SYRTE l'Observatoire de Paris | PSL

SYstèmes de Référence Temps-Espace

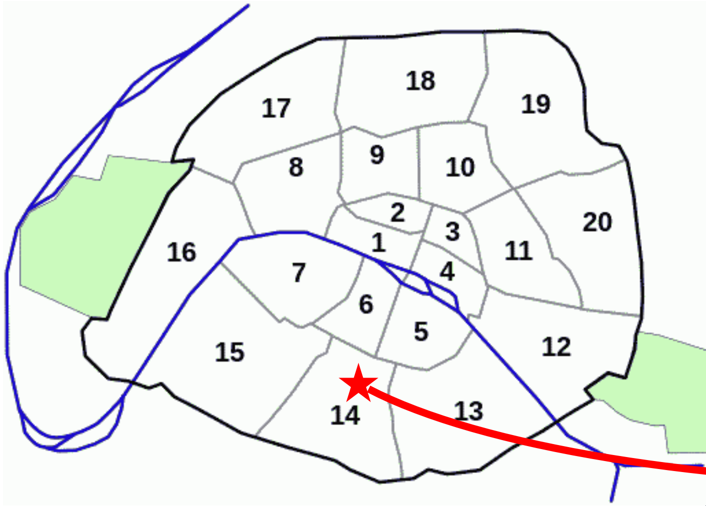
Introduction to the optical frequencies activities at SYRTE, Paris Observatory

