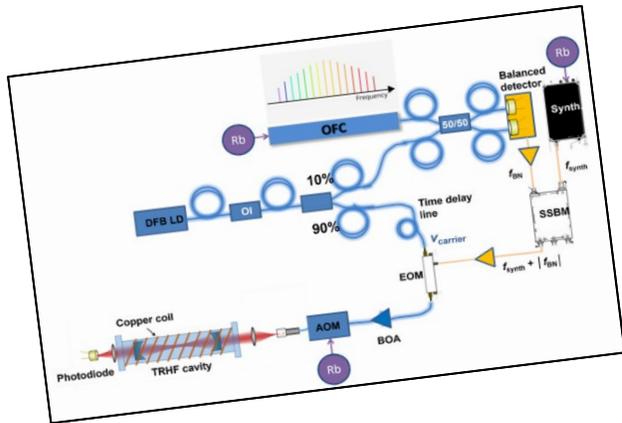
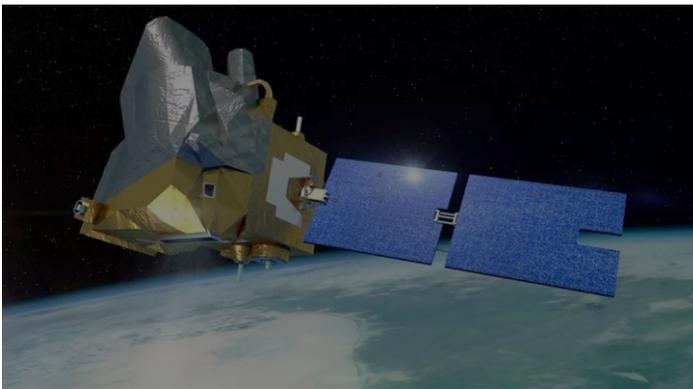


Spectroscopie moléculaire de haute précision: Repousser les limites avec le signal REFIMEVE

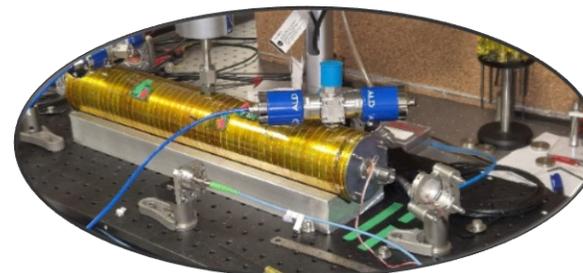


*Samir KASSI, Alain CAMPARGUE, Hélène FLEURBAEY,
Didier MONDELAIN, Daniele ROMANINI.*

*CNRS, Université Grenoble-Alpes,
Laboratoire Interdisciplinaire de Physique
140 rue de la Physique, 38402 Saint Martin d'Hères, France*

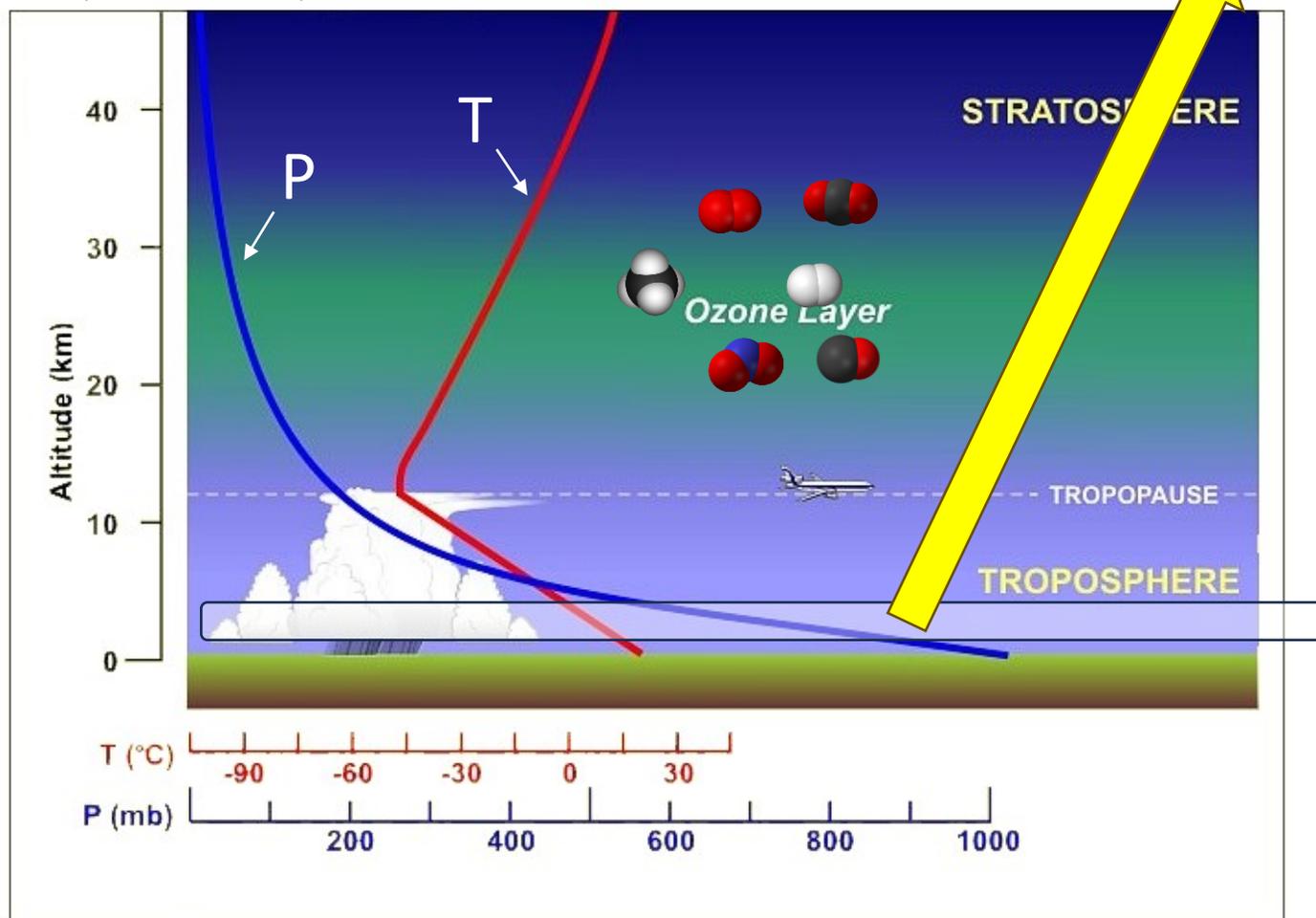


MicroCarb © CNES



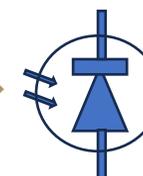
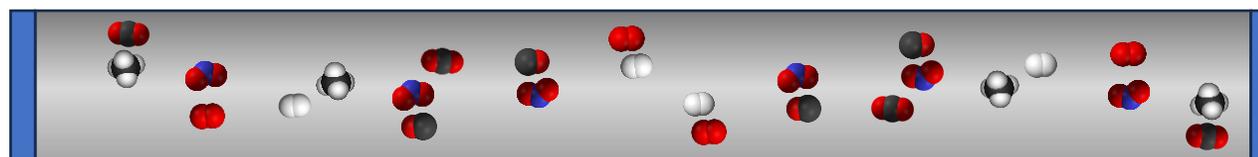
Absorption Spectroscopy a typical example

From <https://www.e-education.psu.edu/>



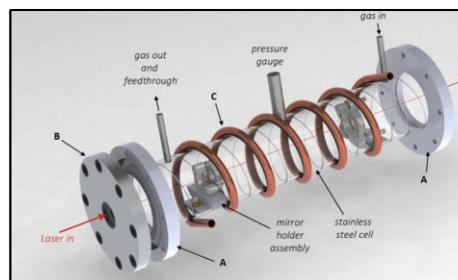
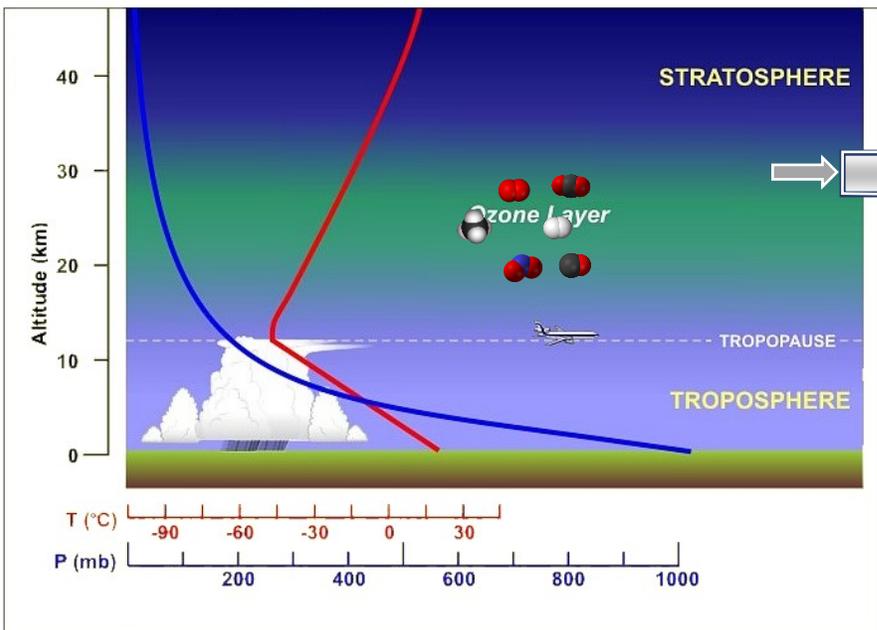
Good point :
*It can be treated
as a sum of layers*

Laser Absorption Spectroscopy



Photodiode

$P, T, n_{N_2}, n_{O_2}, n_{CO_2} \dots$



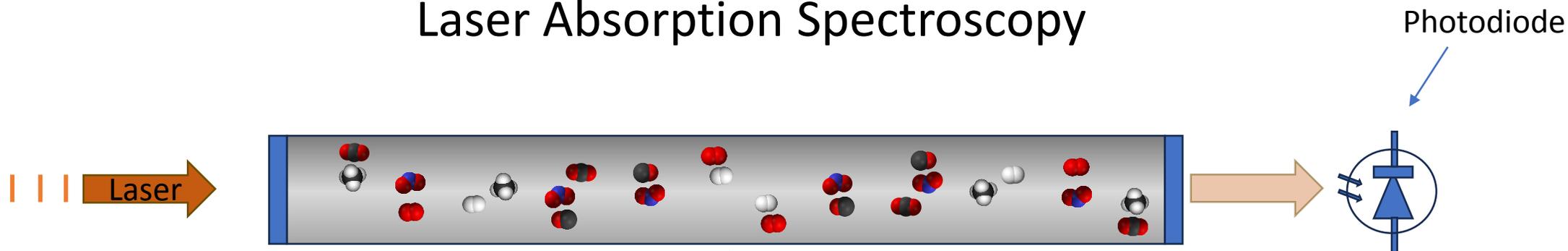
In the lab



In situ

Molecules of atmospheric interest
(and planetary in general)

Laser Absorption Spectroscopy



$P, T, n_{N_2}, n_{O_2}, n_{CO_2} \dots$

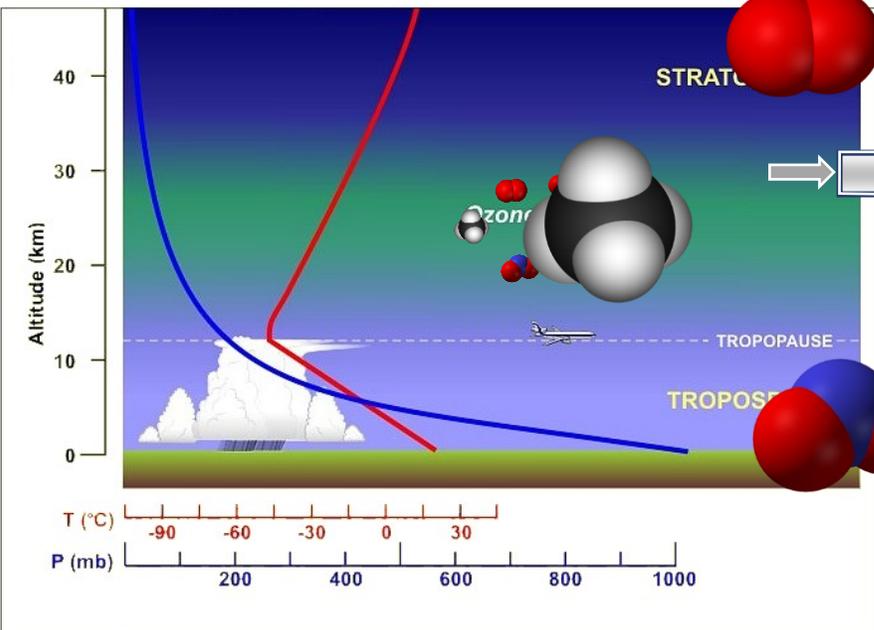
Beer-Lambert law:

$$I = I_0 \cdot e^{-\alpha L}$$

Studying the light absorption induced by a gas sample

Absorption coefficient

Interaction pathlength



What about α ?

Beer-Lambert law:

$$I = I_0 \cdot e^{-\alpha L}$$

What carries α ?

Absorption coefficient:

$$\alpha(\sigma) = N \cdot k \cdot \Phi(\sigma)$$

N : molecular density per cm^3 (P,T dependent)

k : line strength (T dependent)

Φ : line profile (σ , P and T, ... dependent)

What carries α ?

