Metrology of methanol in the near-infrared at the 10^{-13} level

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MW spectroscopy through NIR measurements

The goal of our study is to determine Methanol's **$2_0E \leftarrow 3_{-1}E$ vibrationless transition at $12,178.6$ MHz[1, 2, 3]**, through the measurement of **vibrational transitions near 215 THz**, using Noise-Immune Cavity-Enhanced Optical-Heterodyne Molecular Spectroscopy (**NICE-OHMS**) [4], as this line provides more stringent limits on the **hypothetical variation of the electron-to-proton mass ratio**.

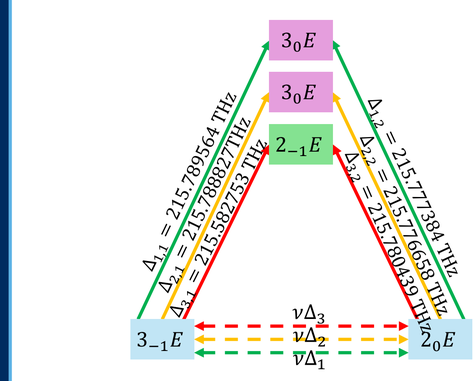

Fig.1 : Identified paths of NIR transitions for combination difference.

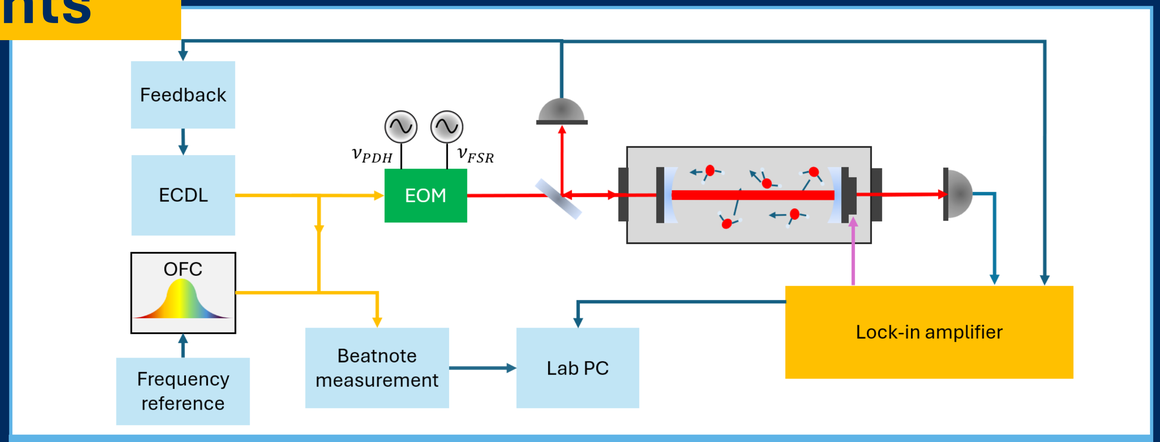

Fig. 2 : Simplified experimental setup scheme. ECDL : External Cavity Diode Laser, EOM : Electro-Optic Modulator, OFC : Optical Frequency Comb.

Methanol metrology

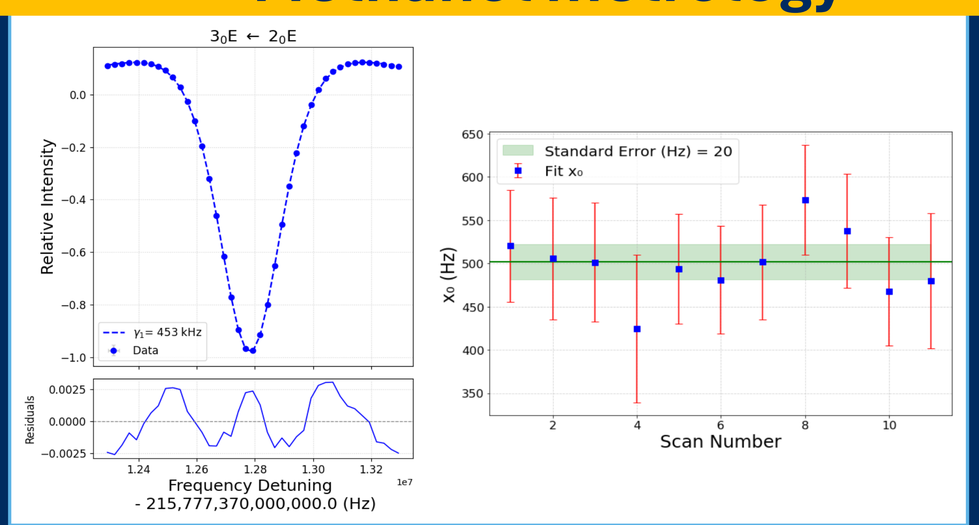

Fig. 3 : Left : Fitting of one scan with a derivative Lorentzian profile, Right : Fitted frequency (x_0) over scan number, with mean frequency and associated Standard Error of the Mean (S.E.M., green)

Pressure :
0.1 Pa ($\pm 2\%$)
Round-trip power :
$1 - 2$ W
8 minutes per scan
SNR ~1000
Fit uncertainty over each scan :

$$\mathbf{60\ Hz\ or} \frac{\delta\nu}{\nu} = 3 \times 10^{-13}$$

Six vibrational transitions were measured with **sub-kHz accuracy**, at different powers and pressures, to extrapolate the transition's frequency for 0 pressure and 0 power using a linear regression.

