

# Detection of Forbidden Singlet-Triplet Transitions of $^{12}\text{C}^{16}\text{O}$

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**Abstract:** Twenty rovibronic transitions of the  $e(v'=5)-X(v''=0)$  band of  $^{12}\text{C}^{16}\text{O}$  for which experimental wavelengths were previously unavailable were recently detected by vacuum ultraviolet laser induced fluorescence excitation spectroscopy. The data is important in astrophysical applications and for comparison to the latest model of  $^{12}\text{C}^{16}\text{O}$ . The experimental techniques that facilitated these measurements will be highlighted.

## 1. Introduction

Carbon monoxide (CO) is the second most abundant molecule in outer space. Measurement of its absorption spectrum in the vacuum ultraviolet (VUV), and in particular of the forbidden bands, by satellite based spectrographs finds application in the determination of the column density of CO in interstellar clouds [1]. The forbidden bands of  $^{12}\text{C}^{16}\text{O}$  consist of rovibronic transitions from the singlet  $X^1\Sigma^+(v''=0)$  ground state to one of the triplet states, such as the  $e^3\Sigma^-(v'=5)$  state. Calculated wavelength values for the forbidden transitions are available, but accurate laboratory measured wavelengths for many of these transitions do not exist [2]. We have developed a setup for high resolution laser induced fluorescence (LIF) excitation spectroscopy in the VUV optimised for the investigation of these transitions [3]. We report on the characteristics of our setup and optimisation of experimental parameters that made the measurements possible and discuss recent results.

## 2. Results and Discussion

Our setup for LIF excitation spectroscopy in the VUV has been shown before to provide the spectral resolution needed to resolve individual rovibronic lines and the sensitivity to detect weak lines, such as that of rare CO isotopomers. In the investigation of the forbidden singlet-triplet rovibronic transitions in the  $e^3\Sigma^-(v'=5)-X^1\Sigma^+(v''=0)$  band of  $^{12}\text{C}^{16}\text{O}$  additional experimental challenges were encountered. These forbidden lines lie among the lines of the allowed  $A^1\Pi(v'=3)-X^1\Sigma^+(v''=0)$  band of  $^{13}\text{C}^{16}\text{O}$  which normally dominate the spectrum and tend to obscure the weak forbidden lines. The longer fluorescence lifetime of the triplet state was exploited to facilitate the detection of the forbidden transitions by optimising the timing between the CO gas pulse, laser pulse and detection gate. The  $^{13}\text{C}^{16}\text{O}$  lines were employed for wavelength calibration using data from Morton and Noreau [1].

The wavelengths of 20 rovibronic transitions of the  $e^3\Sigma^-(v'=5)-X^1\Sigma^+(v''=0)$  band of  $^{12}\text{C}^{16}\text{O}$  were recently obtained from our spectra. For five of the lines that were resolved individually experimental wavelengths were determined to an average uncertainty of 0.28 pm. For the remaining 15 lines an average wavelength was obtained for each group of closely spaced transitions. The experimental wavelengths were compared to the calculated wavelengths obtained from the latest model of  $^{12}\text{C}^{16}\text{O}$  by Eidelsberg and Rostas [2]. The complete wavelength data and analysis are given elsewhere [4]. The systematic blue shift of  $1.1\pm 0.28$  pm of the calculated wavelengths relative to the experimental wavelengths is significant as it exceeds the experimental uncertainty by a factor 4 and is large compared to the differences in the data of other vibronic bands in the paper of Eidelsberg and Rostas [2]. This result is important to astrophysical applications.

## 3. Conclusions

The detection of forbidden transitions of  $^{12}\text{C}^{16}\text{O}$  was facilitated by the spectral resolution, sensitivity and the optimisation of the detection system of our LIF excitation spectroscopy setup. The results demonstrate the need for further spectroscopic investigation of the forbidden transitions of  $^{12}\text{C}^{16}\text{O}$  in order to understand the reasons for the difference between experiment and model and to provide accurate data to the astrophysics community.

## 4. References

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