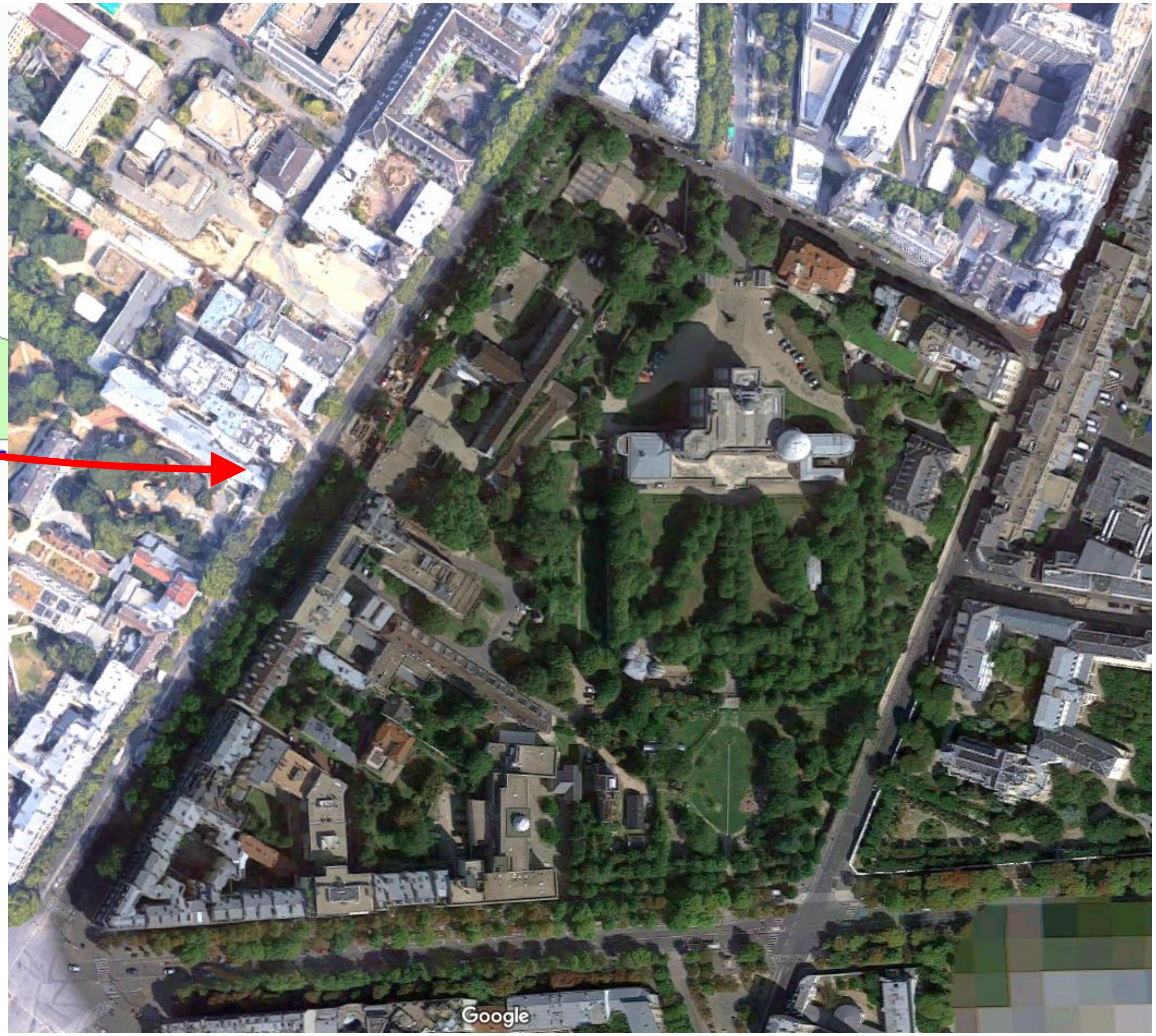
SORBONNE UNIVERSITÉ

LNE LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS

cnrs

Observatoire de Paris





⇨ **Where**: next to Denfert-Rochereau, 75014

RER B

M 4 6

BUS 88 83 38 68 91

SYRTE laboratory

- SYRTE: laboratoire Systèmes de Référence Temps-Espace
- 7 scientific teams

Interférométrie Atomique Capteurs inertiels

Métrologie des fréquences optiques

Rotation de la terre et géodésie spatiale

Histoire de l'astronomie

Références micro-ondes et échelles de temps

Théorie et métrologie

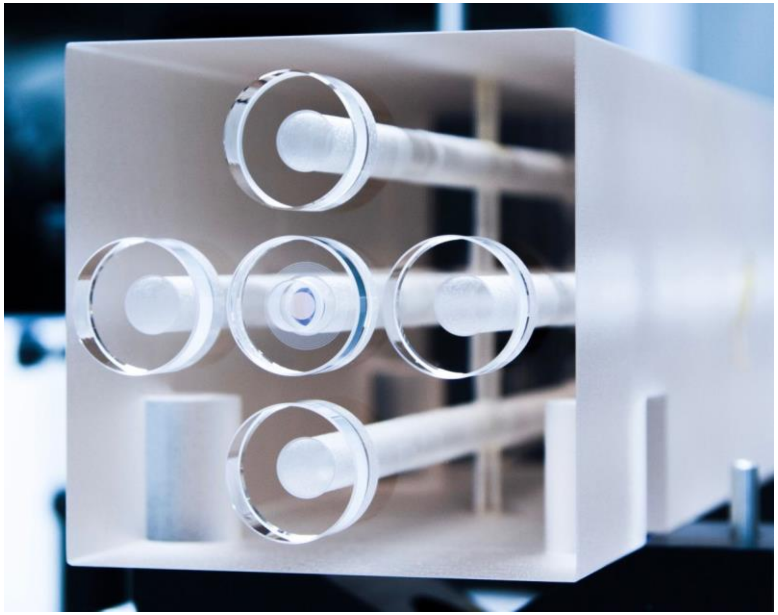
Systèmes de référence célestes

FOP (Optical frequencies team)

- Around 25 people (7 permanent staff members)
- Group meeting every Thursday, Lab Wiki to share information and knowledge

- Strong support from:
  - IT team (support to experimental network/computers/clouds)
  - Mechanical team (design and assembly)
  - Electronics team (design and assembly)

