

Uses and diagnostic of the Refimeve signal for high resolution spectroscopy

Mathieu Collombon

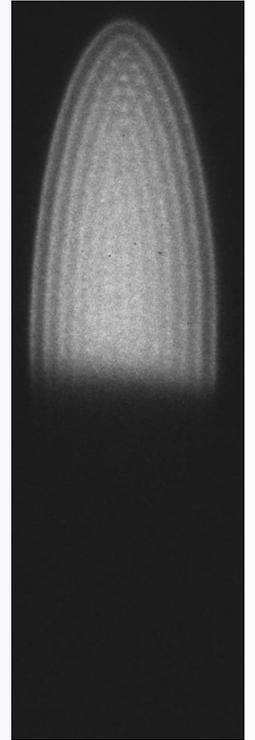
Confinement d'Ions et Manipulation Laser

PIIM - AMU – CNRS

Marseille

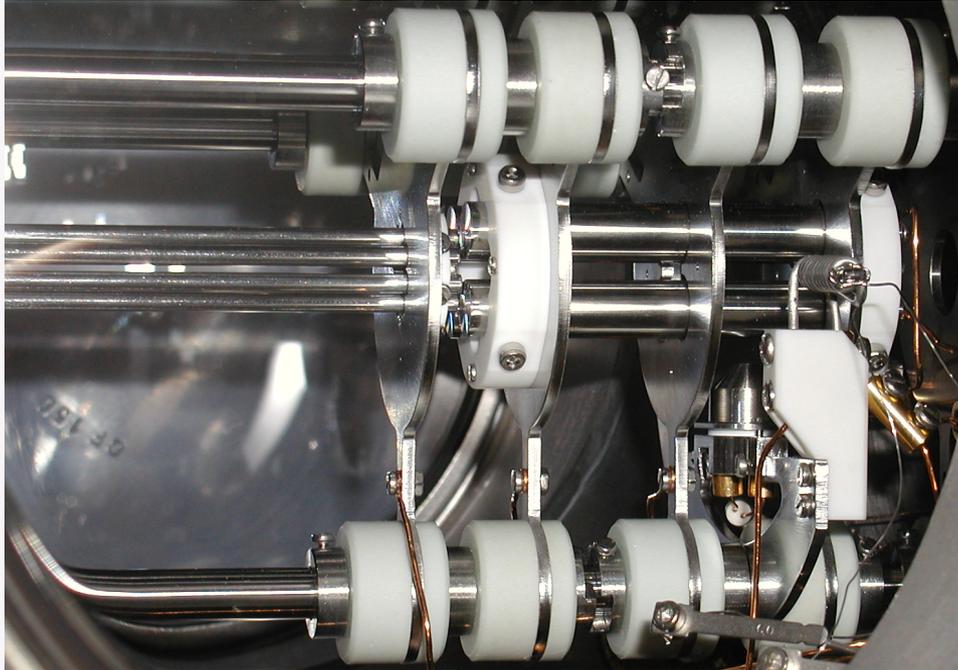
-
- High resolution spectroscopy on Ca^+
 - Metrological challenges
 - Experimental setup

 - Uses and diagnostic of the Refimeve signal



High resolution spectroscopy on Ca^+

- Two quadrupolar traps
- One octupole

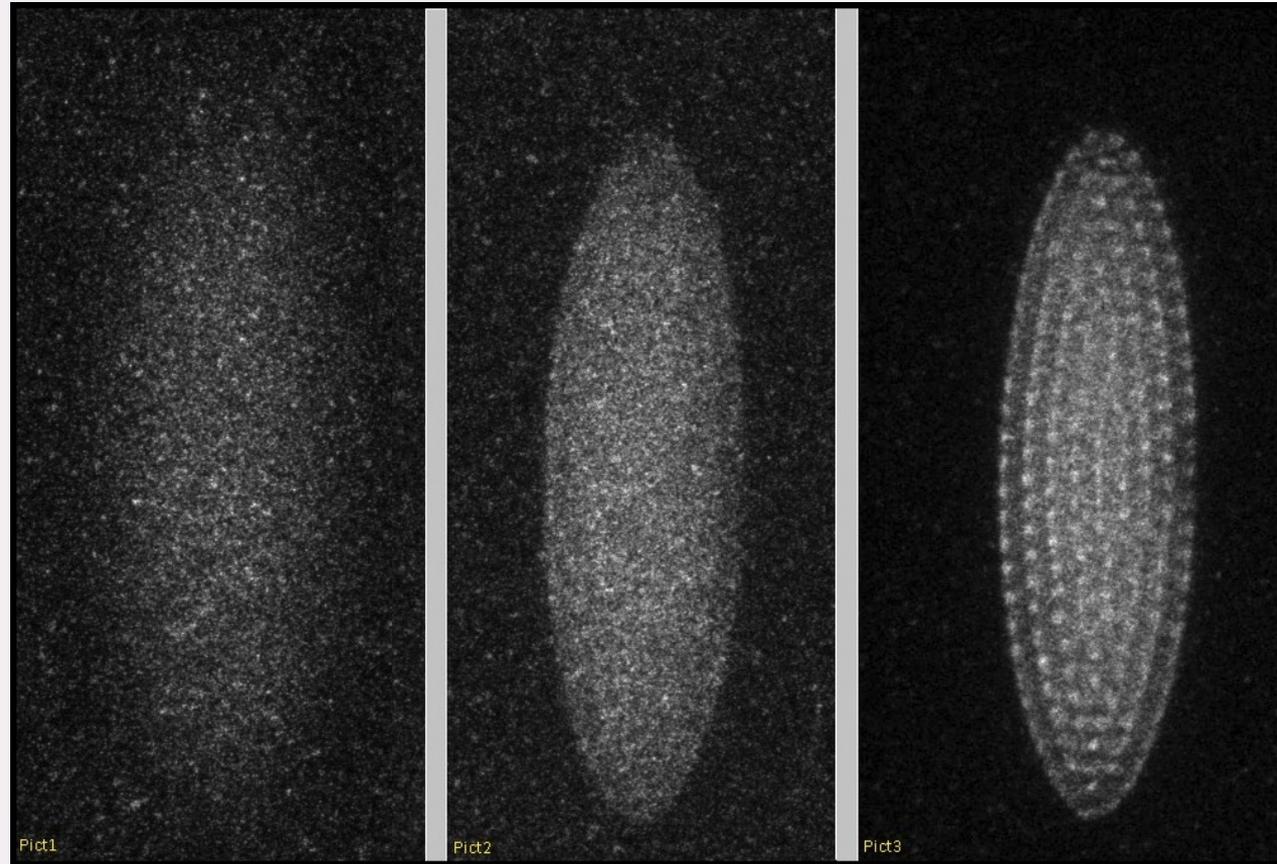
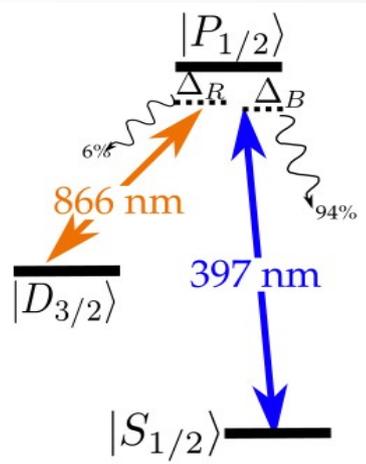