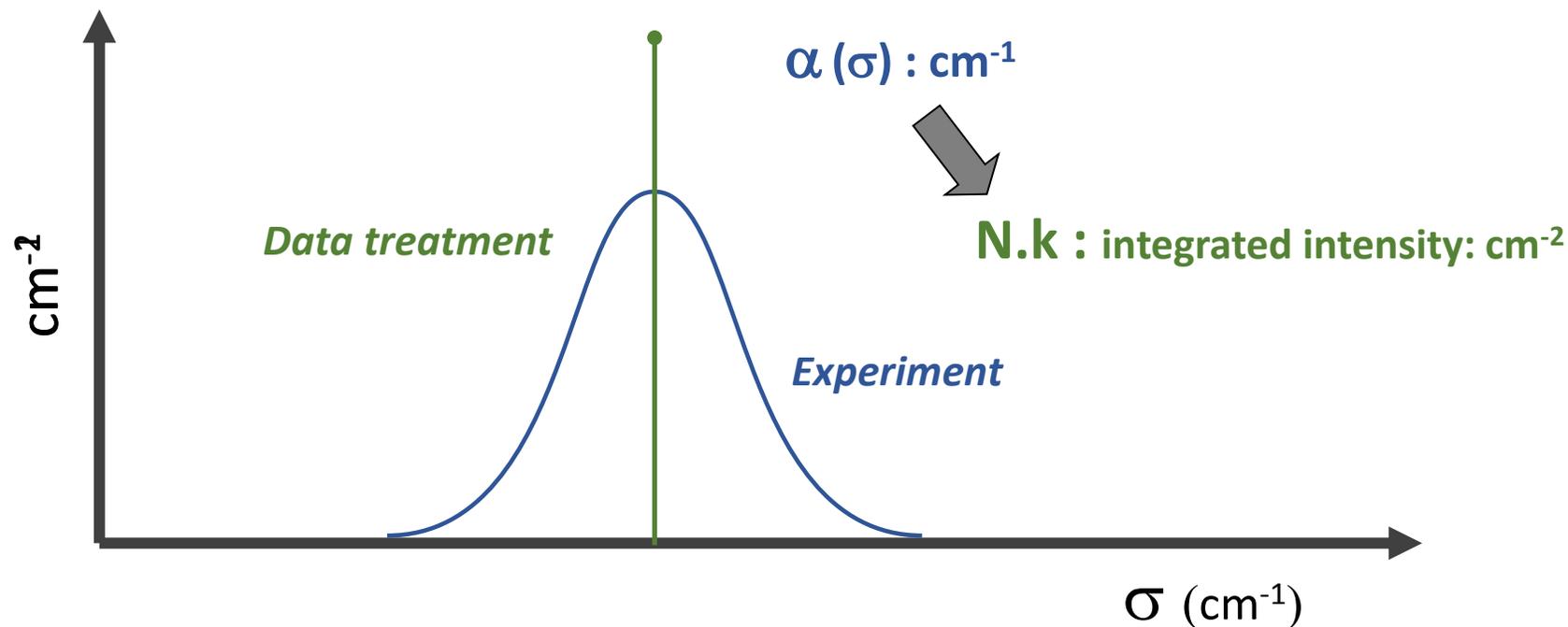
N : molecular density per cm^3 (P,T dependent)

k : line strength (T dependent)

Φ : line profile (σ , P and T, ... dependent)

Absorption coefficient:

$$\alpha(\sigma) = N.k.\Phi(\sigma)$$



What carries α ?

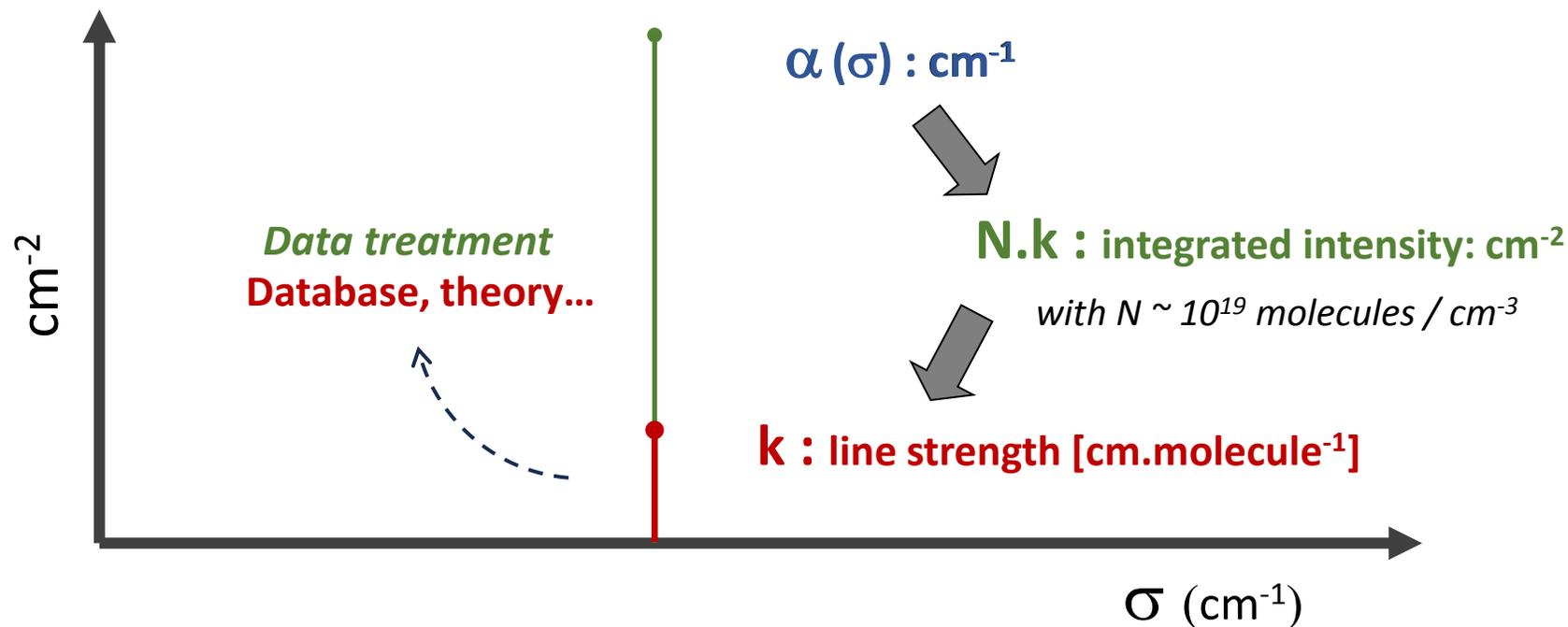
N : molecular density per cm^3 (P,T dependent)

k : line strength (T dependent)

Φ : line profile (σ , P and T, ... dependent)

Absorption coefficient:

$$\alpha(\sigma) = N.k.\Phi(\sigma)$$



What carries α ?

N : molecular density per cm^3 (P,T dependent)

k : line strength (T dependent)

Φ : line profile (σ , P and T, ... dependent)



Instruments

Absorption coefficient:

$$\alpha(\sigma) = N.k.\Phi(\sigma)$$

Trace
detection

Lasers

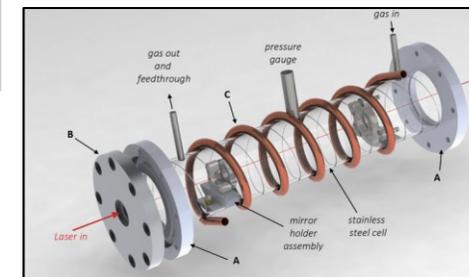


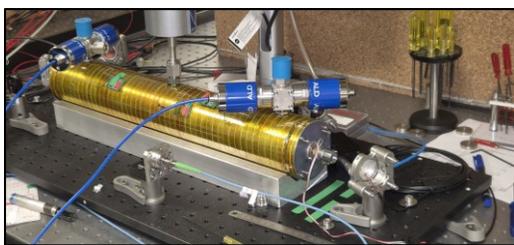
Physics

Spectroscopy

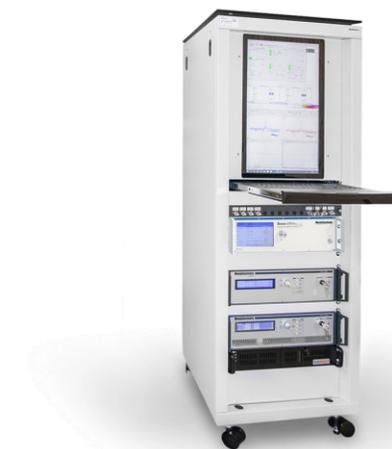
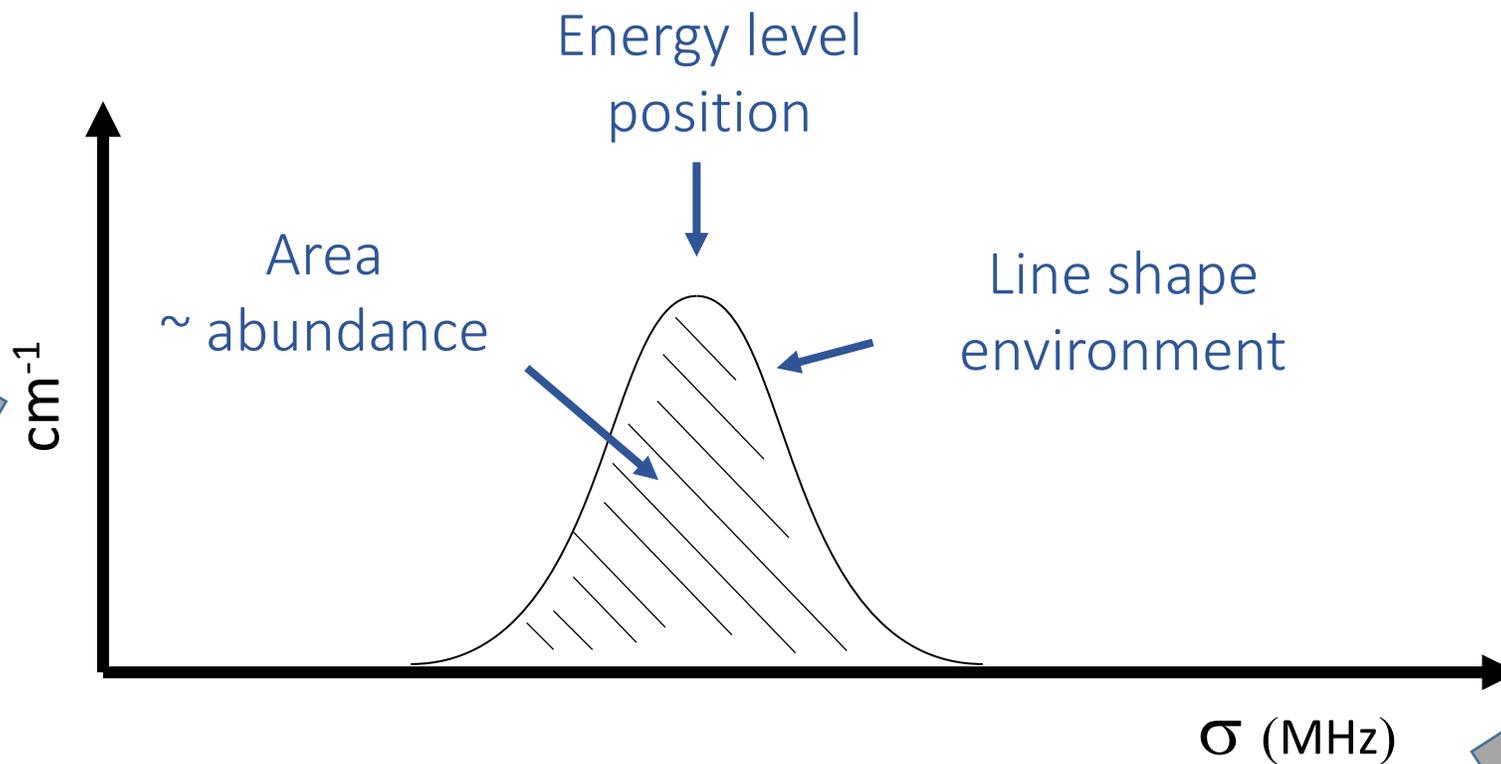
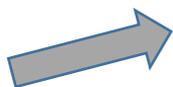
Physics
& databases
(Hitran etc..)

Cells

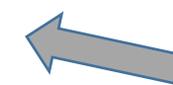




CRDS provides
Y axis accuracy



OFC provides
X axis accuracy



Both Absorption and Frequency are essential !!!

What about Y scale ?

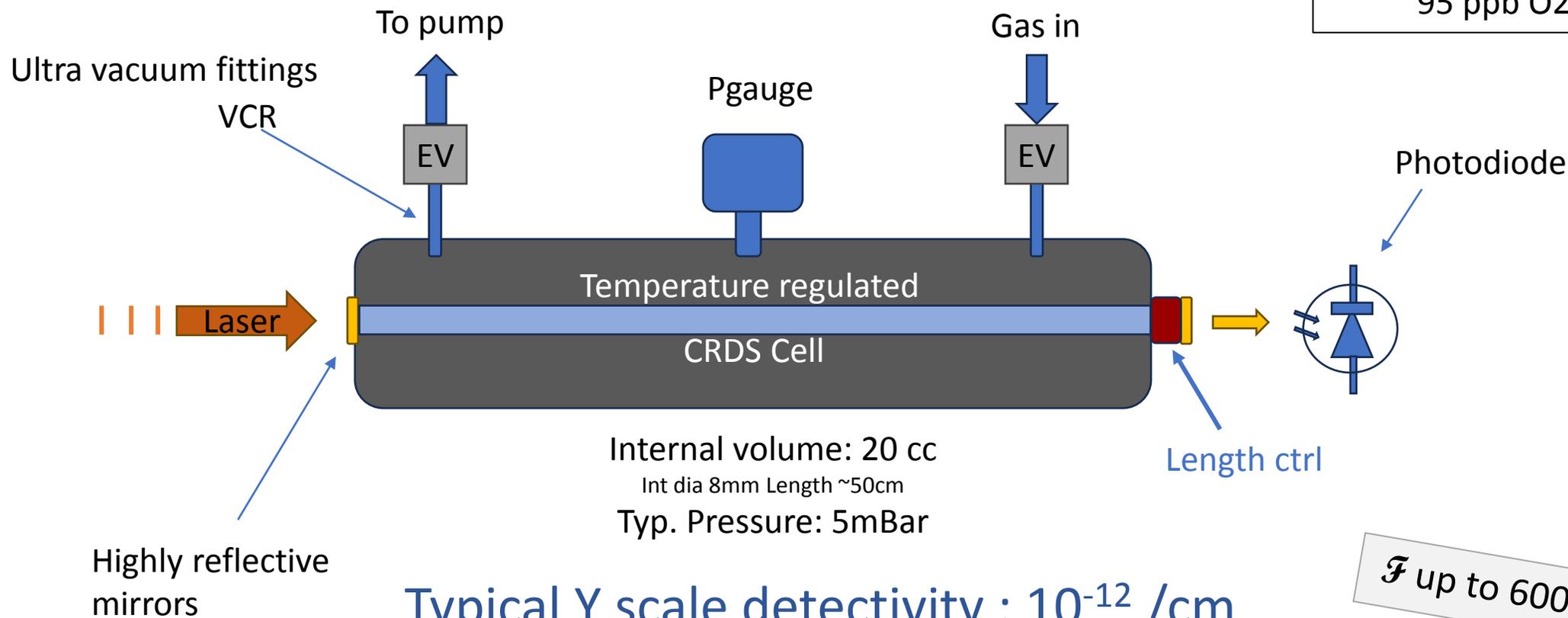
Beer-Lambert law:

$$I = I_0 \cdot e^{-\alpha L}$$

The need for huge and accurate pathlength

Ultra trace detection

Detectivity @ 70 mBar N₂
 1 ppt H₂O / H₂S
 6 ppt CH₄
 0.1 ppb CO₂ (4 ppt @ 2 μm)
 95 ppb O₂