- Research fields:
  - Optical lattice clocks (strontium and mercury)
  - Frequency combs
  - International ultrastable fiber links (EQUIPEX REFIMEVE+)
  - Free space optical links
  - Fundamental Physics
  - Laser sources with extreme stability (Spectral Hole Burning, exploratory crystalline coatings techniques, stabilization to iodine vapors)



- A multi-disciplinary and transverse training:
  - Links to industry (SODERN, THALES, FRAUNHOFER …)
  - Teaching in various Licence/master courses in the Paris universities
  - SYRTE Alumni typically join universities in France or abroad, space agencies, patent offices, ministerial/diplomacy positions, industrial or consulting companies
  - Links to space agencies (CNES, ESA) to design and study bricks of upcoming space missions

FOP (Optical frequencies team)

- Fields of expertise:
  - Cold atoms
  - Optical trapping
  - Tests of Fundamental Physics
  - Ultra-narrow Lasers and transfer of spectral purity
  - Optical frequency combs
  - Frequency and noise measurements
  - Automating and remote control of experiments

- Publications notably in:
  - Physical review letters
  - Nature Photonics
  - Nature Communications
  - Metrologia
  - Optics Letters
  - Optica

- Fundings:

European Research Council
Established by the European Commission

FIRST TF

SIRTEQ

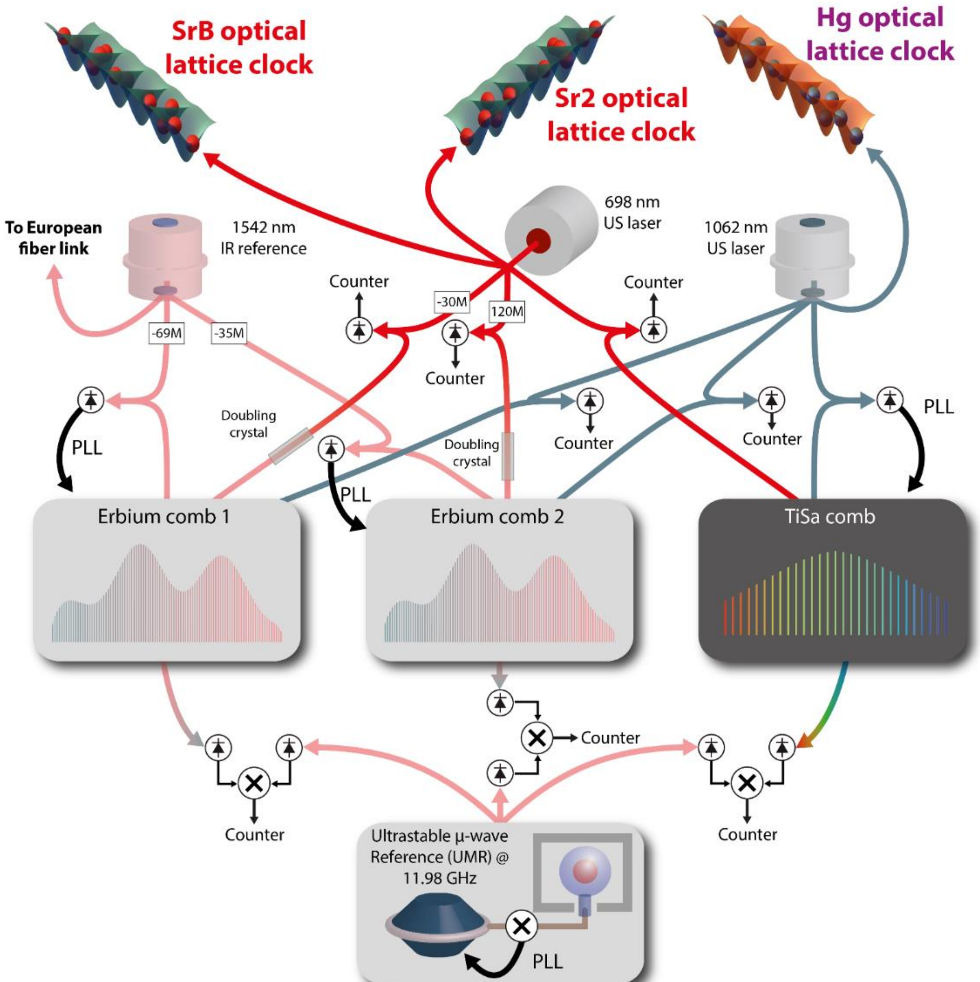
îledeFrance
Demain s'invente ici

European Space Agency

Projet financé par l'ANR - Project funded by the ANR

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Ultra high accuracy optical lattice clocks (Sr, Hg)



- 3 optical lattice clocks (strontium, mercury)
- among the most advanced in the world, control of the frequency over 17 digits
- Ideal testbench for **atomic physics** effects (fermionic collisions, black-body radiation …), **quantum Engineering** and **fundamental physics** (Lorenz invariance, possible drift of fundamental constants, tracking of dark matter …)

Achievements

- Non destructive detection of atomic populations for quantum states engineering

G. Vallet et al., New Journal of Physics 19, 083002 (2017)

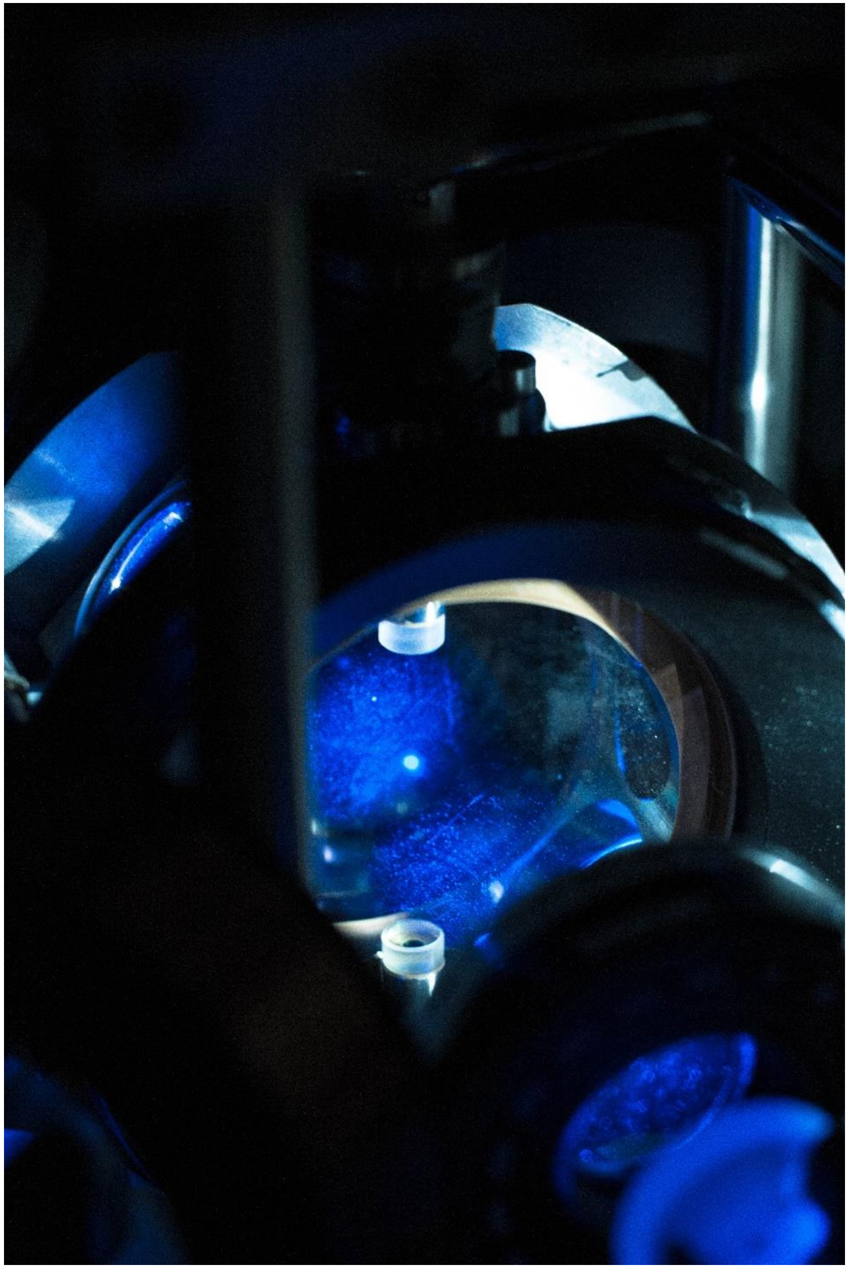
- Short cycles with a 2D MOT enhanced flux
- First contribution to the Temps Atomique International with optical clocks
- Tests of fundamental physics with optical clocks