* 21 mm x 4 mm
* 60 à 3000 Ca^+

$\Omega = 5.2$ MHz
 $w_x \sim 200$ kHz
 $w_z \sim 130$ kHz

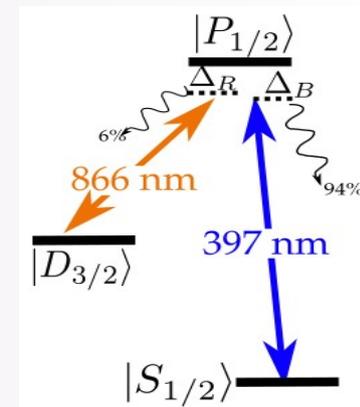
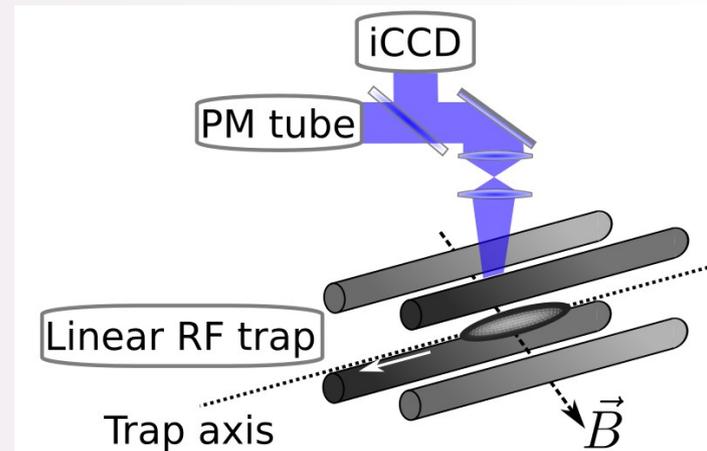
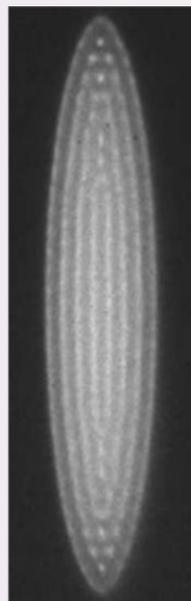
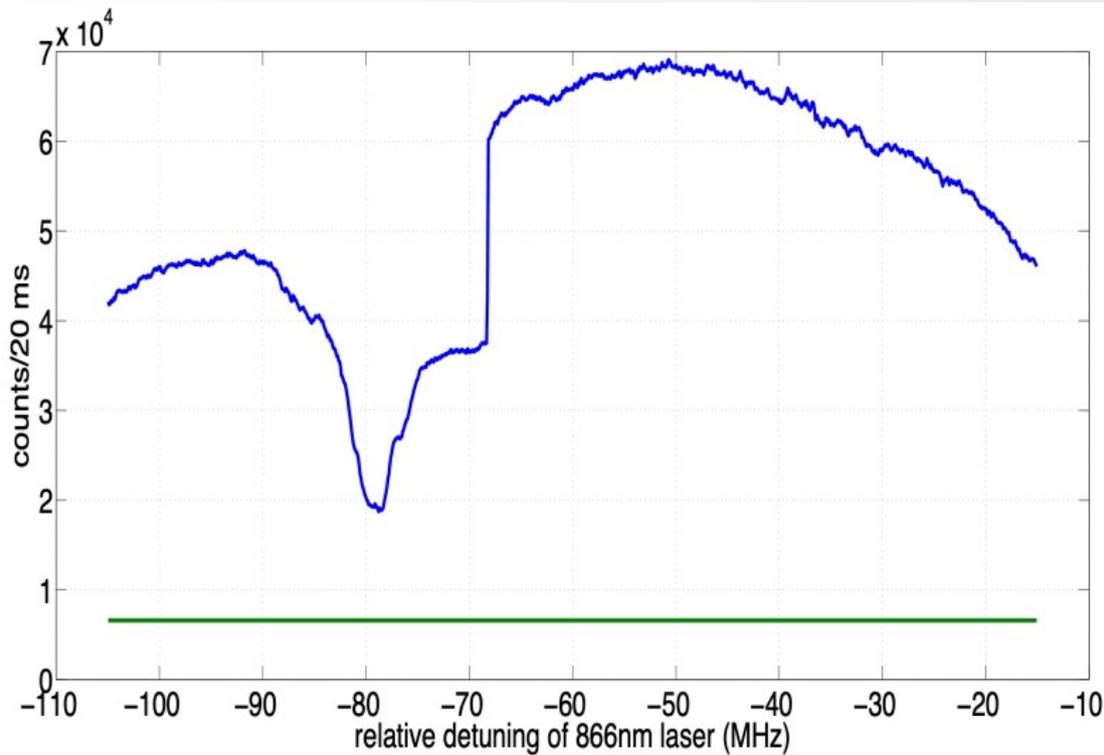
High resolution spectroscopy on Ca^+