Typical Y scale detectivity : 10^{-12} /cm
 + time domain measurement

\mathcal{F} up to 600 000

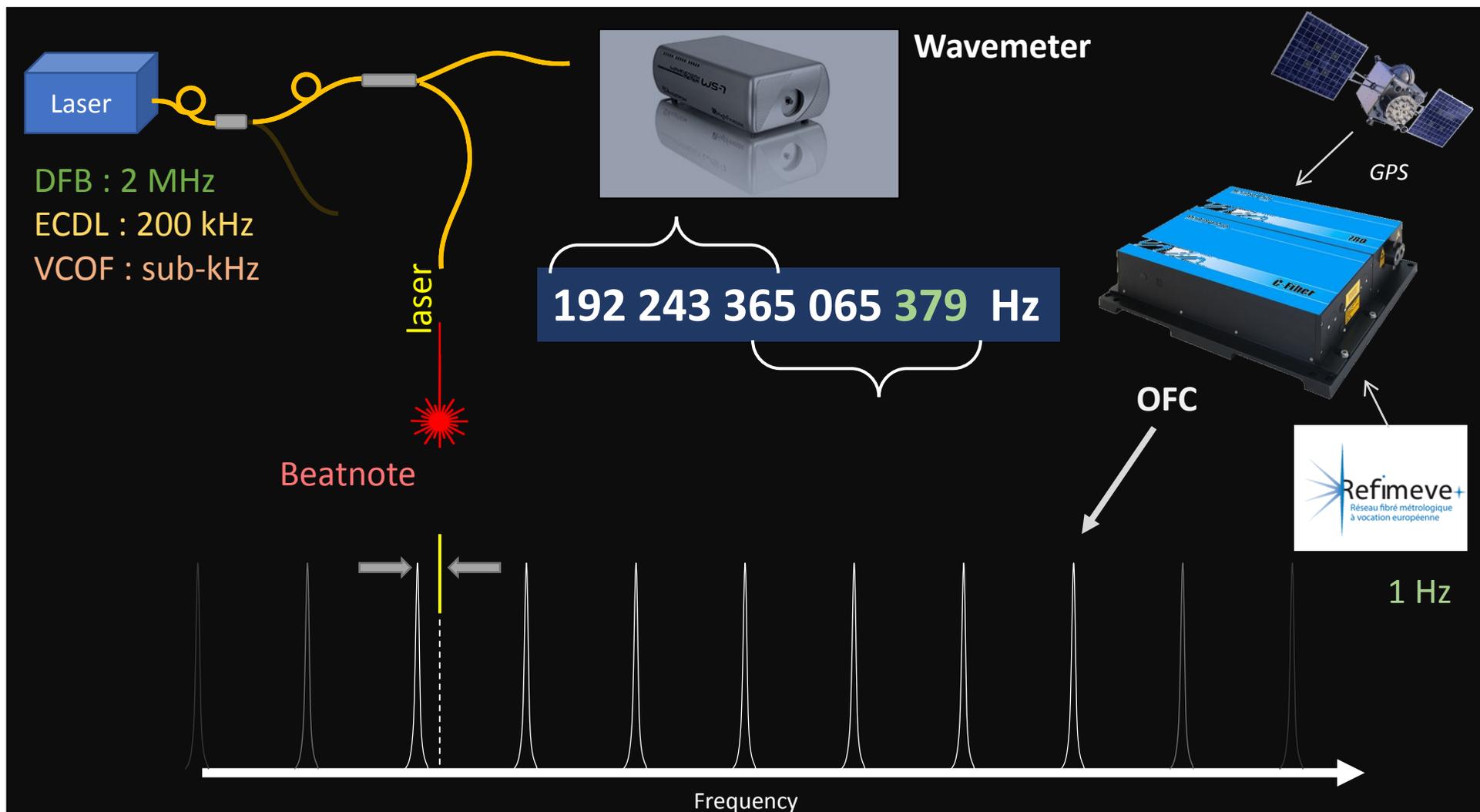
What about X scale ?



*Laser emission frequency
stability and determination*

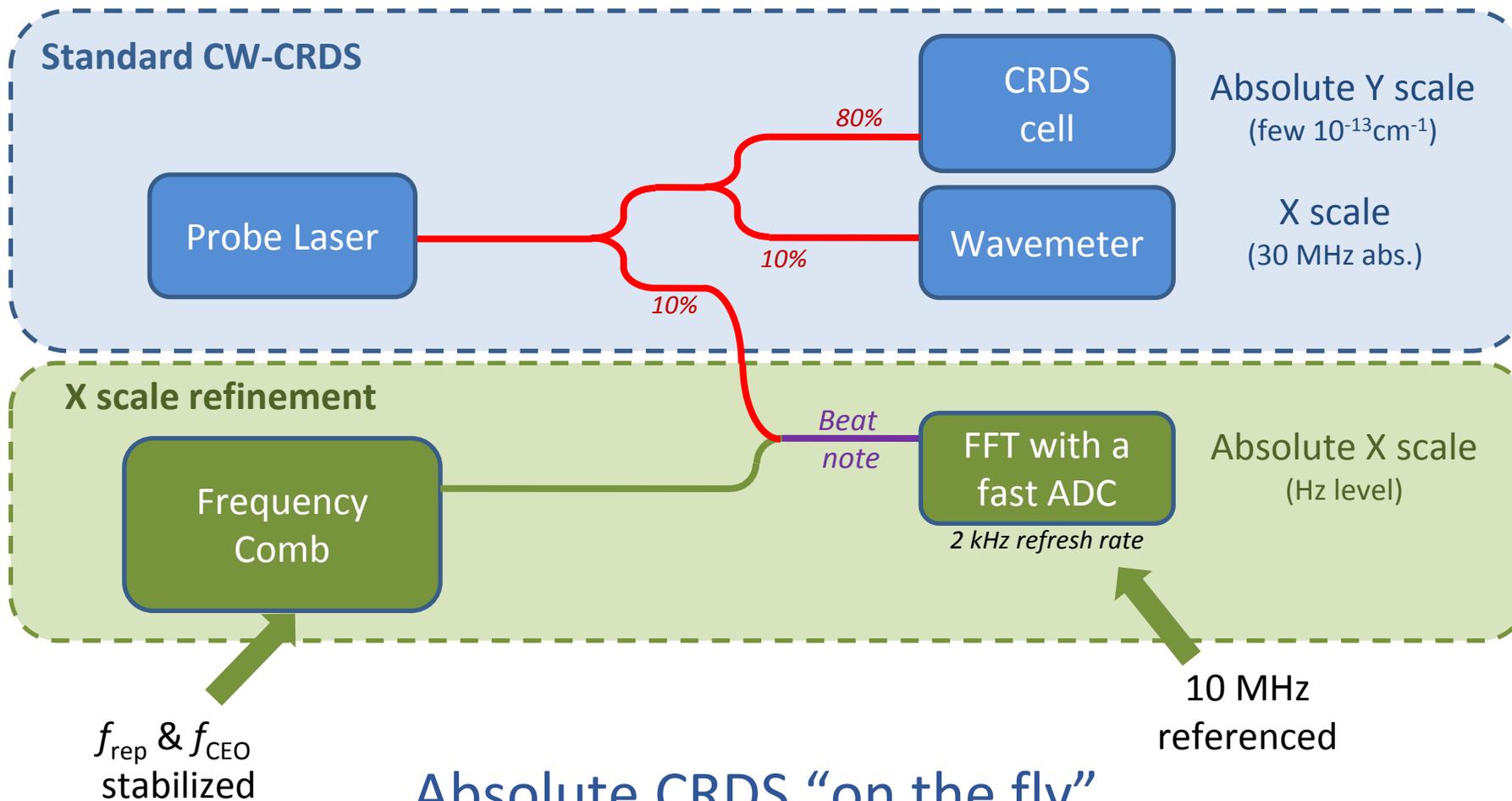
Absolute optical frequencies

X scale : beating laser with an Optical Frequency Comb

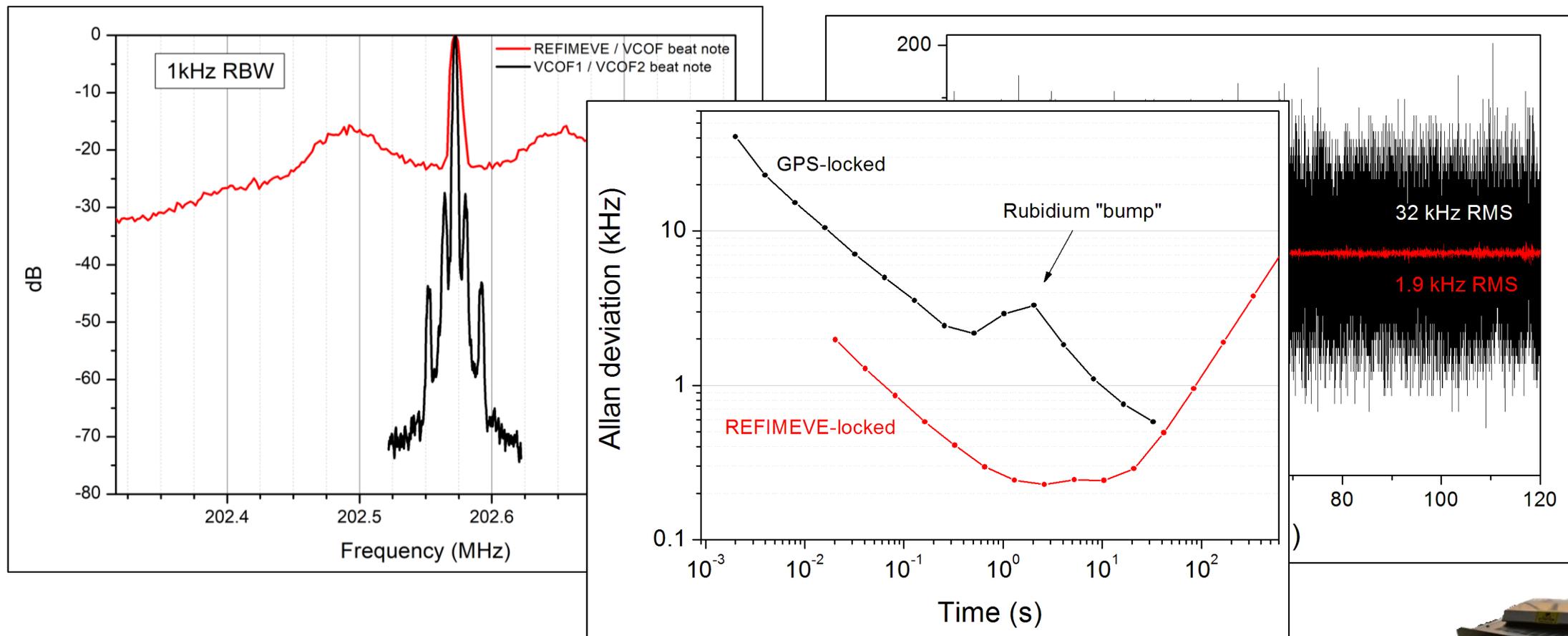


Laser absolute frequency determination down to a few Hz

X scale : beating laser with an Optical Frequency Comb



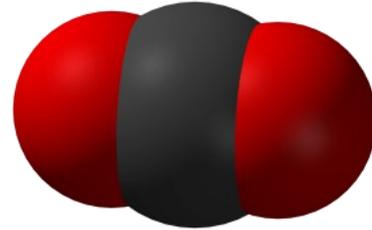
Absolute CRDS “on the fly”
(the laser is weakly locked)

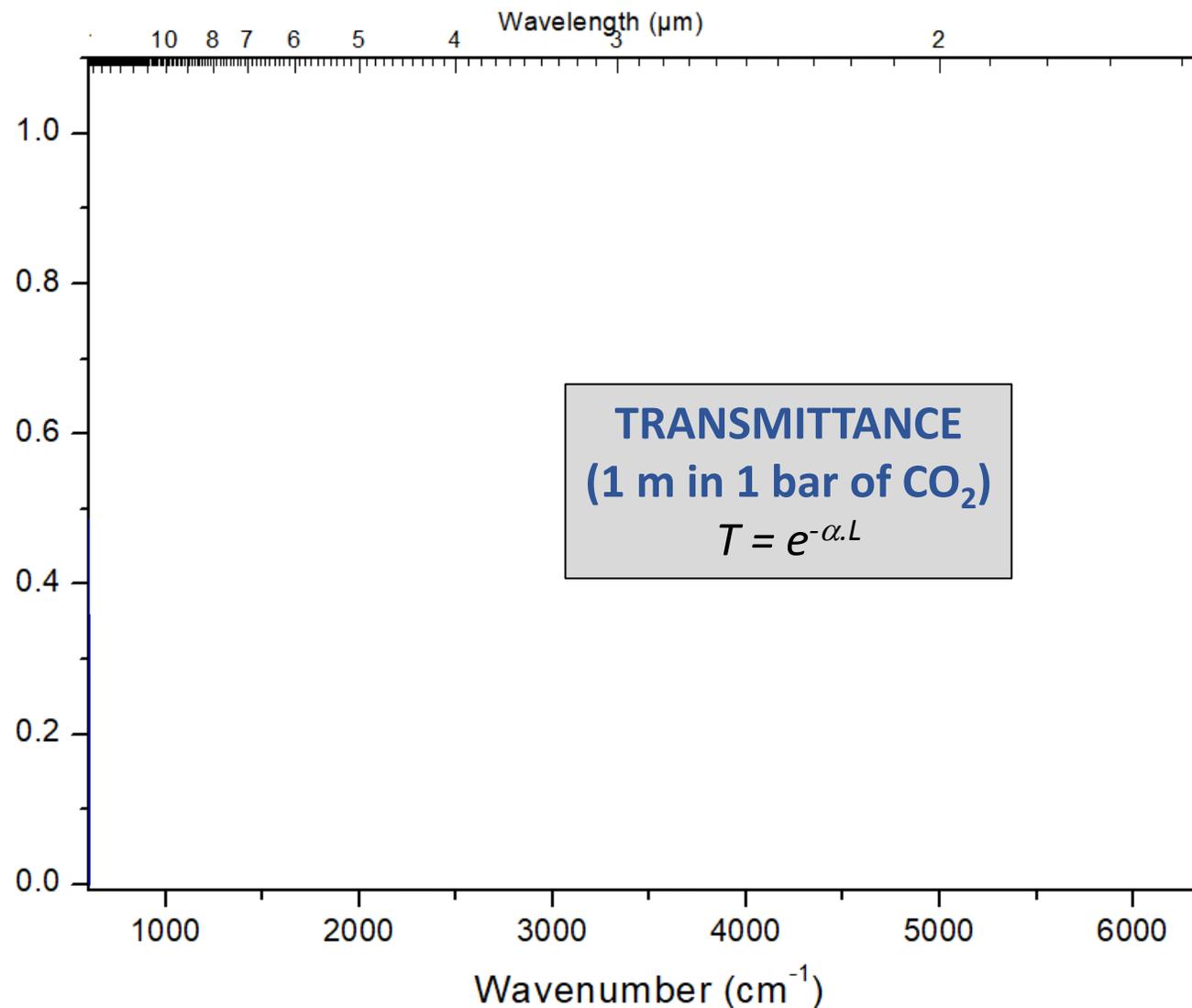
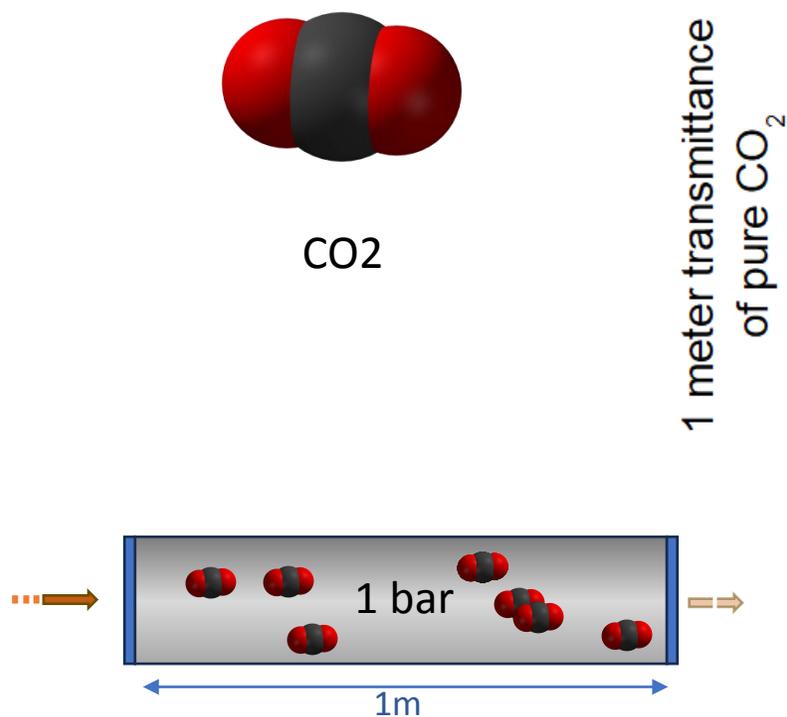


