Oscillator Strengths and Predissociation Rates for $W - X$ Bands and the $4p5p$ Complex in $^{13}\text{C}^{16}\text{O}$ and $^{12}\text{C}^{18}\text{O}$

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Outline

Background
New Results from SOLEIL
Summary
Background

• CO observed in many astronomical environments
  – Diffuse and dark, molecular interstellar clouds
  – Circumstellar shells of asymptotic giant branch stars and planetary nebulae
  – Circumstellar disks around newly formed stars
  – Comets and planetary atmospheres

• Experimental data for photochemical models, including those for the Solar Nebula
  – Electronic transitions (ultraviolet)
  – Oscillator strengths
  – Predissociation rates
SOLEIL Experiments

- DESIRS beamline with a VUV FTS at SOLEIL Synchrotron
SOLEIL Experiments

• The FTS (de Oliveira et al. 2009, Rev. Sci. Instru., 80, 043101; de Oliveira et al. 2011, Nature Photonics, 5, 149)
  – Resolving power as high as 750,000 (here we used 350,000)
  – Based on wave front division instead of amplitude division
  – Relies on modified bimirror configuration requiring only flat mirrors
  – Path difference scanning through translation of one reflector
SOLEIL Experiments

- Need calibration band: use $B - X (0,0)$
  - This band is isolated
  - For $^{12}\text{C}^{16}\text{O}$, its band $f$-value is well characterized (with weighted uncertainty of 7%)
  - For $^{13}\text{C}^{16}\text{O}$ and $^{12}\text{C}^{18}\text{O}$, close-coupling model of interaction between $B \, ^1\Sigma^+$ and $D' \, ^1\Sigma^+$ indicates $f$-value varies less than 1.7% among isotopologues (Stark et al. 2014, ApJ, 788, 67)

![Graph of B-X (0-0) band](image)

SOLEIL Experiments

- $W - X$ bands [see Alan Heay’s presentation on (1,0) bands]
SOLEIL Experiments

- $W - X$ bands (cont.)
  - $f$-values consistent with earlier determinations, regardless of spectral resolution, because predissociation rates large
  - Agreement found with earlier predissociation rates, but now see $J$-dependence
  - For (0,0) and (3,0) bands, also see differences for $e$- and $f$-parity levels
### SOLEIL Experiments

- *W – X bands (cont.)*

<table>
<thead>
<tr>
<th>Isotopologue/Band</th>
<th>$f$-value ($\times 10^3$)</th>
<th>Predissociation Rates ($10^{11}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>$e$ parity</td>
</tr>
<tr>
<td>$^{12}$C$_{16}$O$_a$ (0,0)</td>
<td>14.3(1.1)</td>
<td>0.09(0.02)+0.019(0.001)x</td>
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<tr>
<td>$^{13}$C$_{16}$O</td>
<td>12.67(0.82)</td>
<td>0.220(0.060)+0.011(0.001)x</td>
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<tr>
<td>$^{12}$C$_{18}$O</td>
<td>13.94(0.86)</td>
<td>0.226(0.021)+0.0147(0.0004)x</td>
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<tr>
<td>$^{12}$C$_{16}$O$_a$ (2,0)</td>
<td>28.9(2.1)</td>
<td>1.12(0.05)+0.010(0.001)x</td>
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<tr>
<td>$^{13}$C$_{16}$O</td>
<td>27.14(1.72)</td>
<td>0.472(0.043)+0.0067(0.0011)x</td>
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<td>+[9.4(0.6)]$10^{-5}$x$^2$</td>
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<tr>
<td>$^{12}$C$_{18}$O</td>
<td>26.40(1.63)</td>
<td>0.644(0.004)+0.00170(0.00087)x</td>
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<td>+[5.27(0.35)]$10^{-5}$x$^2$</td>
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<tr>
<td>$^{12}$C$_{16}$O$_a$ (3,0)</td>
<td>19.2(1.4)</td>
<td>2.07(0.10)+0.046(0.002)x</td>
</tr>
<tr>
<td>$^{13}$C$_{16}$O</td>
<td>15.92(1.02)</td>
<td>1.998(0.064)+0.1500(0.0028)x</td>
</tr>
<tr>
<td>$^{12}$C$_{18}$O</td>
<td>18.10(1.12)</td>
<td>1.70(0.06)+0.164(0.004)x</td>
</tr>
</tbody>
</table>
SOLEIL Experiments

• Results for Rydberg Complexes
  – $f$-values and predissociation rates again similar to values in earlier work, largely because rates very large
  – See evidence for $\Pi^1\Pi (0,0)$ band as additional lines in the spectrum of the P branch for the $5p\pi^1\Pi (0,0)$ band
  – In R branch of the $5p\pi^1\Pi (0,0)$ band in $^{13}\text{C}^{16}\text{O}$ see additional lines attributed to $4p\sigma (2,0)$ band
  – Unlike $^{12}\text{C}^{16}\text{O}$, no continuum absorption seen
  – Sums of $f$-values among bands within $4p5p$ complex for the three isotopologues are comparable
SOLEIL Experiments

- Results for Rydberg Complexes (cont.)
Summary

- VUV FTS allows us to extract data on individual bands, including predissociation rates that vary with $J$
- Detailed analysis of $W – X$ (1,0) bands in next talk
- Summed oscillator strengths for $4p5p$ complex consistent with results on $^{12}\text{C}^{16}\text{O}$