Access to different phases depending on cooling efficiency



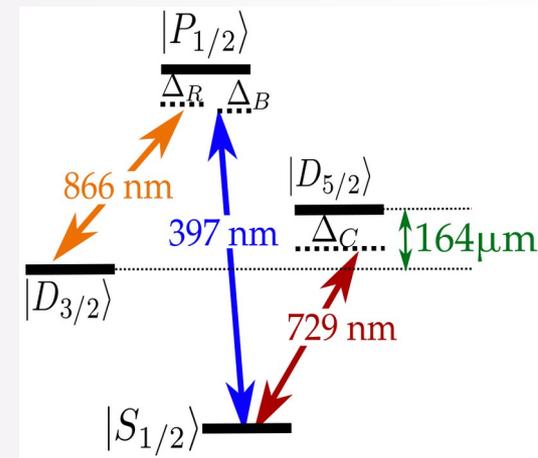
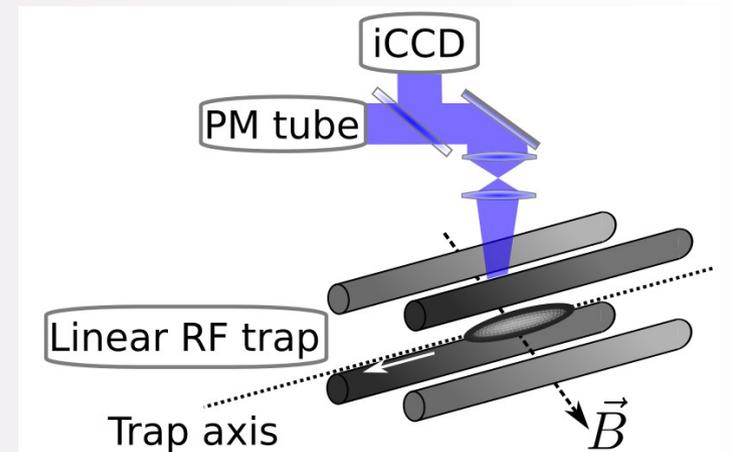
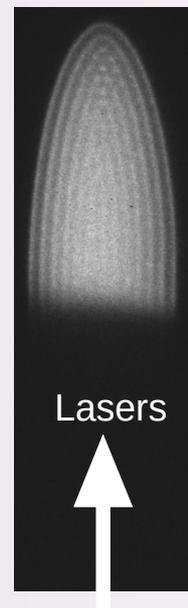
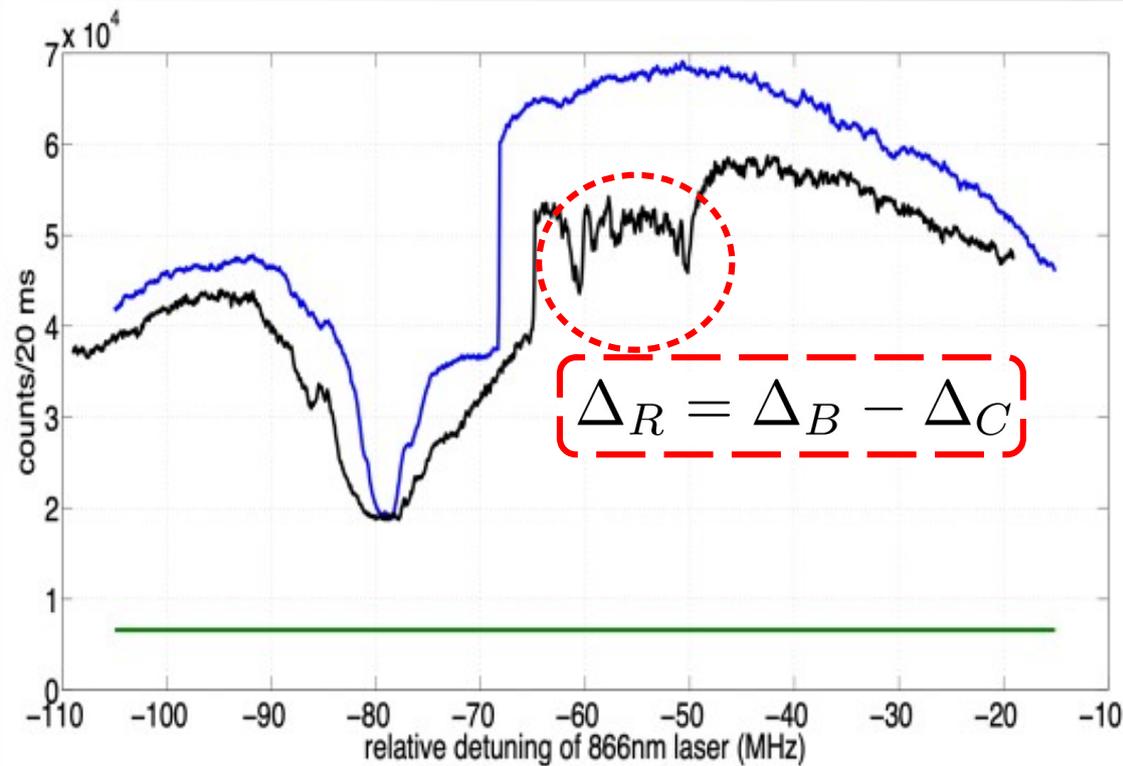
High resolution spectroscopy on Ca^+

- Ca^+ cloud in quad trap : collect photon from «blue» transition



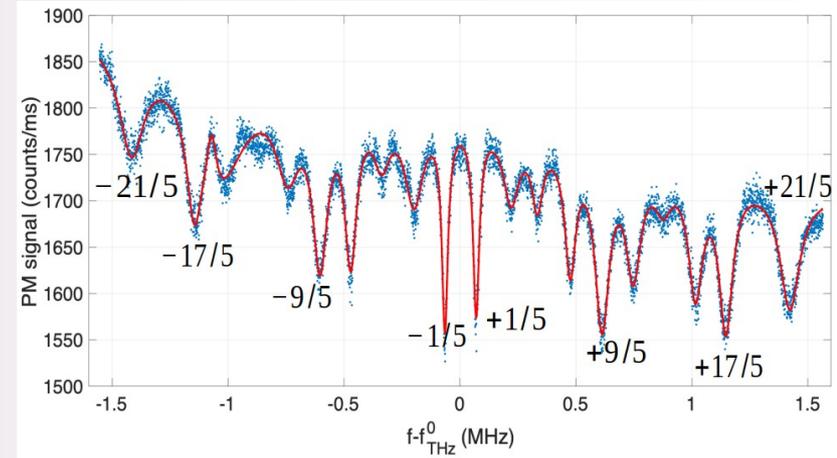
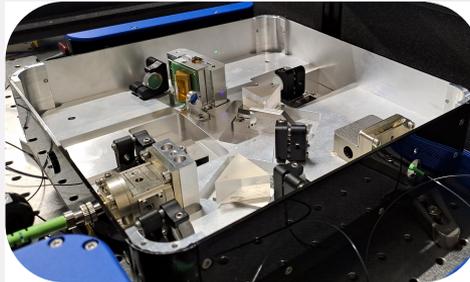
High resolution spectroscopy on Ca^+

- Three photon dark resonance (CPT)



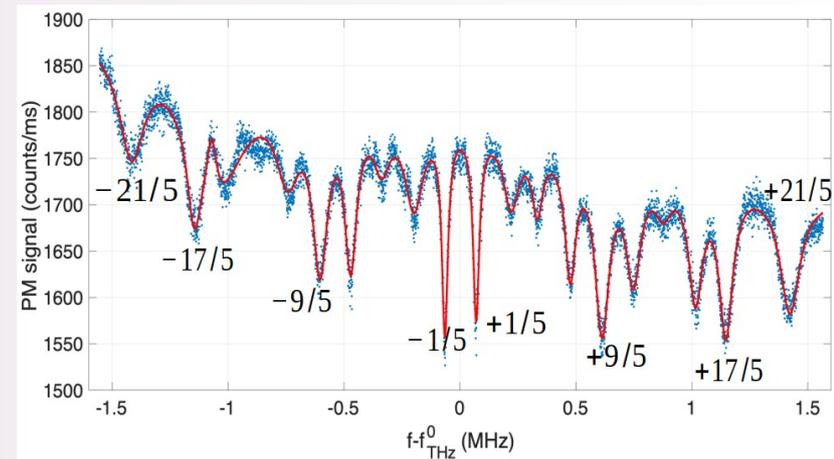
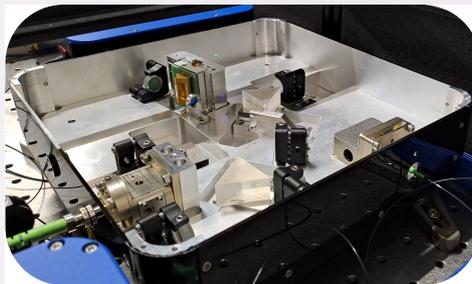
Metrological challenges

- Ultrastable laser at 729 nm (LUS)
- Phase locking of the three lasers involved : optical frequency comb.