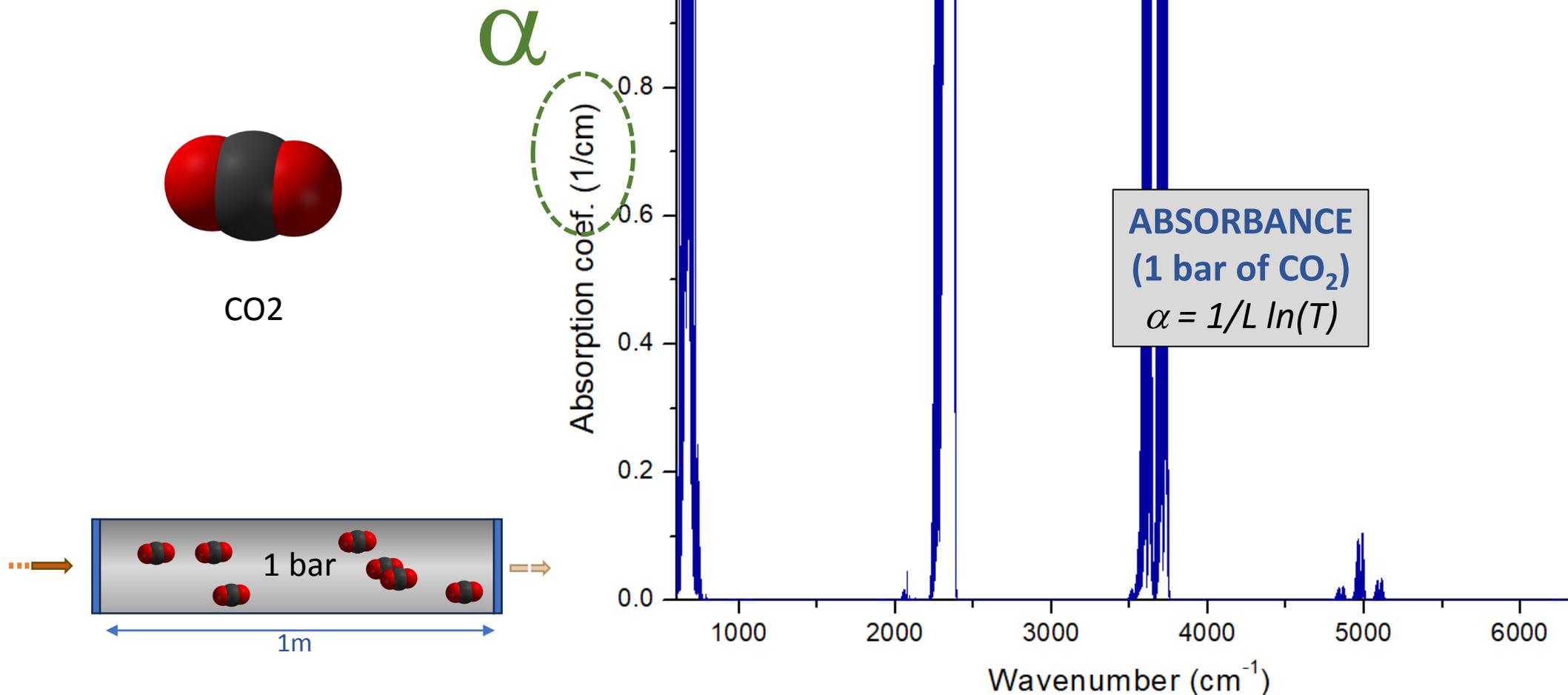
REFIMEVE signal is typically 6 kHz broad but still ultra-stable

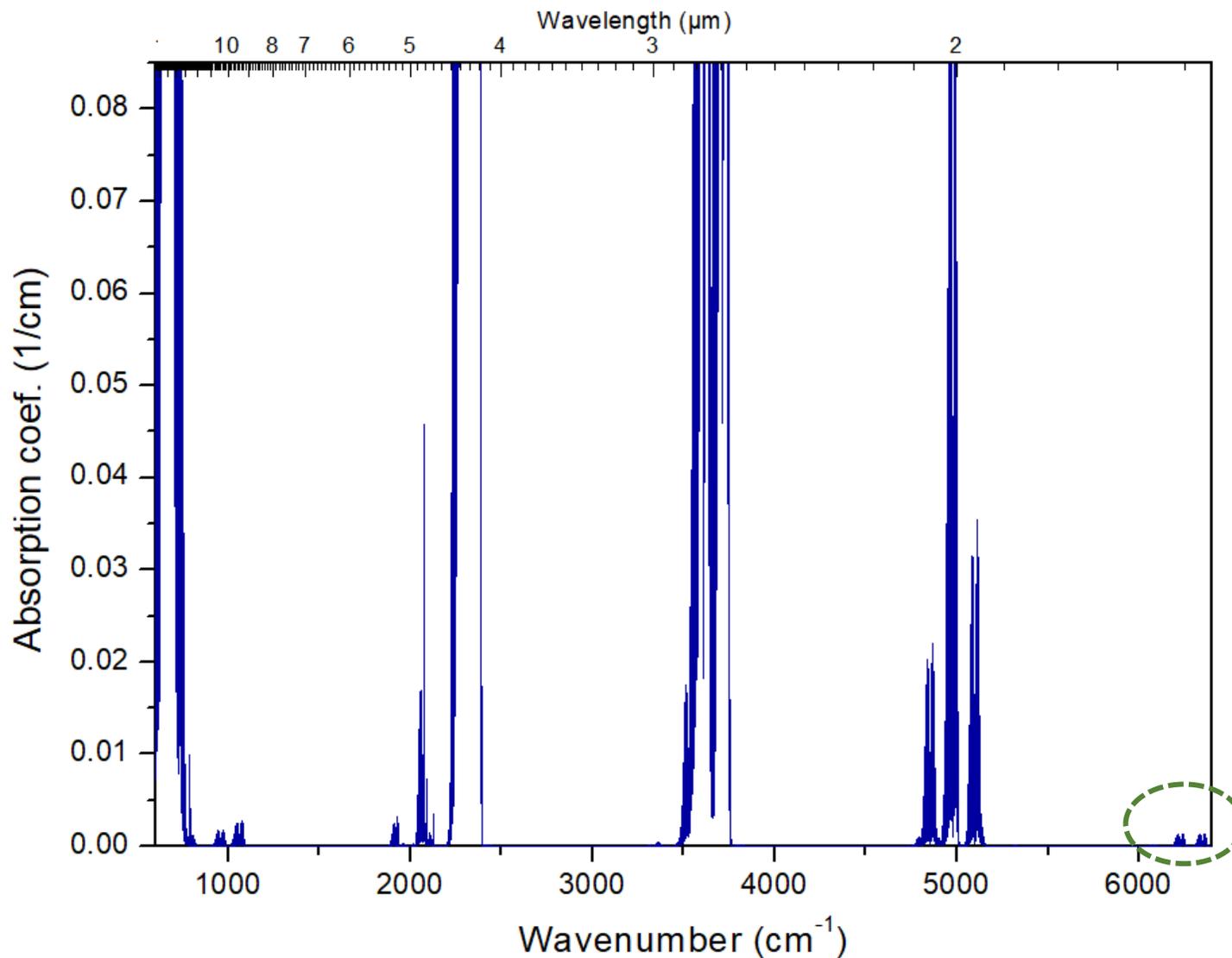
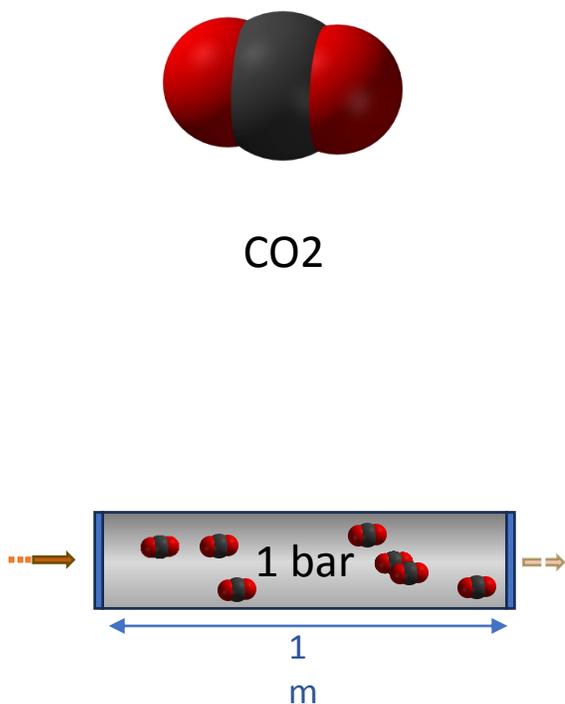


Spectroscopy an example on CO₂

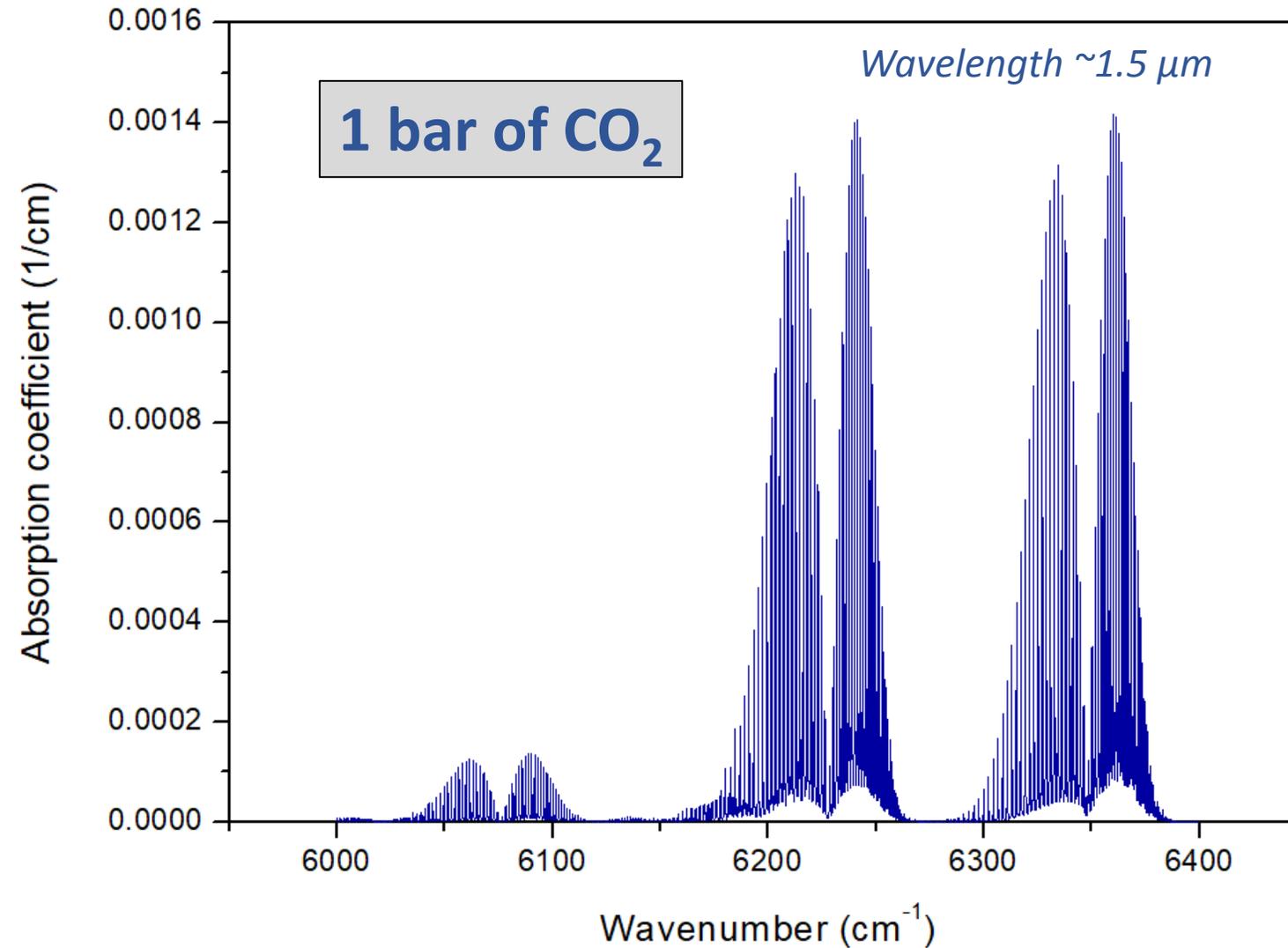
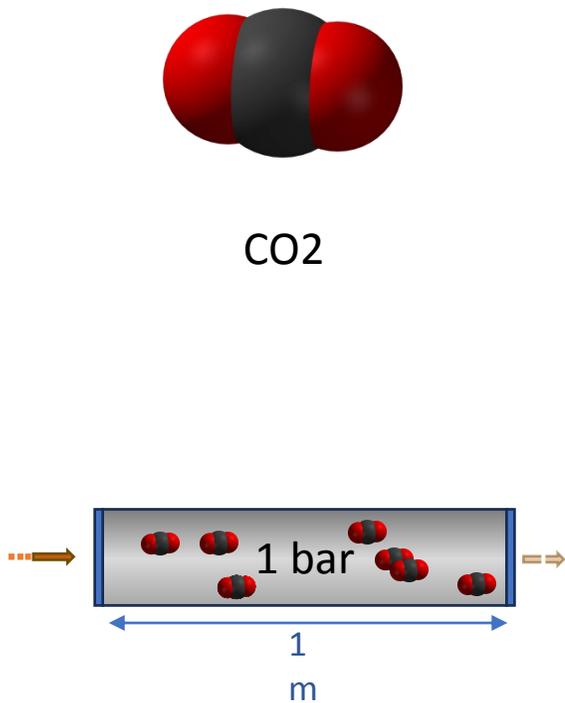


