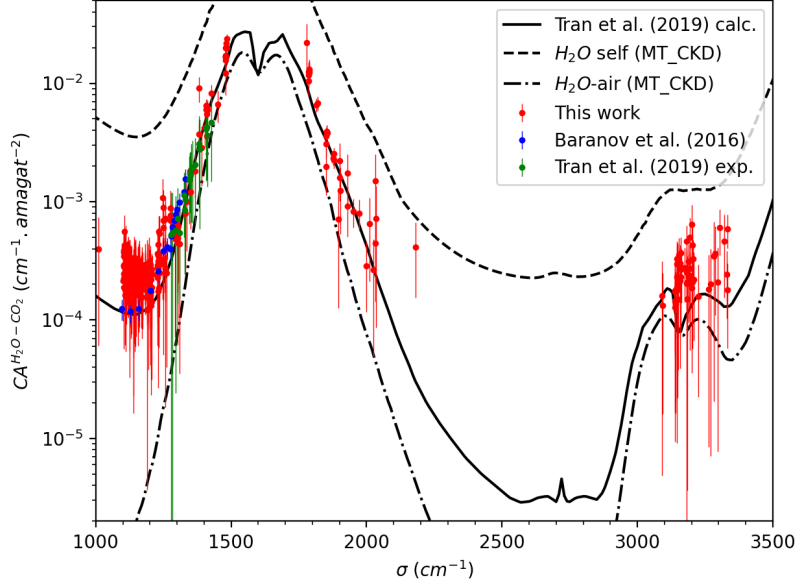
234 The first thing to be noticed is that, between 1100 and 1200 cm<sup>-1</sup>, our  
 235 continuum values are on average larger than the previous measurements  
 236 (Baranov, 2016; Tran et al., 2019) (although all are compatible when  
 237 uncertainties are taken into account) while at higher frequencies in the  
 238 red wing of the  $\nu_2$  band the agreement is better. The center of the  $\nu_2$   
 239 absorption band being saturated it is not possible to extract information on  
 240 the continuum but, in the 1800 – 2000 cm<sup>-1</sup> range we were able to determine  
 241 it, providing the first determination of the H<sub>2</sub>O – CO<sub>2</sub> continuum, which is  
 242 also the case for the 3100–3300 cm<sup>-1</sup> interval.

243 As is well known, the self and foreign H<sub>2</sub>O continua include four  
 244 contributions, all proportional to the product of densities of the species  
 245 involved: (i) What is left of the wings of the pressure-broadened monomer  
 246 lines after the removal of the contribution of the transitions within  $\pm 25$

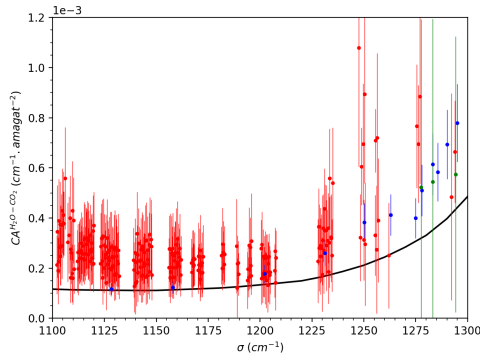
247  $\text{cm}^{-1}$ . (ii) The absorption due to the interaction-induced dipole within free  
 248 colliding pairs (see e.g. Fleurbaey et al., 2022a,b). The participation of  
 249 (iii) bound and (iv) meta-stable or quasi-bound dimers. In the case of the  
 250 water vapor continua the related importance of these four contributions has  
 251 been a controversial and still open issue for decades (see e.g. Hartmann et  
 252 al., 2018b and references therein), whose discussion is largely beyond the  
 253 scope of the present study. However, an empirical approach was proposed  
 254 by Tran et al. (2019) to compute the  $\text{H}_2\text{O} - \text{CO}_2$  continuum. The authors  
 255 rightly or wrongly assumed that the continuum in the  $100\text{-}1500 \text{ cm}^{-1}$  region,  
 256 is entirely due to the far wings of the monomer lines. They consequently  
 257 adjusted a  $\chi_{\text{CO}_2-\text{H}_2\text{O}}$  correction factor on the experimental data as was done  
 258 many years ago for the self- and air-broadened  $\text{H}_2\text{O}$  continua (Clough et  
 259 al, 1989). In the absence of any other theoretical approach for comparison  
 260 with our measurements, we used this model, with results displayed in Fig.  
 261 2. As can be seen, the agreement between calculations and experiments in  
 262 the newly studied regions is quite good, which demonstrates the predictive  
 263 capabilities of the  $\chi$  factor approach. However, note that concluding from  
 264 this that the continuum in whole studied regions is only due to the monomer  
 265 far wings would be highly hazardous.  
 266 Finally, the top panel in Fig. 2 enables to compare the  $\text{H}_2\text{O} - \text{CO}_2$  continuum  
 267 with those, taken from Mlawer et al. (2012), for pure  $\text{H}_2\text{O}$  and  $\text{H}_2\text{O}$ -air. As  
 268 can be seen the values for  $\text{H}_2\text{O} - \text{CO}_2$  are slightly larger than those for  $\text{H}_2\text{O}$ -air  
 269 and significantly smaller than those for  $\text{H}_2\text{O} - \text{H}_2\text{O}$  (Brown et al., 2007). This  
 270 is consistent with the quasi static predictions of Ma and Tipping (1992) and  
 271 with the fact that the broadening coefficients of  $\text{H}_2\text{O}$  lines by  $\text{CO}_2$  (Brown et  
 272 al., 2007) are slightly larger than those by air and significantly smaller than  
 273 those for pure  $\text{H}_2\text{O}$  (Gordon et al., 2022).