Metrological challenges

- Ultrastable laser at 729 nm (LUS)
- Phase locking of the three lasers involved : optical frequency comb.
- Absolute frequency measurement and control

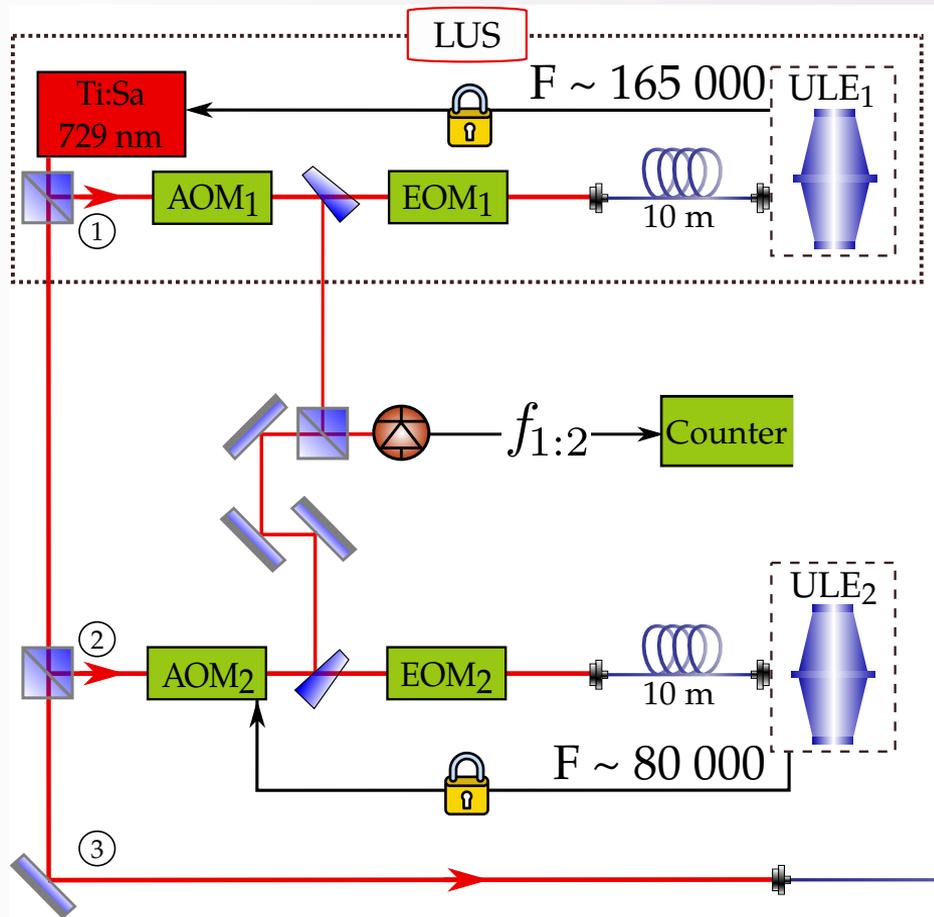


FWHM \sim 8 kHz Prec. 80 Hz

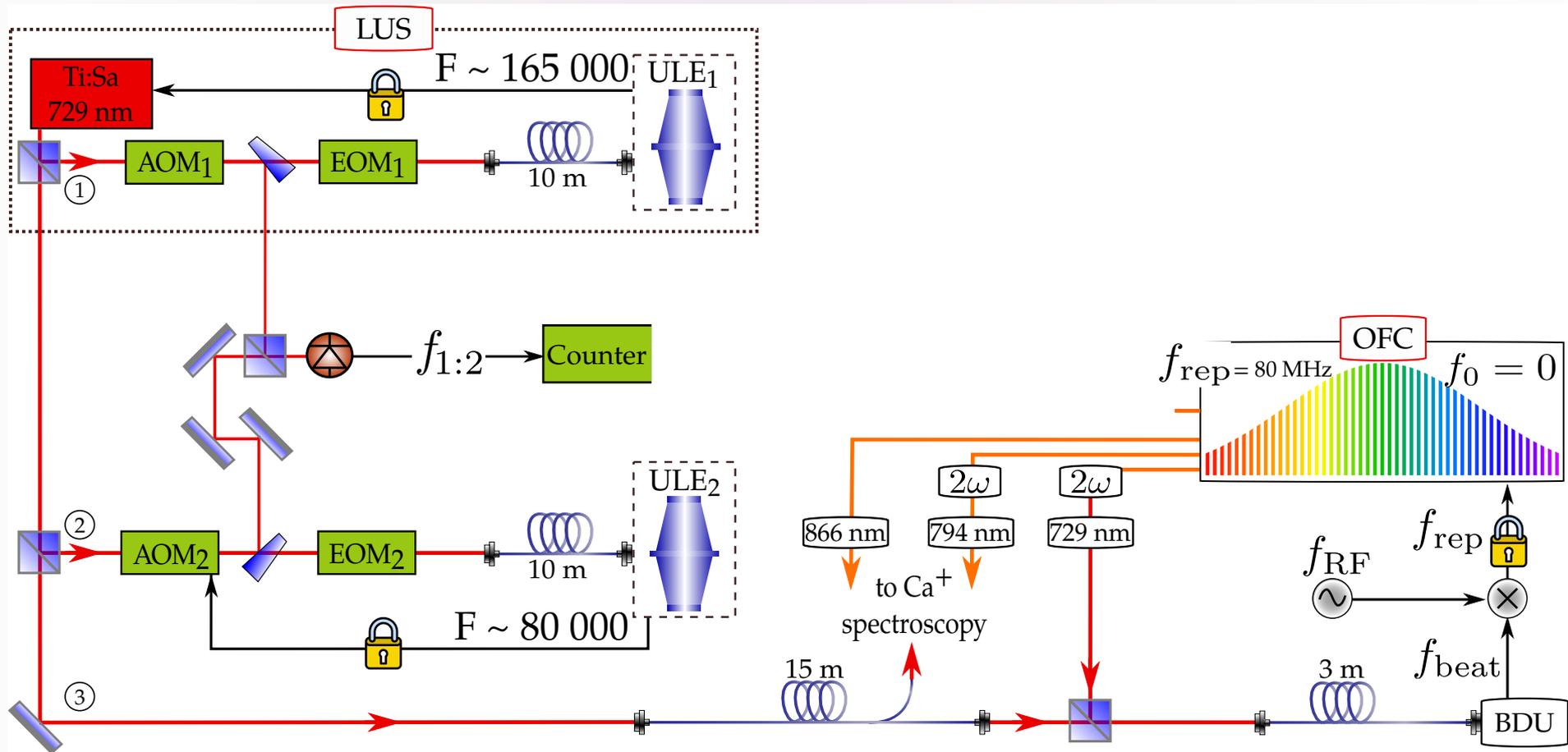
$$\nu_{THz} = \nu_R - \nu_B + \nu_C + syst.$$