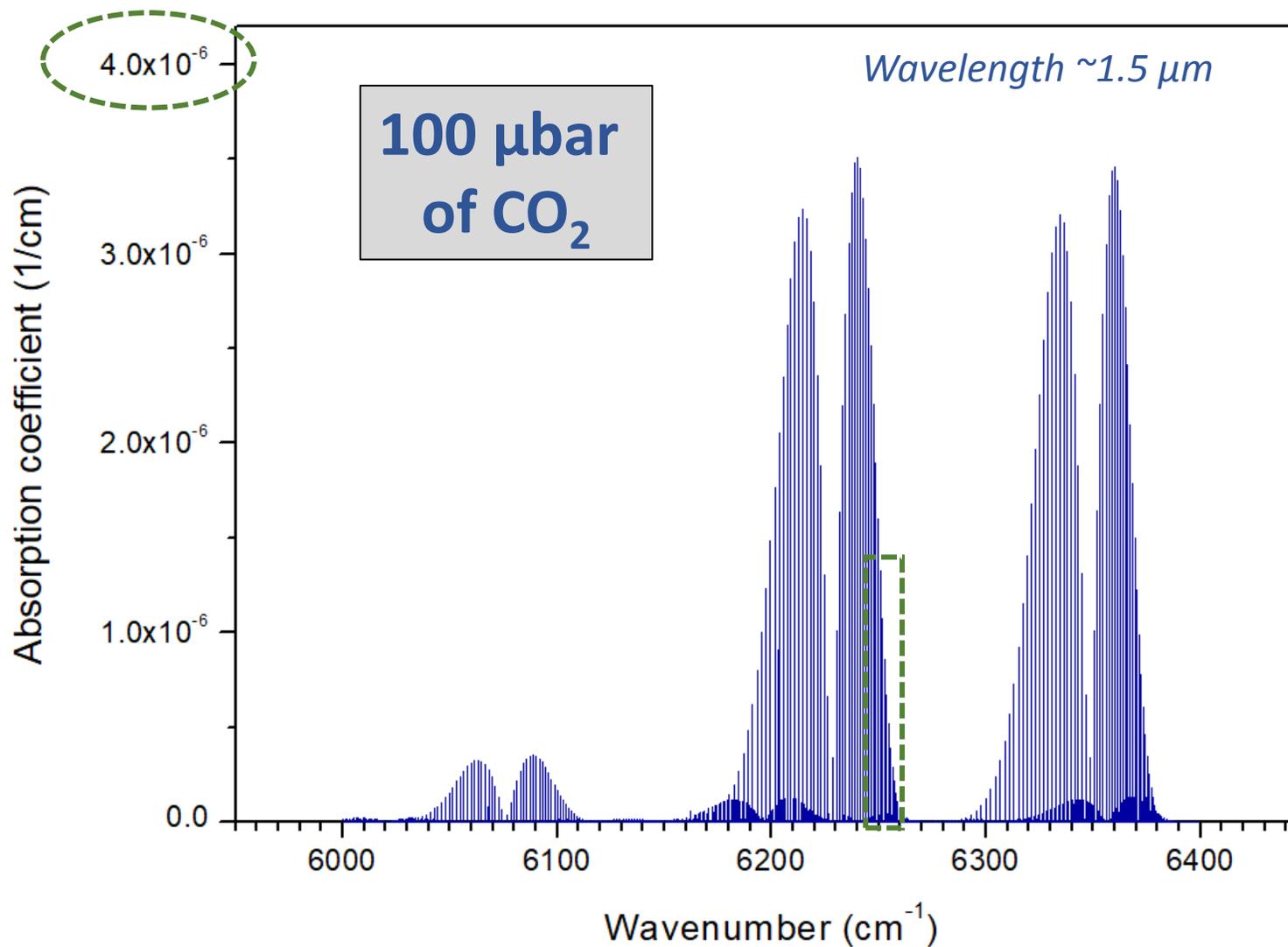
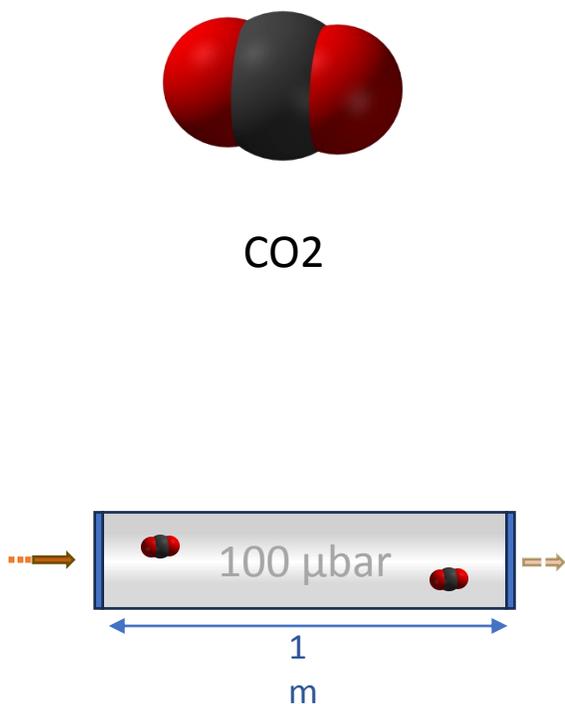