The combined differences give us the three frequencies for the **$2_0E \leftarrow 3_{-1}E$ vibrationless transition** at * :

$$\nu_{\Delta 1} = 12\,178\,595.34(0.19)\ \text{kHz}$$
$$\nu_{\Delta 2} = 12\,178\,595.98(0.42)\ \text{kHz}$$
$$\nu_{\Delta 3} = 12\,178\,595.00(0.57)\ \text{kHz}$$

$$\bar{\nu} = 12\,178\,595.41\ (0.17)\ \text{kHz}$$

*Preliminary results

The setup's move across countries

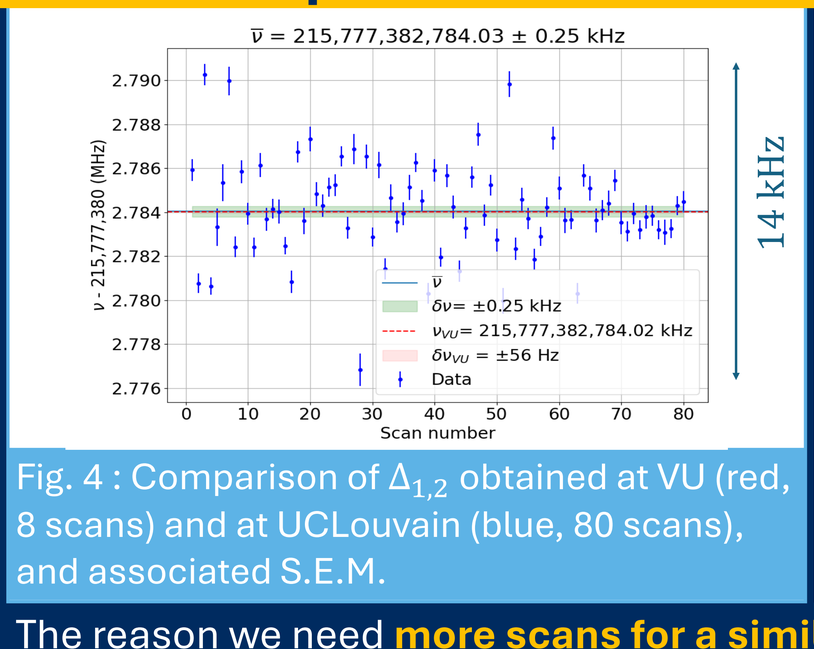

Fig. 4 : Comparison of $\Delta_{1,2}$ obtained at VU (red, 8 scans) and at UCLouvain (blue, 80 scans), and associated S.E.M.

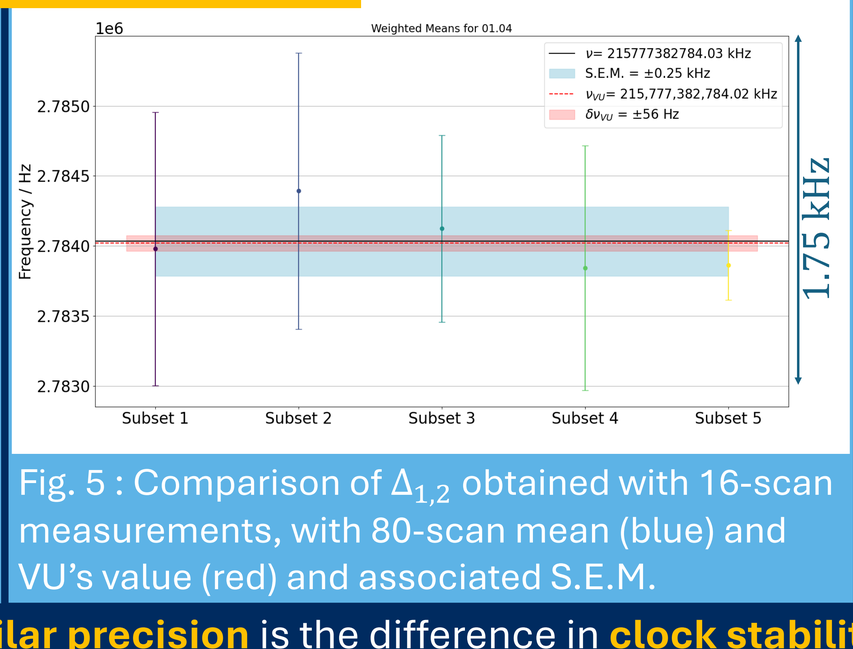

Fig. 5 : Comparison of $\Delta_{1,2}$ obtained with 16-scan measurements, with 80-scan mean (blue) and VU's value (red) and associated S.E.M.

- Values obtained before the move (8 scans) and after the move (80 scans), at 0.1 Pa :

$$\Delta_{1,2}^{VU} = 215\,777\,382\,784.02\ (0.056)\ \text{kHz}$$
$$\Delta_{1,2}^{LLN} = 215\,777\,382\,784.03\ (0.25)\text{kHz}$$
$$\mathbf{\Delta\nu = 100\ (306)Hz}$$

- for 16-scan measurements in UCLouvain :

$$\mathbf{\Delta\nu < 0.5\ (1.5)\ kHz}$$

The reason we need **more scans for a similar precision** is the difference in **clock stability** between VU and UCLouvain. This shows a clear **need for a better frequency reference** in Belgium.

Conclusion and outlook

Our preliminary results show that **sub-kHz accuracy can be achieved for transitions located in the MW through combination differences of NIR transitions**, competing with direct MW measurements. Even after a complete rebuild of the set-up, the results agree within uncertainties and **after 2 hours of measurement, we can obtain sub-2 kHz accuracy**, showing how robust the methodology is. These results should further improve with the installation of a better frequency reference in UCLouvain, leading to **more high-precision measurements of methanol's rotational transitions** in the future. This will find applications in fundamental physics and radio astronomy.

Acknowledgments

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