Measure of $D_{3/2} \rightarrow D_{5/2}$ at 1.819 THz

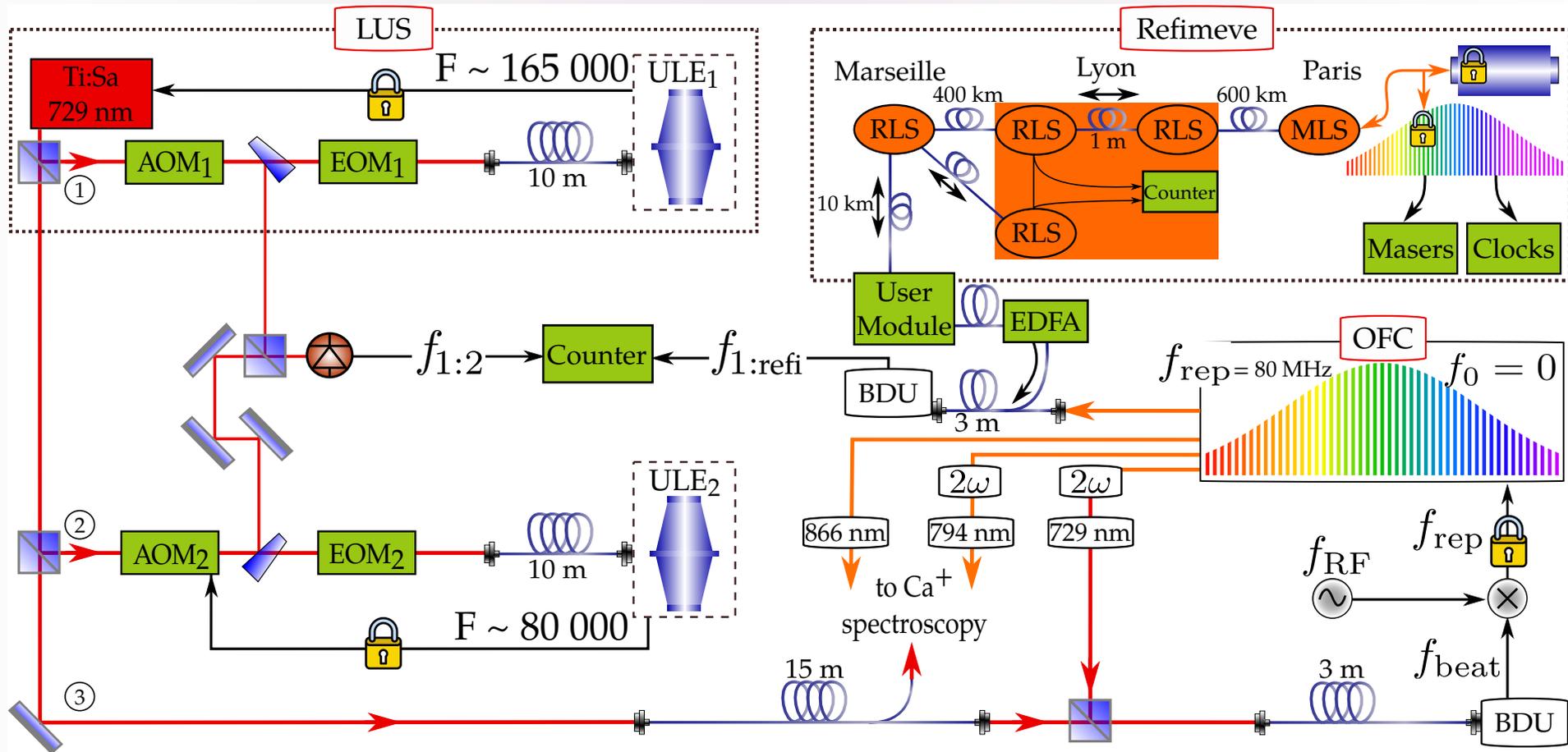
Experimental setup



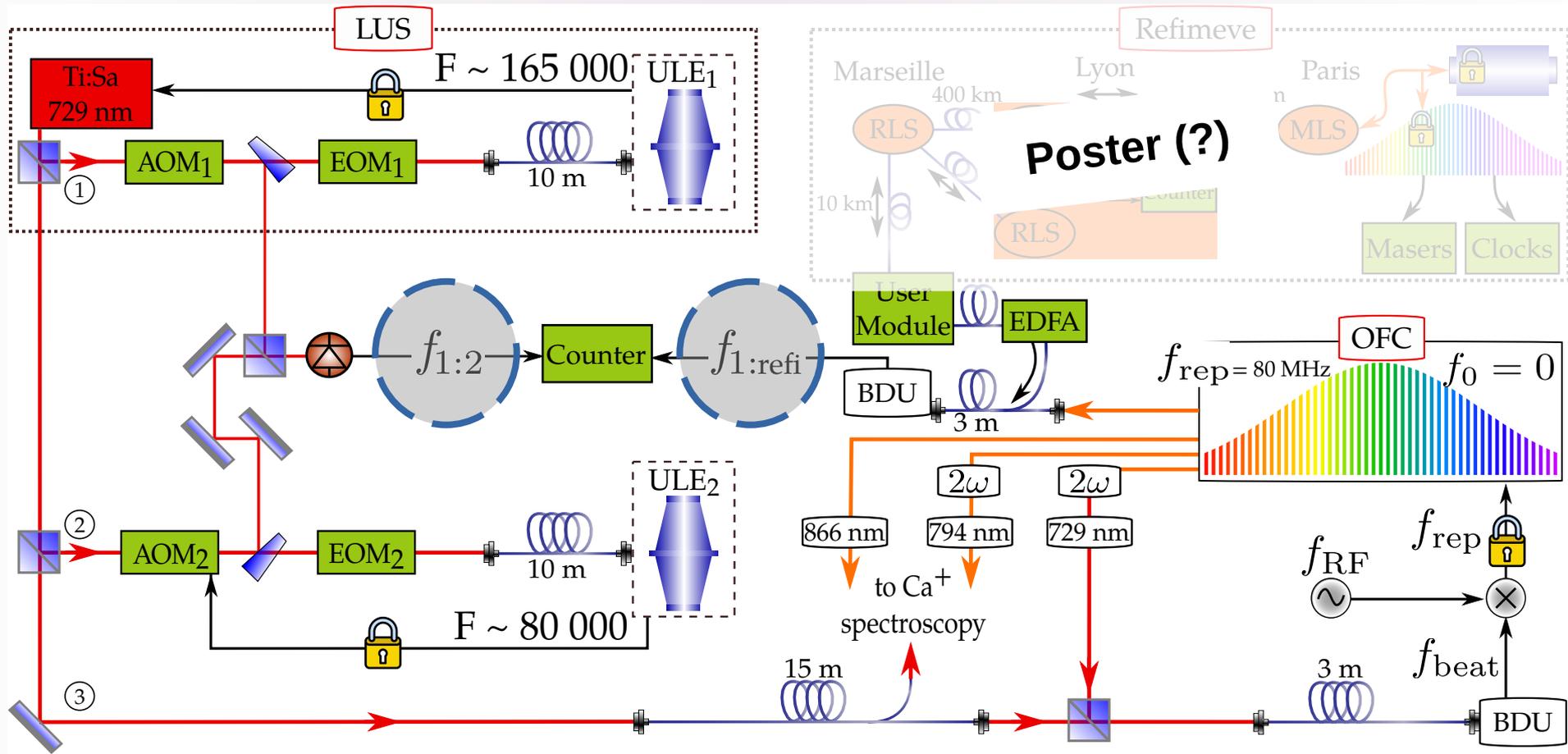
Experimental setup



Experimental setup



Ensemble expérimental



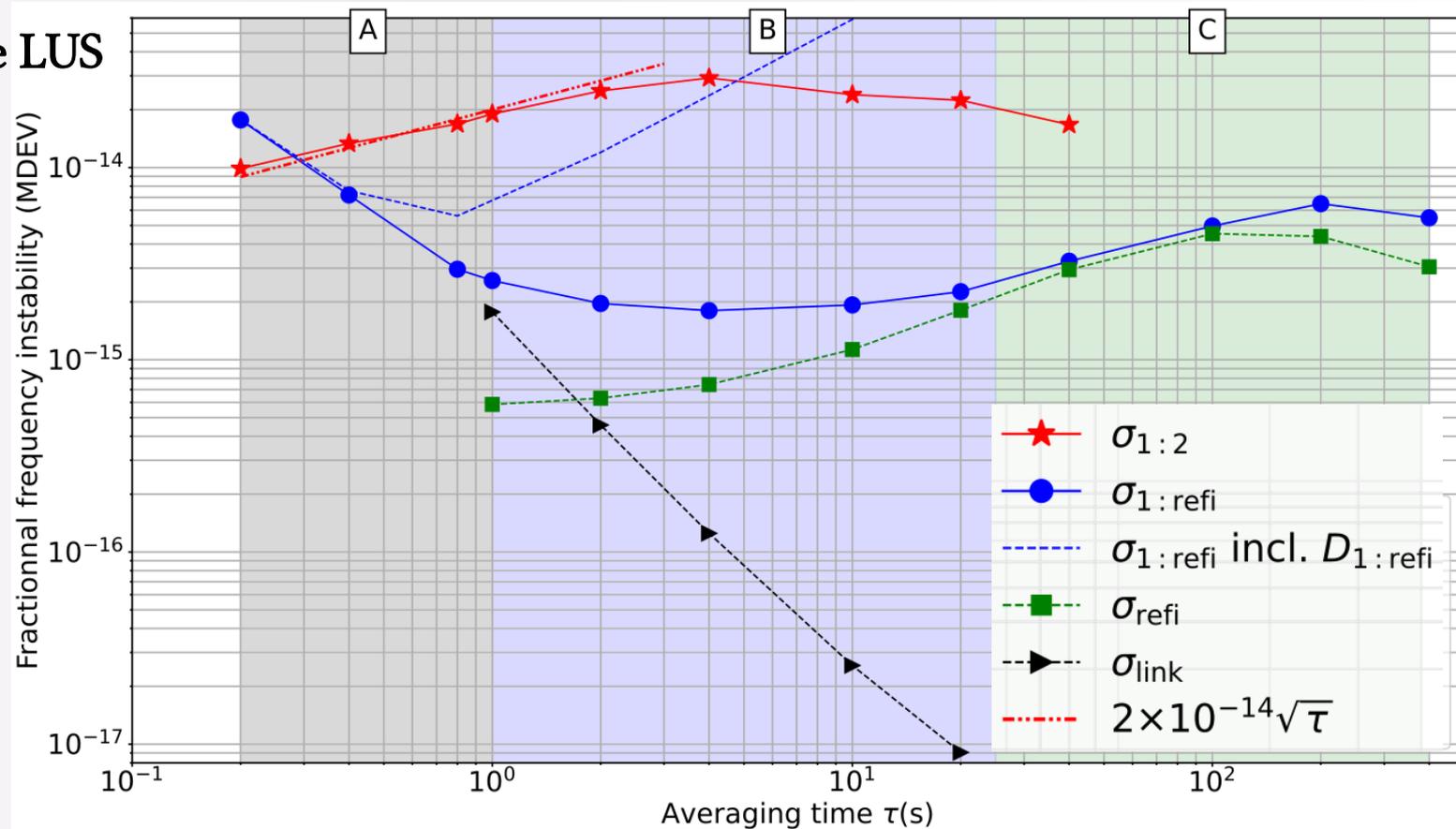
Uses of the Refimeve signal

1) Stability analysis of the LUS

No need of a second cavity

$\sim 3 \times 10^{-15}$ à 1s after drift correction

Confirm the expected behavior of the signal