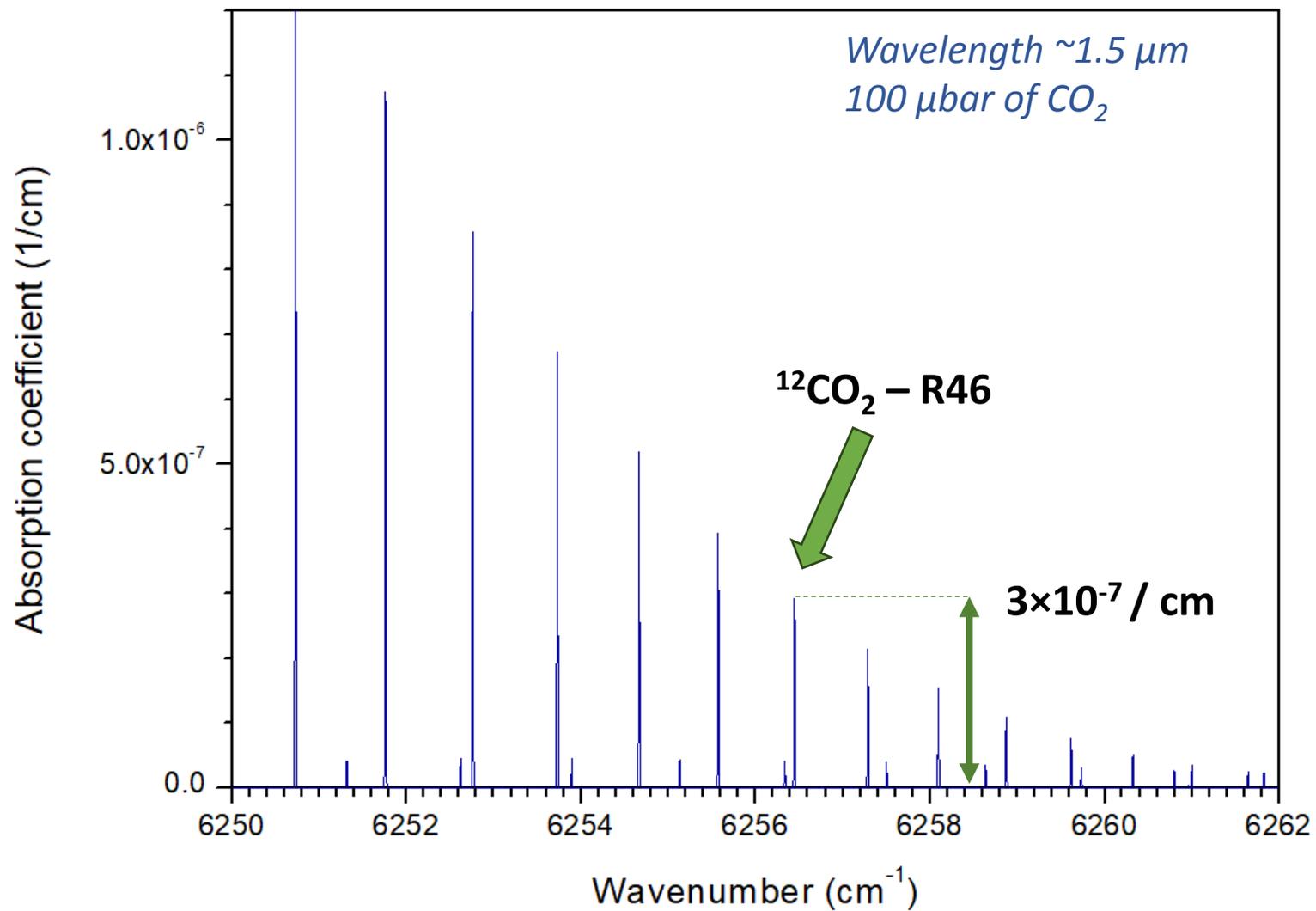
Typical zone
of interest





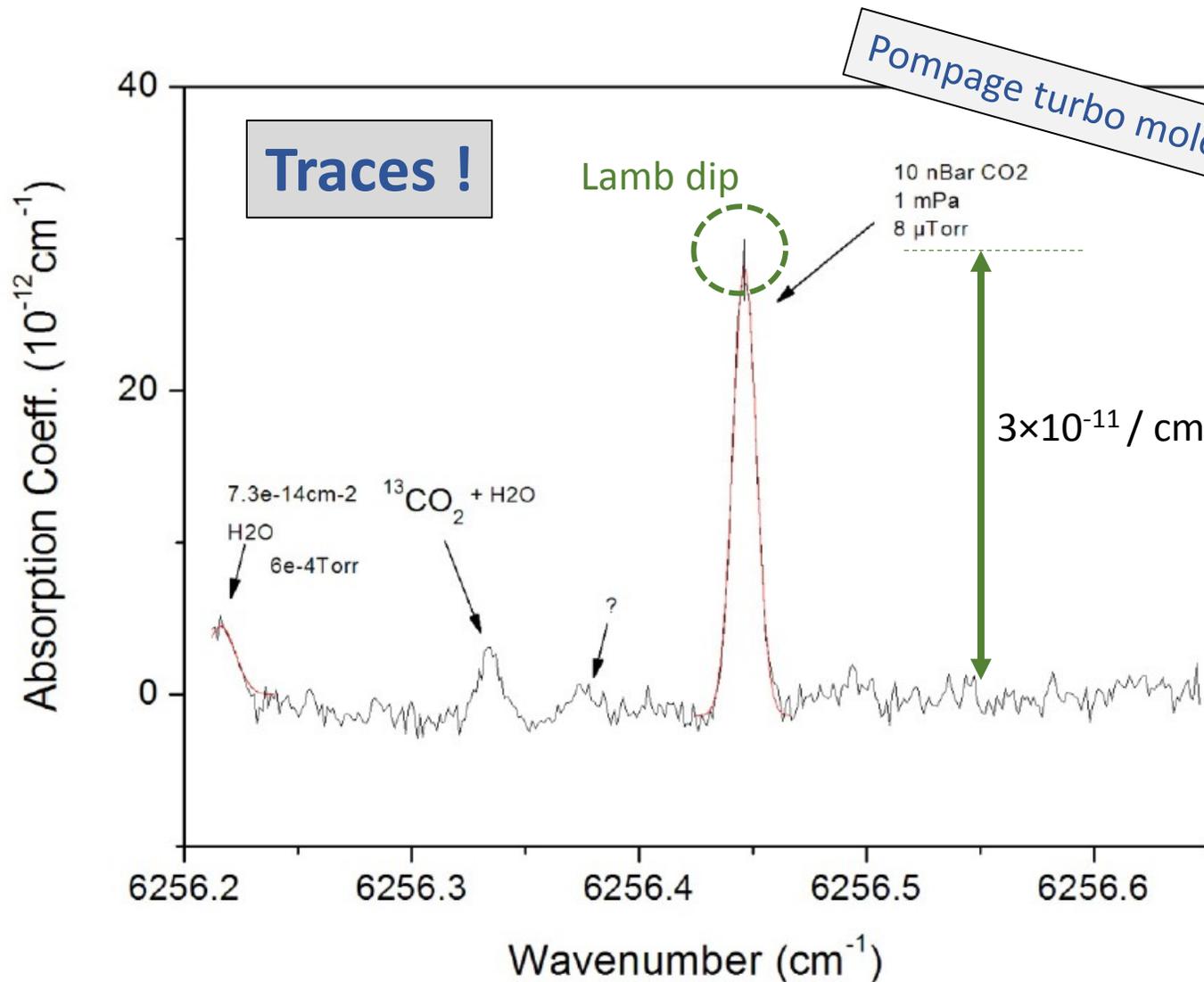


CO₂



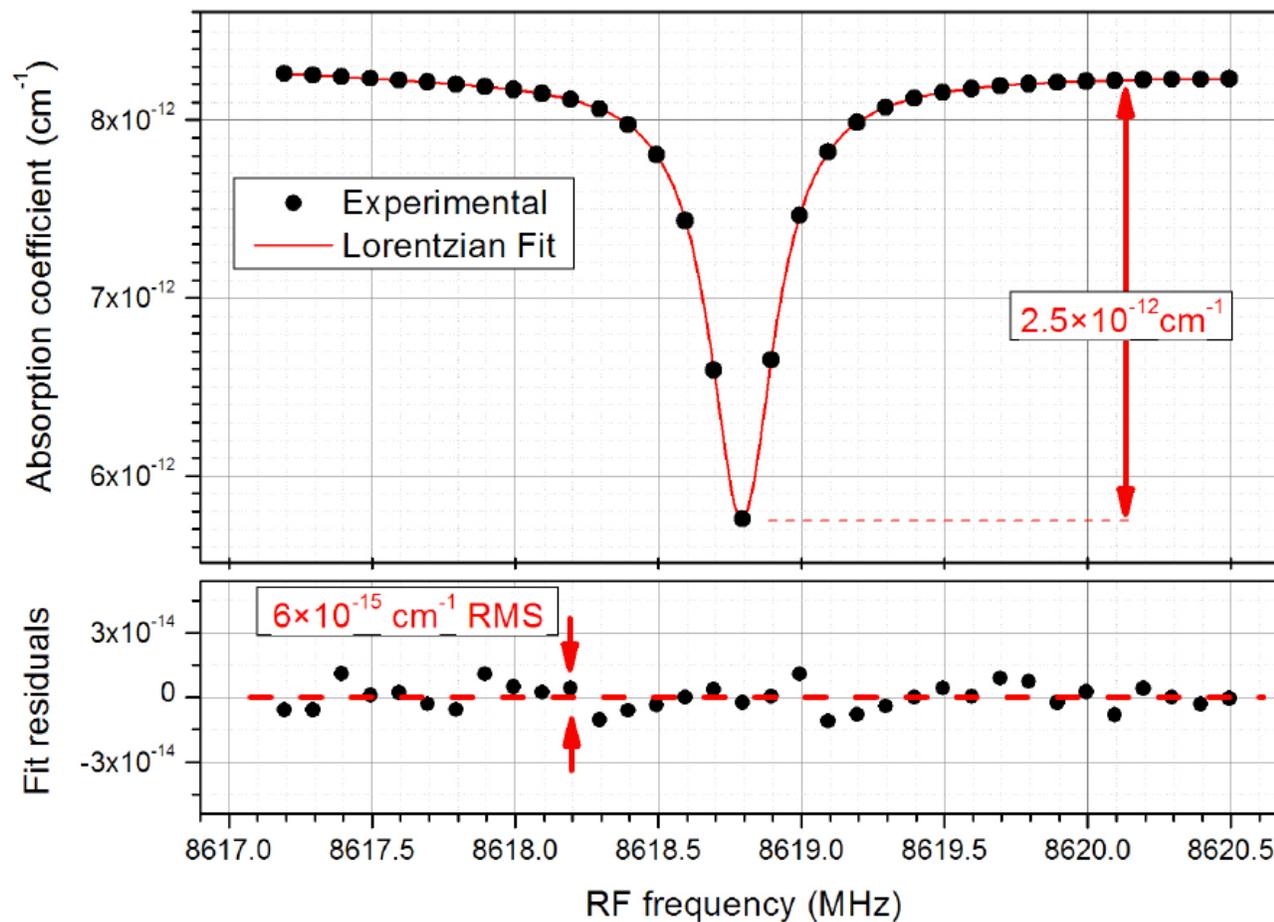


CO2





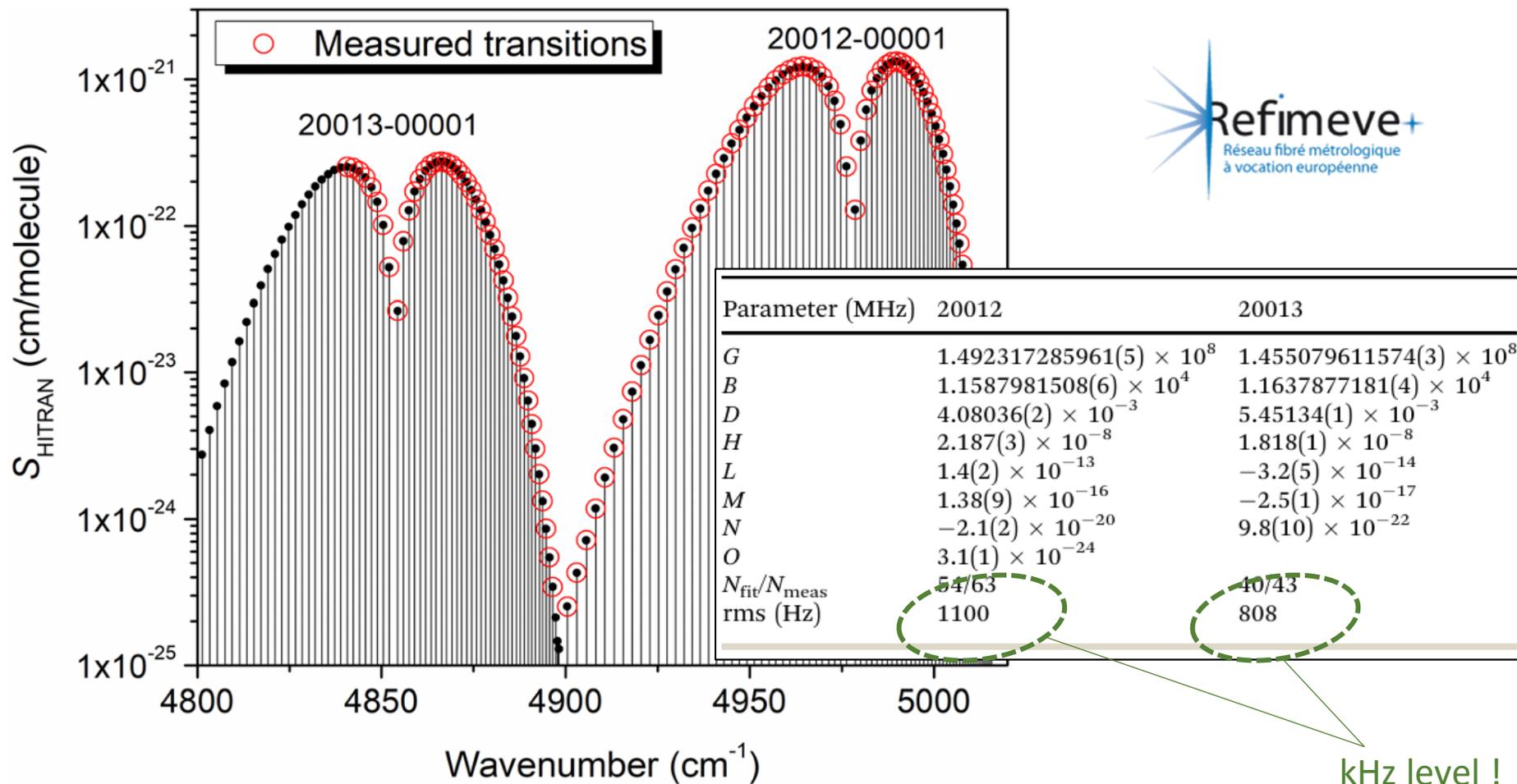
CO₂



Need for ultra stable X scale

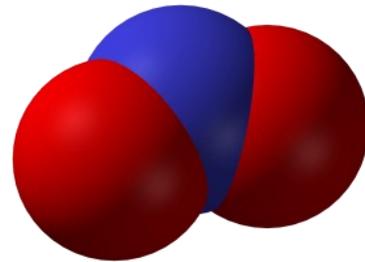


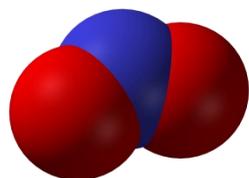
CO2



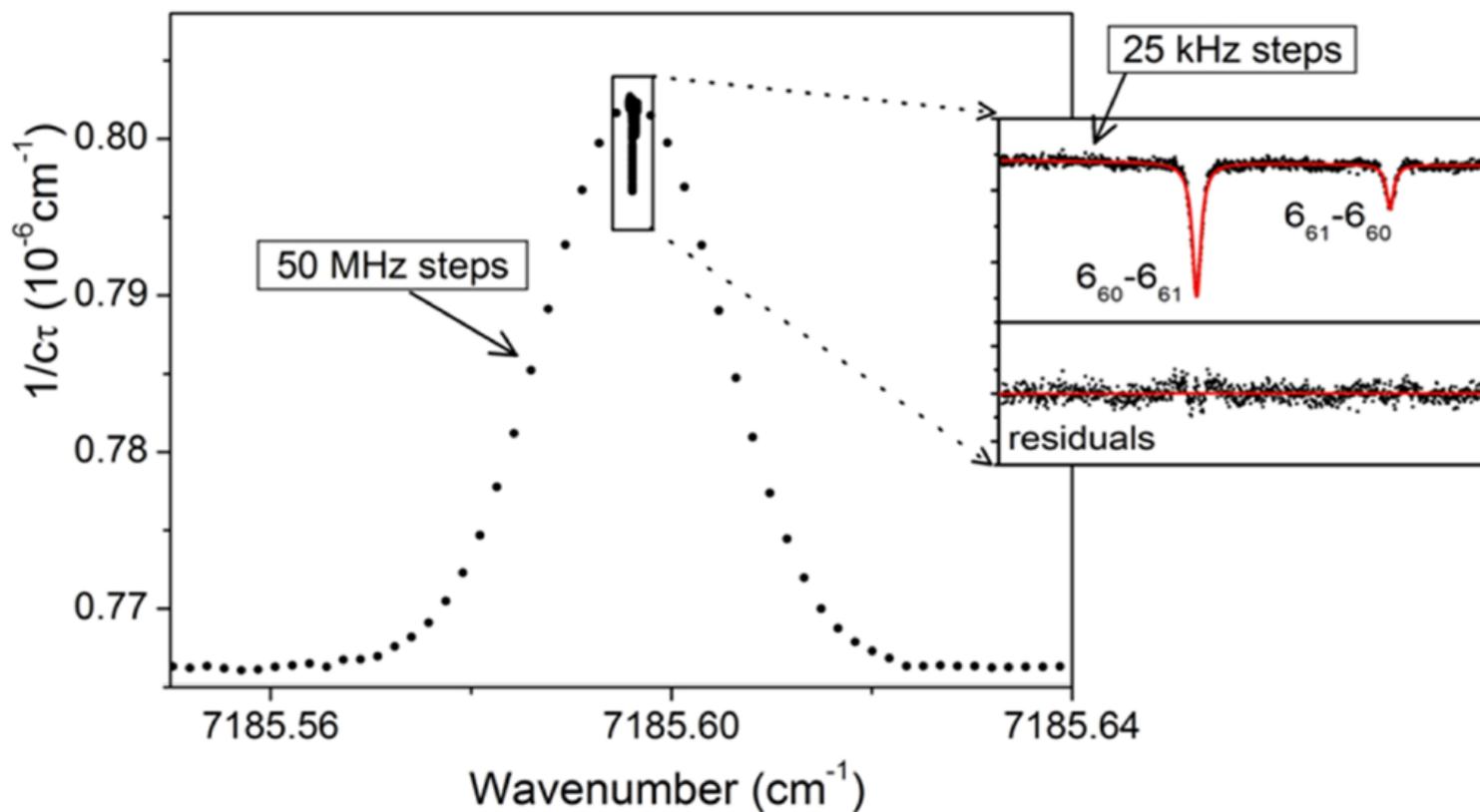
Routine Lamb-dip measurements at 2.1 μm

An example on H₂O



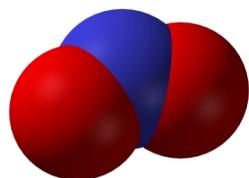


H₂O

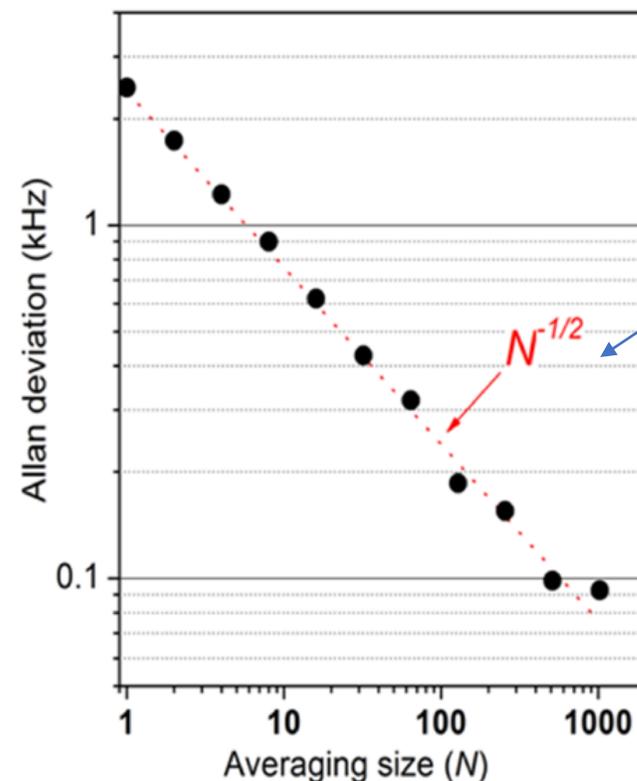
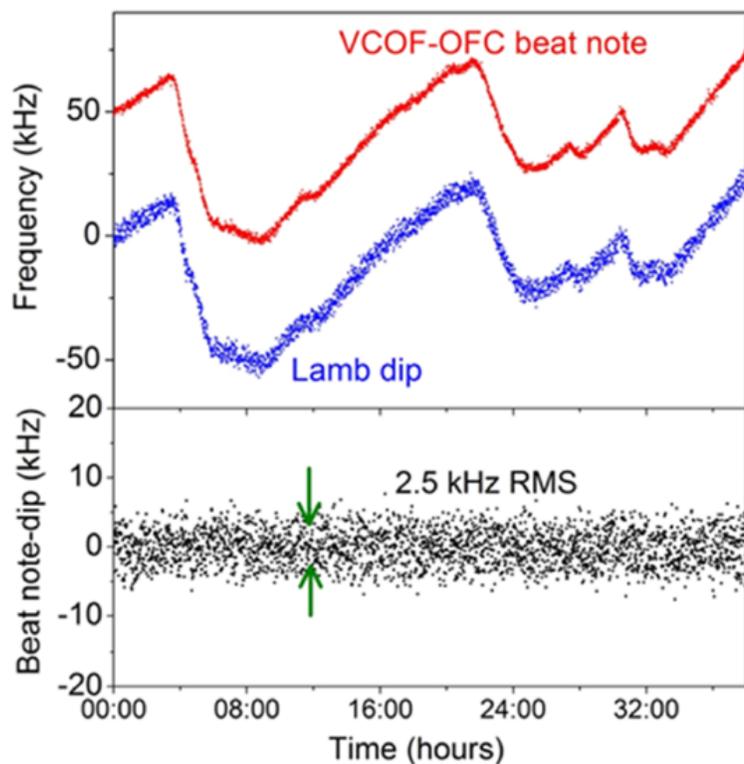