## 274 5. Conclusion

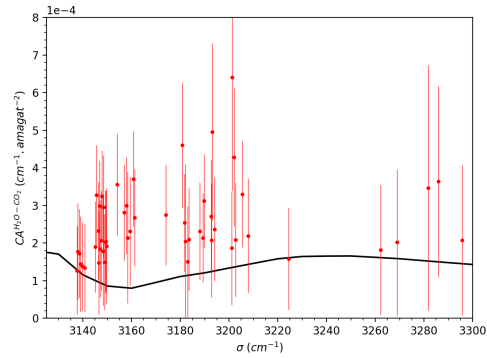
275 We measured the  $\text{H}_2\text{O} - \text{CO}_2$  continuum on both sides of the  $\nu_2$  absorption  
 276 band, as well as around  $3.1 \mu\text{m}$ . The data obtained in the spectral range  $1100$   
 277  $- 1400 \text{ cm}^{-1}$  are consistent with previous measurements (Baranov, 2016; Tran  
 278 et al., 2019) when their respective uncertainties are taken into account. For  
 279 the first time, the continuum has been measured on the high frequency side  
 280 of the  $\nu_2$  band from  $1800 \text{ cm}^{-1}$  to  $2000 \text{ cm}^{-1}$  as well as between  $3100$  and  
 281  $3300 \text{ cm}^{-1}$ . In addition to providing new measured data, this study also  
 282 enabled a successful further test of the  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  factor model proposed in



(a)



(b)



(c)

Figure 2:  $\text{H}_2\text{O}-\text{CO}_2$  continuum – The data measured in this study are shown with red dots and are compared to the results of previous experiments (Baranov, 2016; Tran et al., 2019) respectively displayed in blue and green. The black line represents the values predicted using the  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  factor model developed by Tran et al. (2019). For comparison, we also show the self- and air-broadened  $\text{H}_2\text{O}$  far line wings continuum [computed using the latest version available at [http://rtweb.aer.com/continuum\\_frame.html](http://rtweb.aer.com/continuum_frame.html) of the MT\_CKD model (Mlawer et al., 2012)] with dashed and dashdotted lines, respectively. The top panel (a) displays the results in log scale while the two bottom plots (b) and (c) show respectively the  $1100-1300\text{ cm}^{-1}$  and  $3100-3300\text{ cm}^{-1}$  regions in linear scale.

283 Tran et al. (2019). This demonstration of the predictive capabilities of a  
284 line-shape correction-factor fitted to experimental results below  $1500\text{ cm}^{-1}$  is  
285 of considerable interest, particularly for spectral regions where measurements  
286 have not yet been made. However recall that our experimental data have  
287 been collected at room temperature only, which stresses the crucial need of  
288 investigations at various temperatures.

289 It is worth mentioning that our knowledge of the continua associated with  
290  $\text{H}_2\text{O} - \text{CO}_2$  pairs has significantly increased in the last four years, and  
291 that much progress has been made after the first computations of Ma et  
292 al. (1992) and measurements of Baranov (2016). Many new experimental  
293 data have been provided which confirmed the latter data and considerably  
294 extended the spectral range in which values of the continuum are available.  
295 In addition, the original  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  factor of Ma et al. (1992) has been  
296 significantly improved (Tran et al., 2019). This provides a computational  
297 approach with which a satisfactory agreement with measurements is obtained  
298 at almost all experimentally investigated wavelengths, provided that it  
299 is complemented, around  $6000\text{ cm}^{-1}$ , by a description (Fleurbaey et al.,  
300 2022b) of the collision-induced simultaneous transitions. However, much  
301 still remains to be done: First, new measurements are needed to test the  
302 model in so far unstudied regions, e.g.  $2200 - 3000\text{ cm}^{-1}$ , while experiments  
303 of improved precision are desirable around  $3.1\text{ }\mu\text{m}$ . Last but not least, the  
304 temperature dependence, for which the only information available comes from  
305 the early theoretical study of Pollack et al. (1993) must be investigated  
306 experimentally.

### 307 **Declaration of Competing Interest**

308 The authors declare no conflicts of interest

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313 absorption coefficient using the  $\chi_{\text{H}_2\text{O}-\text{CO}_2}$  factor model.

314 **Supplementary material**

315 The measured data of the  $\text{H}_2\text{O} - \text{CO}_2$  continuum presented in this work  
316 are available in the supplementary material

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