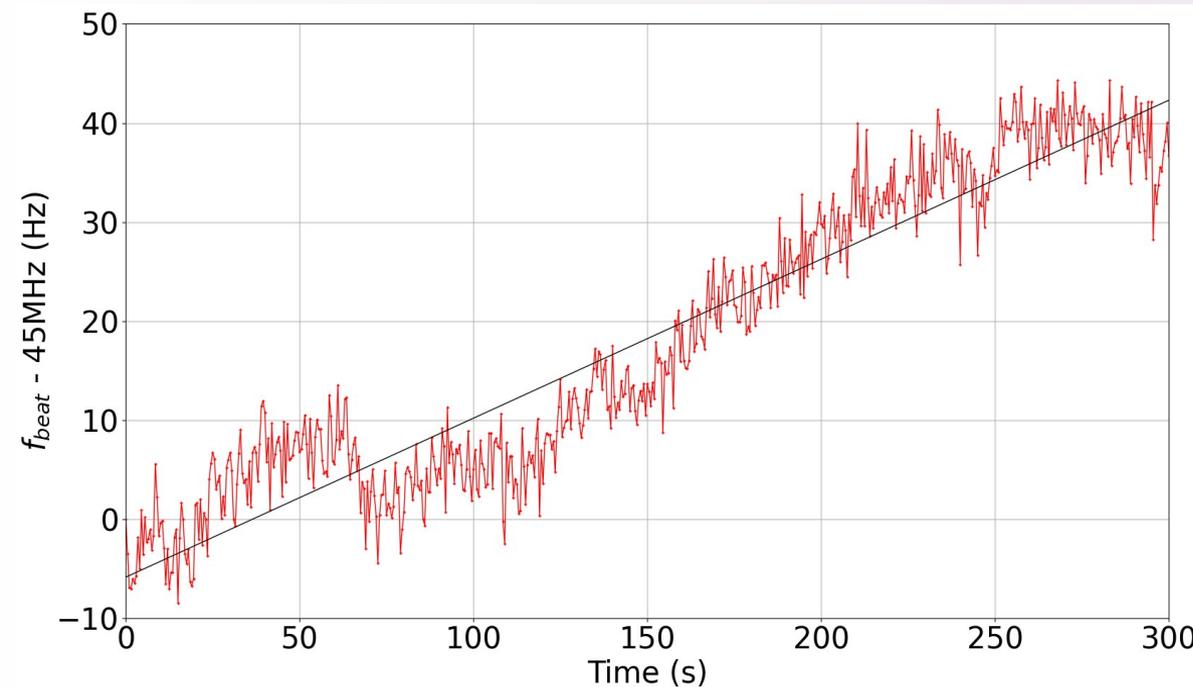


Uses of the Refimeve signal

$$\nu_{refi} = 194400008500000 \text{ Hz} \pm 5\text{Hz}$$

2) Frequency measurements

- Takes advantage of the comb scaling factor



If freq counting : need about 30min to be outside the noise

Counting of the Refimeve beat :
X 0.47 of the LUS drift

About 5min are enough to extract a drift of 320 mHz/s on the LUS.

On the three photons transition :

GNSS (frep)