Ultra-stable VCOF source

Routine saturated absorption on water

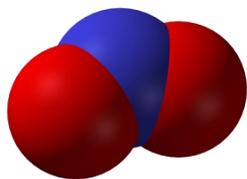


H₂O

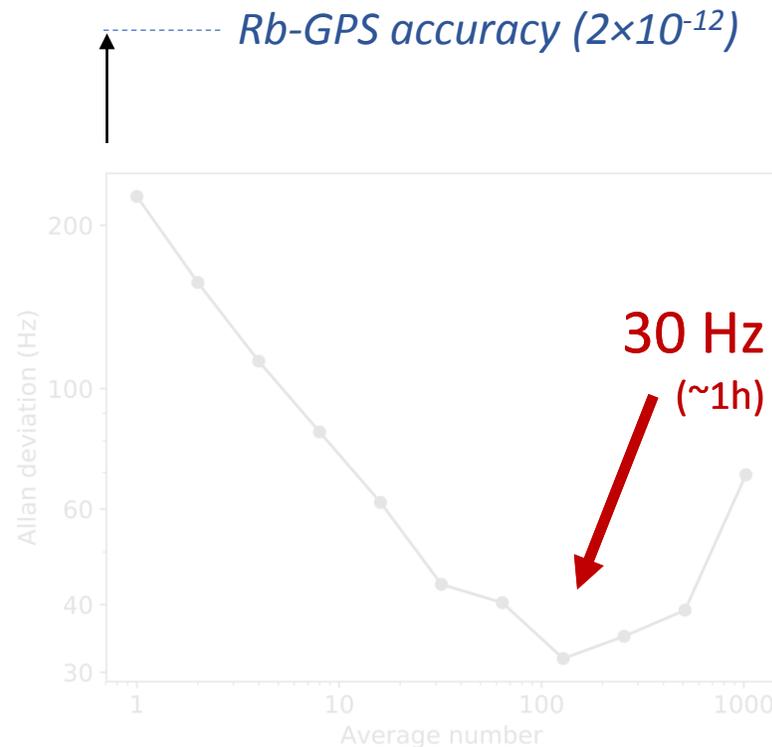
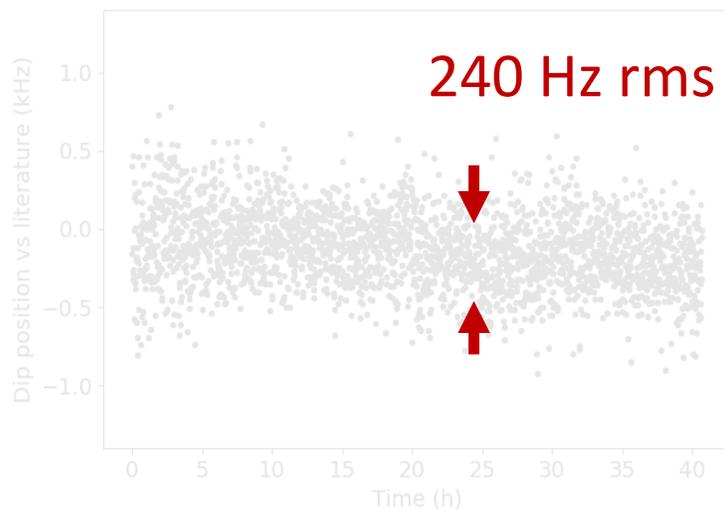
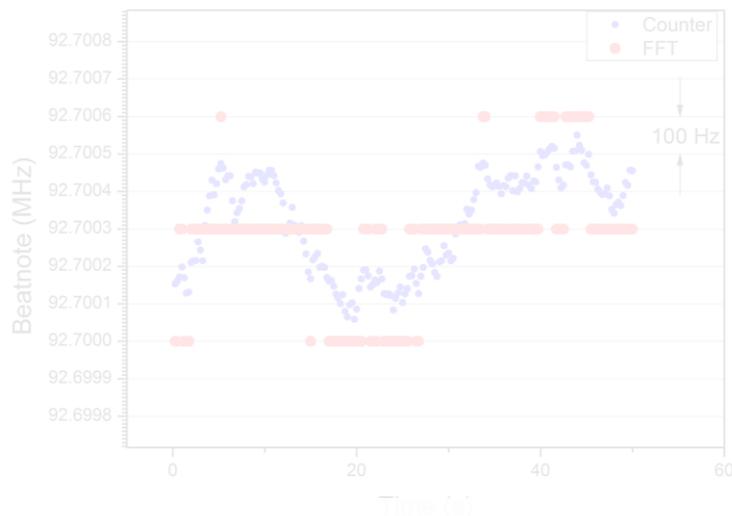


Ultra-stable VCOF source

Comb f_{rep} locked to GPS



H₂O



@ 200 THz



1.6×10^{-13}



Ultra-stable VCOF source

Comb f_{rep} locked to REFIMEVE

One comb to rule them all !

THz

Difference
frequency

8.45 μm

Cavity length
stabilization

2.1 μm

Feedforward
laser correction

1.6 μm

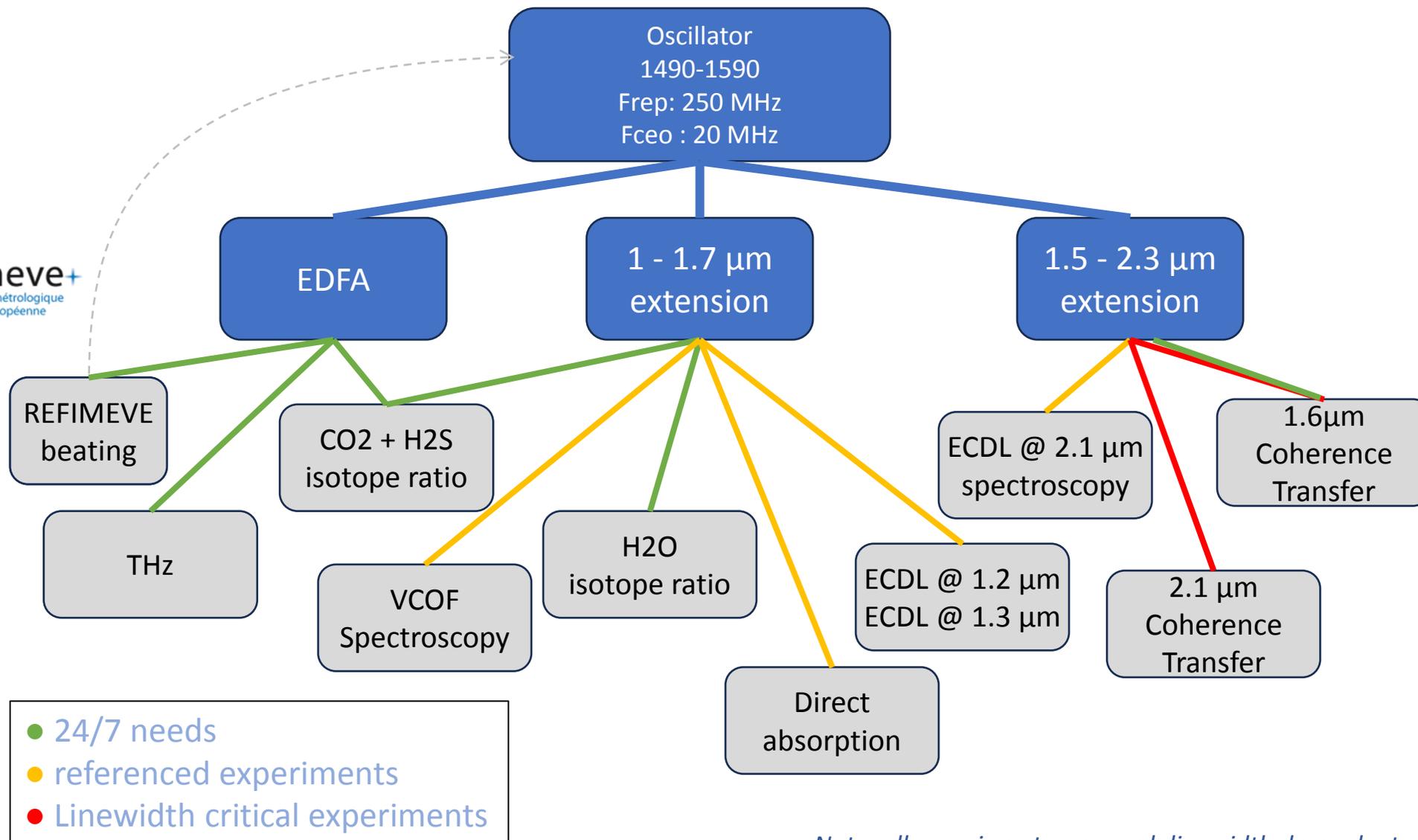
Direct frequency
measurement

1.2 μm

ECDL
stabilization

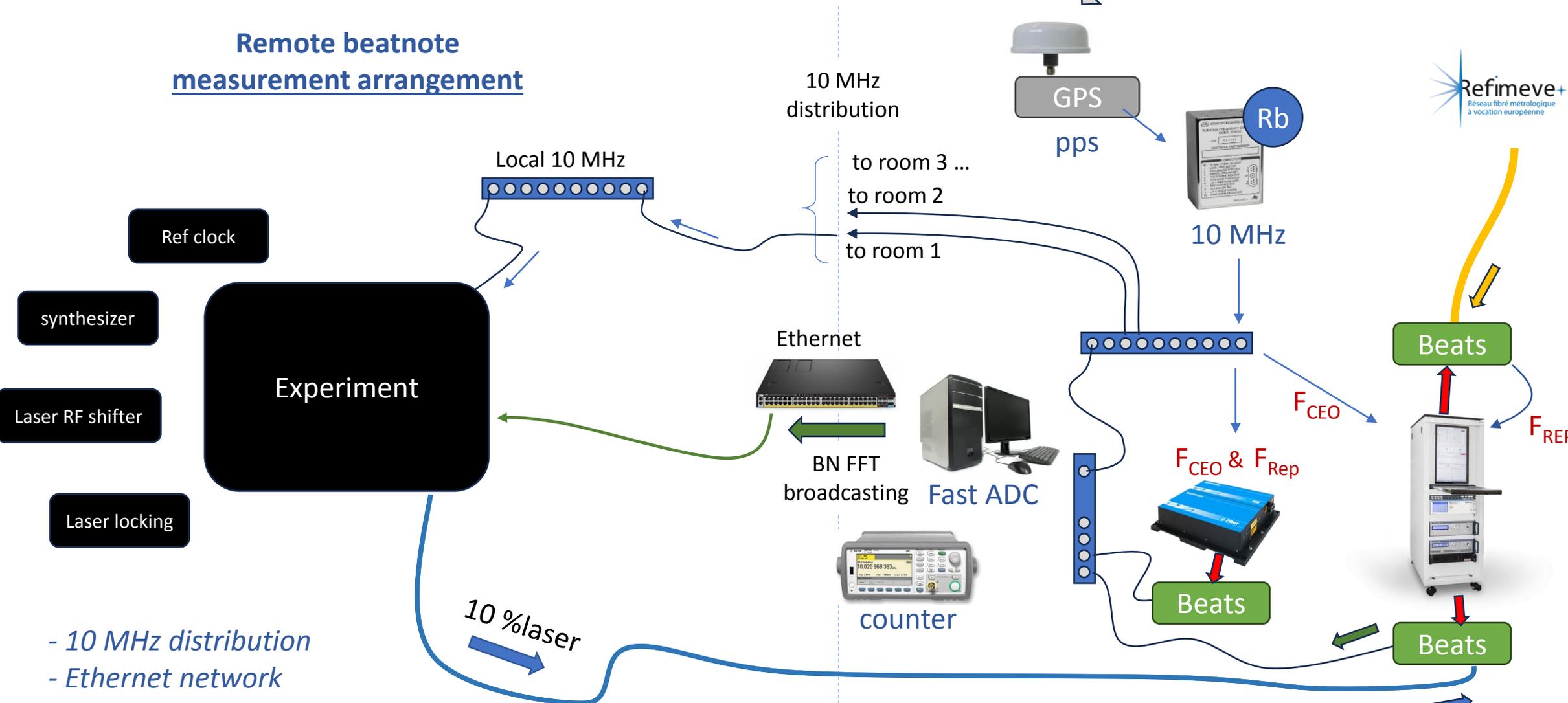
0.6 μm
experiment?

Comb to comb?