$\sigma_{THz} \approx 20 \text{ Hz}$ Not yet limiting

Refimeve

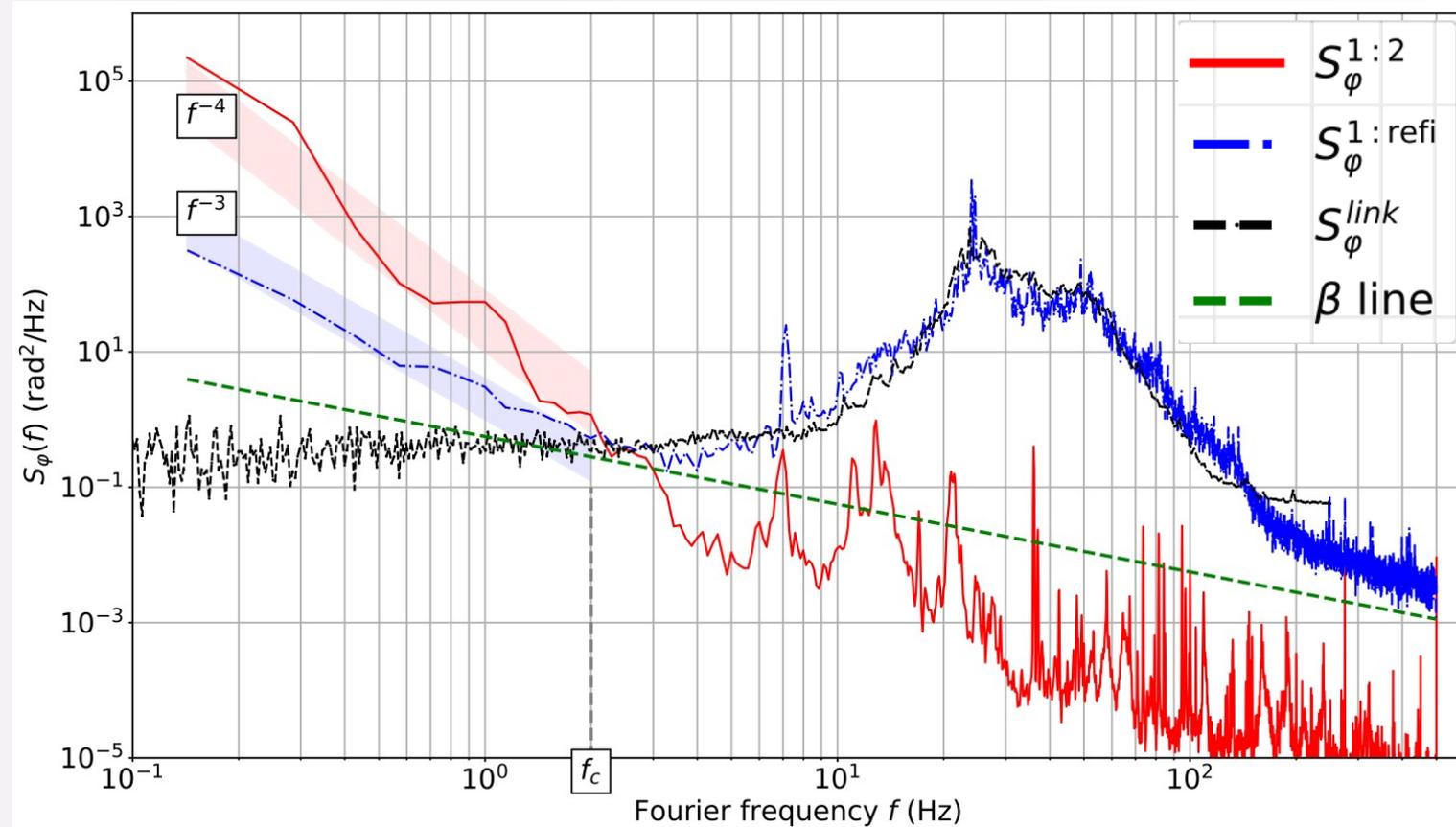
$\sigma_{THz} \approx 50 \text{ mHz}$

Diagnostic of Refimeve, after 1000km of propagation

Phase noise measurement

In agreement with the two-ways data after 2 Hz

Allows to access the LUS phase noise below 2 Hz

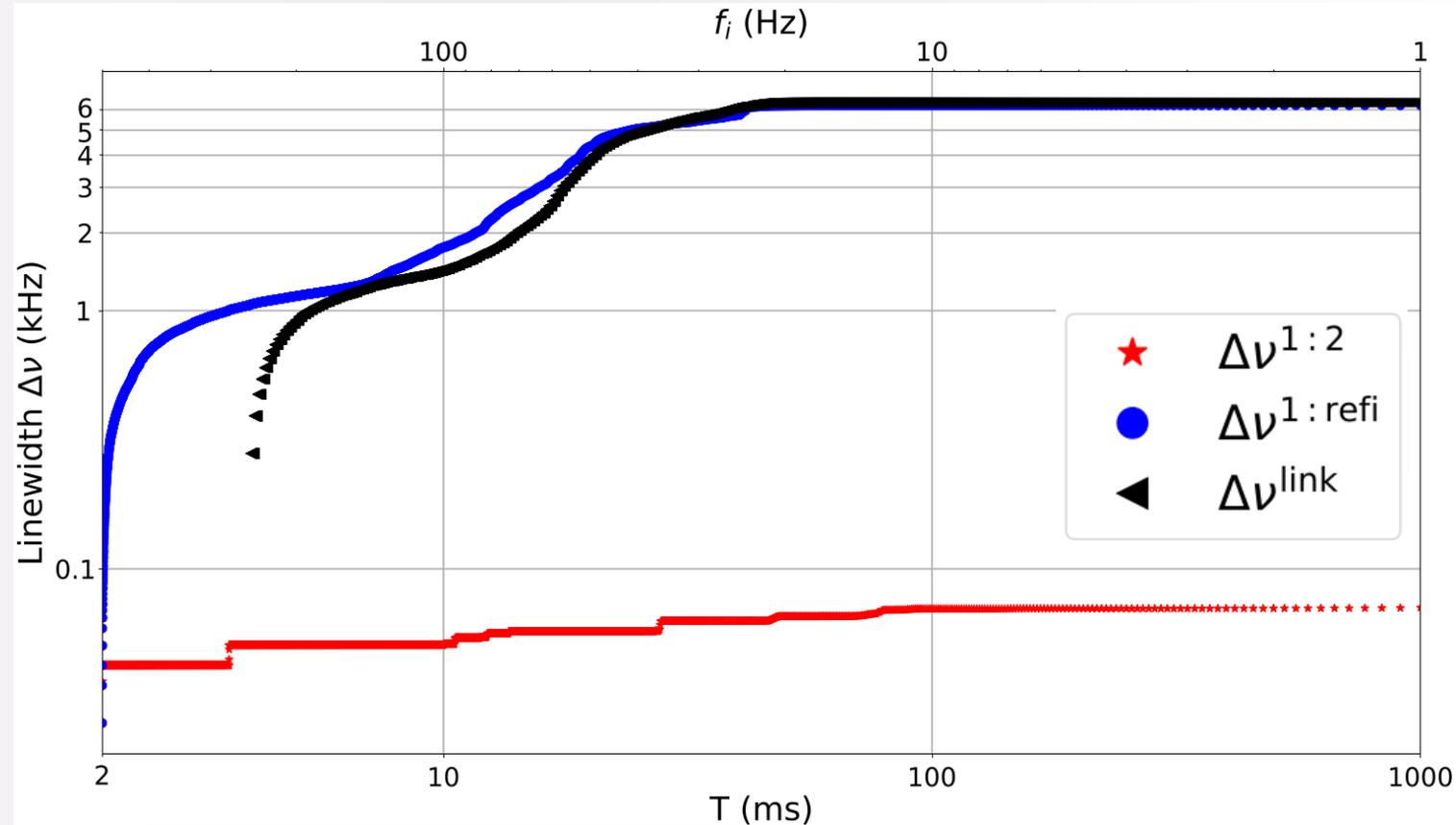


Diagnostic of Refimeve, after 1000km of propagation

Integral of the phase noise

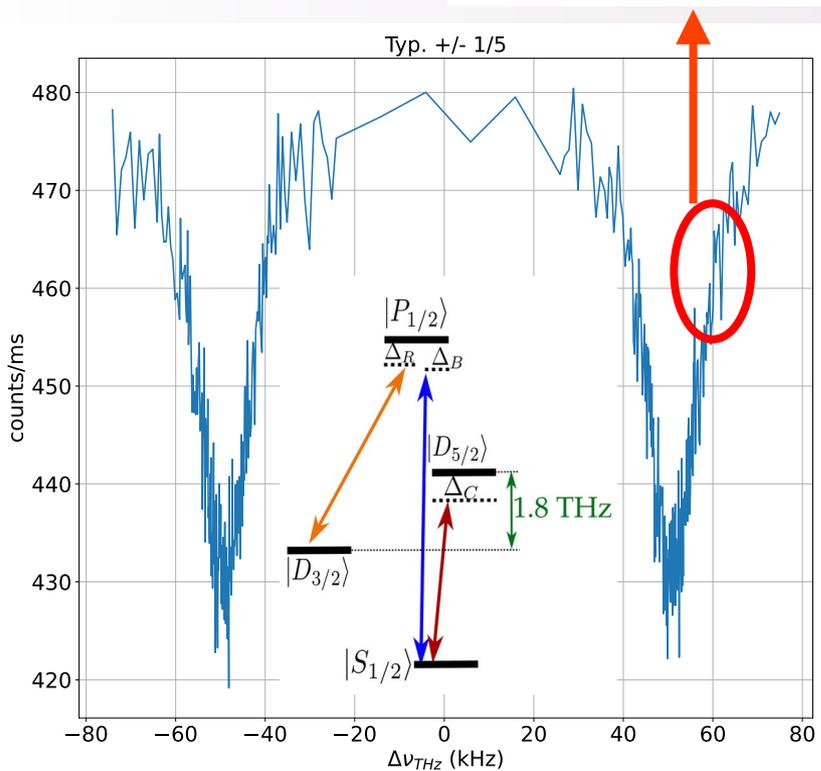
Access to the Refimeve
laser linewidth :

6.2 kHz after 40 ms



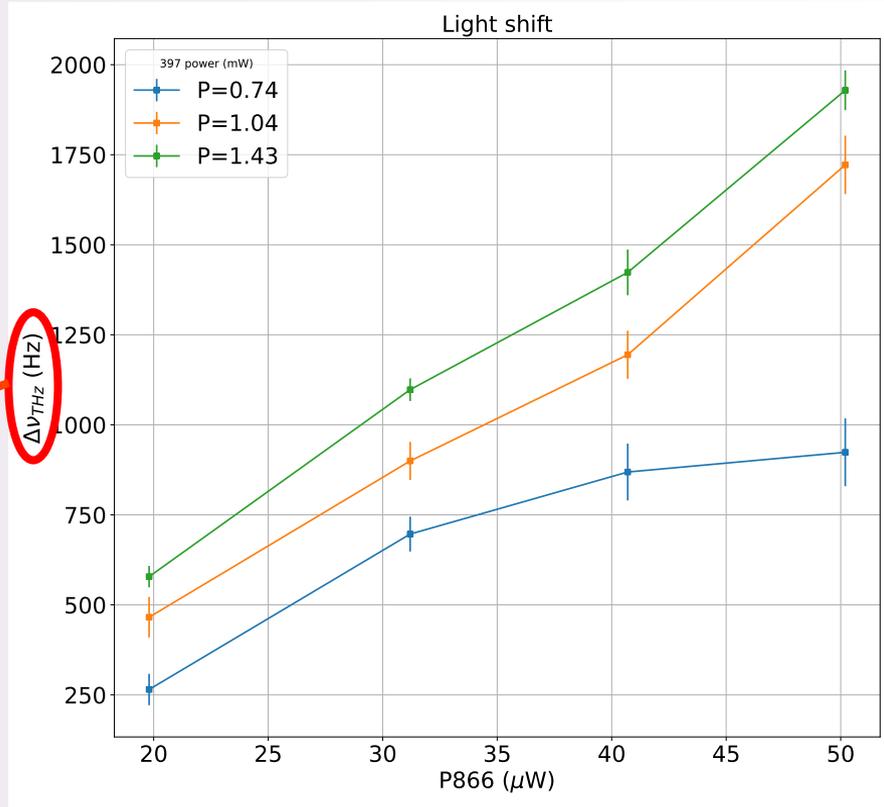
Spectroscopy results (prélim.)

1 pt = moyenne sur 1s (1ms gate)



Absolute THz shift computed with Refimeve

Typ. Lightshift : still not compatible with zero (Δ ~200Hz)



Conclusions

Research Article Vol. 42, No. 10 / October 2025 / Journal of the Optical Society of America B 1

Journal of the Optical Society of America B OPTICAL PHYSICS

Performance and uses of the Refimeve metrological signal, 1000 km from the source

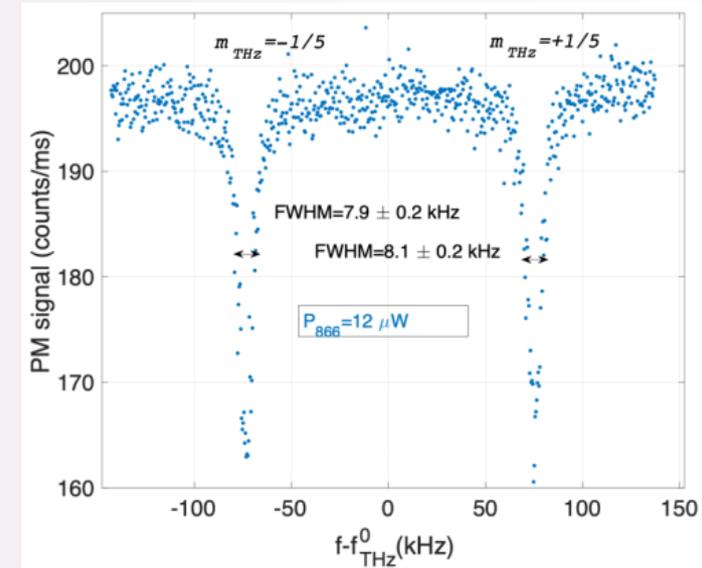