Note: all experiments are comb linewidth dependent

Remote beatnote measurement arrangement



- 10 MHz distribution
- Ethernet network
- Fiber links

Note: all experiments are comb linewidth dependent

Application to geosciences (and exobiology)



PROGRAMME
DE RECHERCHE
ORIGINES

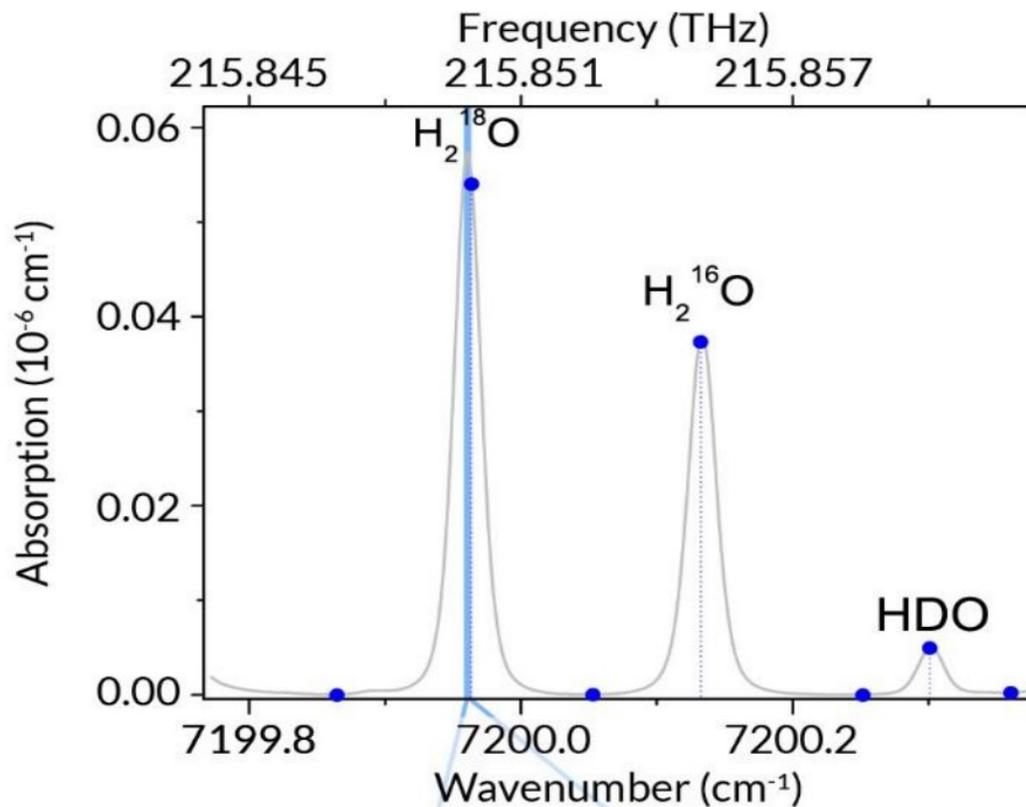


Funded by
the European Union



European Research Council
Established by the European Commission





Paleoclimate
study in
polar regions



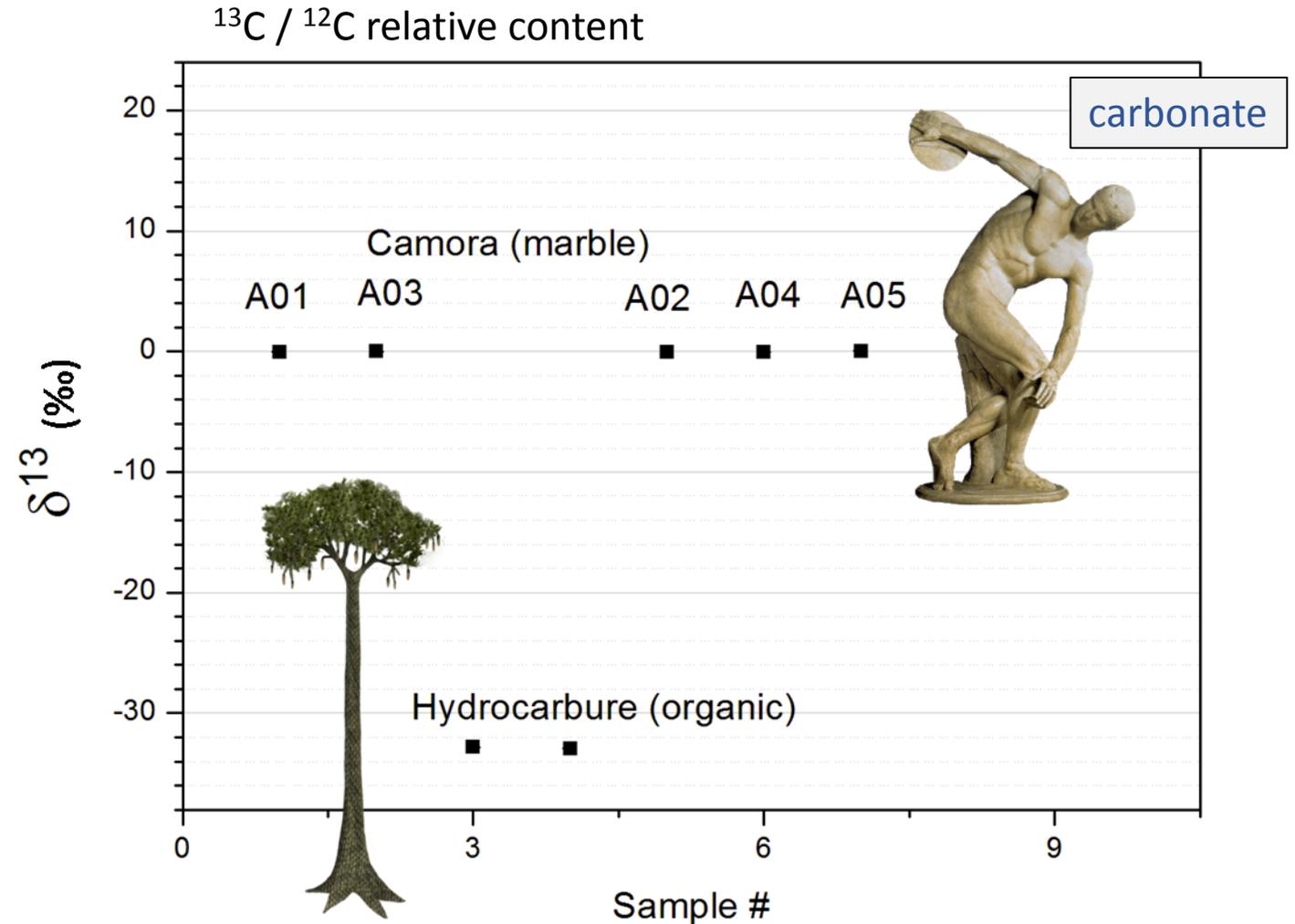
Ultra-stable
VCOF source

The OFC permits to correct for frequency drift

Long term stability and accuracy

Optical determination of isotopic ratio

Thanks to frequency accuracy



Optical determination of Isotopic ratio of CO₂

5 mBar of
pure CO₂

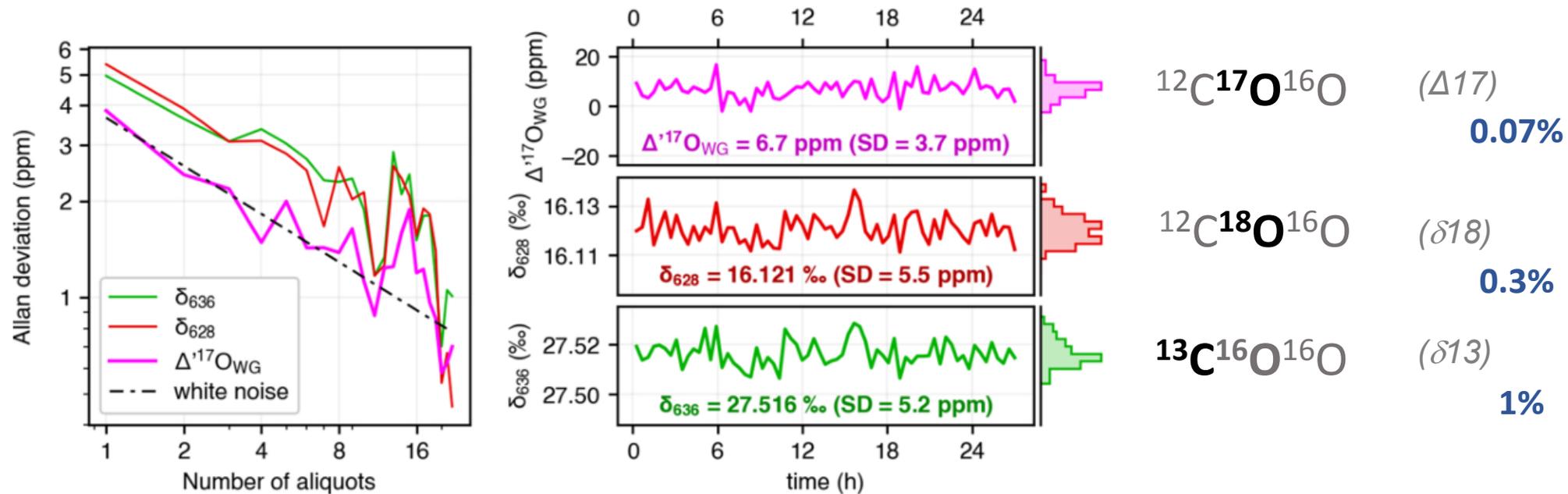


Fig. 4. Allan plot (left) and $\Delta^{17}\text{O}_{\text{WG}}$, δ_{628} , δ_{636} , time series corresponding to the working-gas measurements of Fig. 3. Analytical scatter of repeated aliquots behaves as expected for white noise.

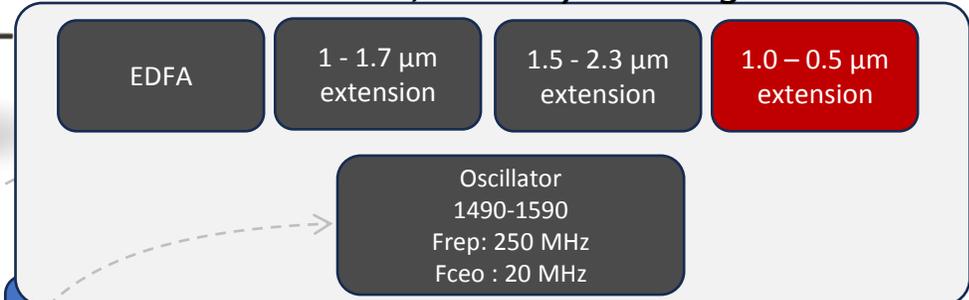
... LSCE is already connected to REFIMEVE



Connected to
REFIMEVE
Refimeve+
Réseau fibré métrologique à vocation européenne



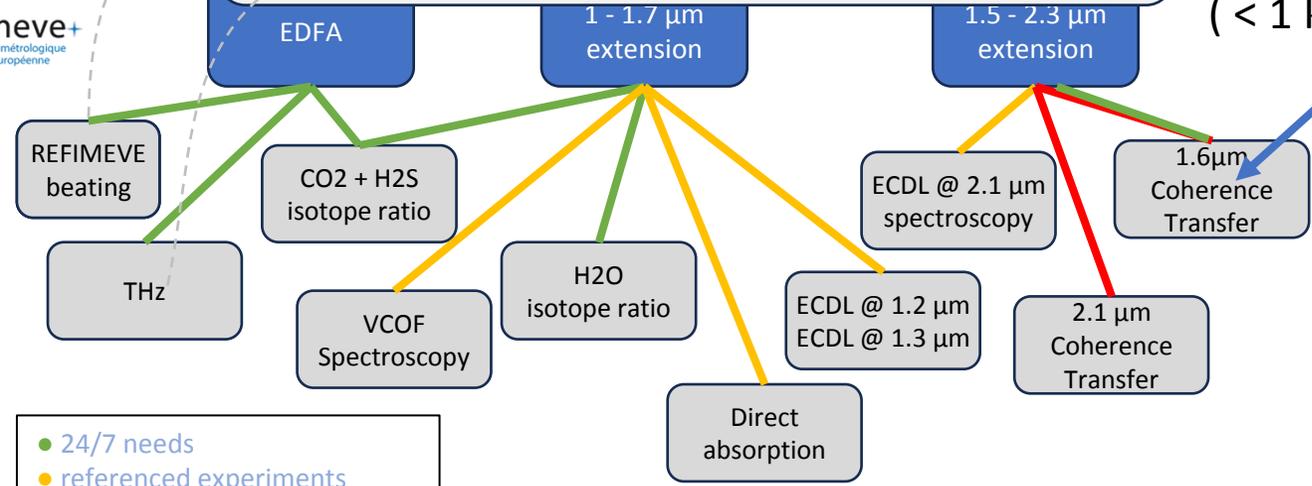
New comb, already running



8 fiber bundle (< 1 km)



Laser frequency measurement

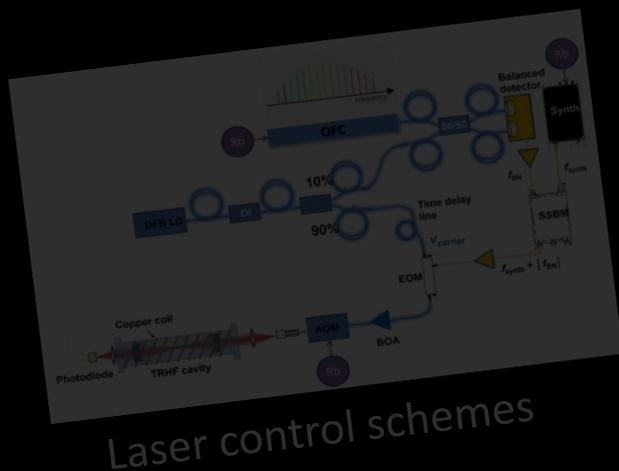


- 24/7 needs
- referenced experiments
- Linewidth critical experiments

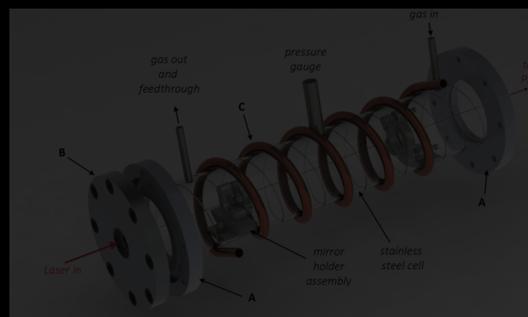
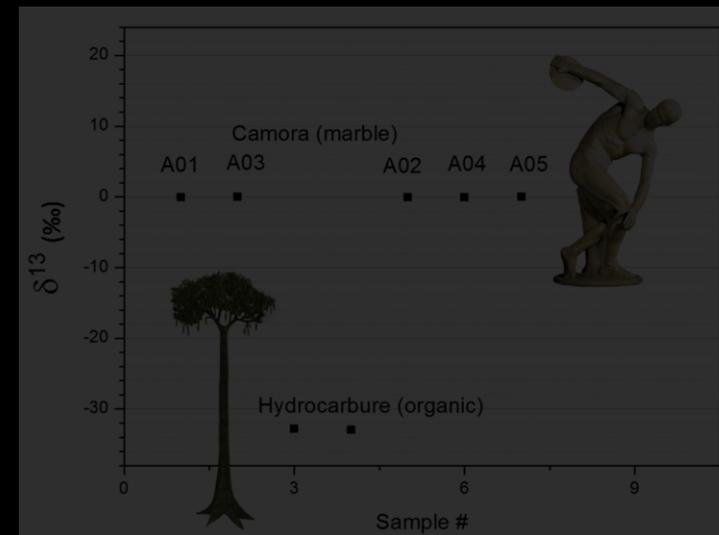
Note: all experiments are comb linewidth dependent

To be discussed





Demanding
science



Original ringdown cells



Innovative sources
and industrialisation





Thank you



CO₂