MATHIEU COLLOMBON,^{1,*} ETIENNE CANTIN,² GAËTAN HAGEL,¹ PAUL-ERIC POTTIE,³ MARIE HOUSSIN,¹ AND CAROLINE CHAMPENOIS¹

¹Laboratoire PIIM, Aix-Marseille Université, CNRS, Marseille, France
²Laboratoire de Physique des Lasers (LPL), Université Sorbonne Paris Nord, CNRS, Villetaneuse, France
³Laboratoire Temps Espace (LTE), Observatoire de Paris, Université PSL, Sorbonne Université, Université de Lille, LNE, CNRS, Paris, France

- Refimeve/LUS comparison confirm the two-ways data
- Demonstrate the possibility for the community to use Refimeve for Laser Phase noise and Stability measure to an excellent level after $\sim 1s$ (10^{-15})
- At short time scale, a LUS is still needed for low phase noise spectro applications

On the spectro side : Work in Progress...

- FWHM < 8 kHz
- ~ 200 Hz shift





Merci !



L'équipe CIML fin 2024

Merci à Etienne Cantin, Anne Amy-Klein, Rodolphe le Targat,
Benjamin Pointard, Biplab Dutta et Paul-Eric Pottie

Utilisation du signal Refimeve

2) Mesure de fréquence

Exemple : suivi de la dérive du mode ULE1