B. M. Roberts et al., New J. Phys. 22 093010 (2020)
P. Wcisło, Science Advances eaau4869 (2018)

- Metrology and international clock comparisons

F. Riedel et al., Metrologia 57 045005 (2020)
R. Tyumenev et al., New J. Phys. 18 113002 (2016)
C. Lisdat et al., Nat Commun7, 12443 (2016)

Ultra high accuracy optical lattice clocks (Sr, Hg)



Next challenges

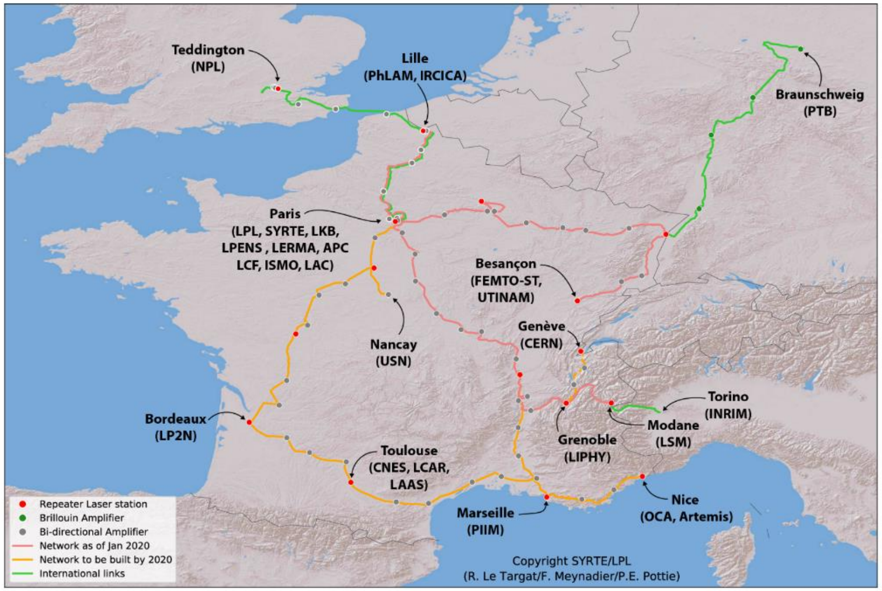
- Sr clocks:
  - improve accuracy with multi-site trapping in a Laguerre-Gauß shaped optical lattice, the use of Rydberg atoms as field sensors, and new vacuum chambers
  - improve the frequency stability with cavity-assisted non-destructive detections
  - regular metrological applications (contribution to TAI/UTC) with autonomous clocks.
- Hg clock: investigate an optical lattice clock based on bosonic isotopes

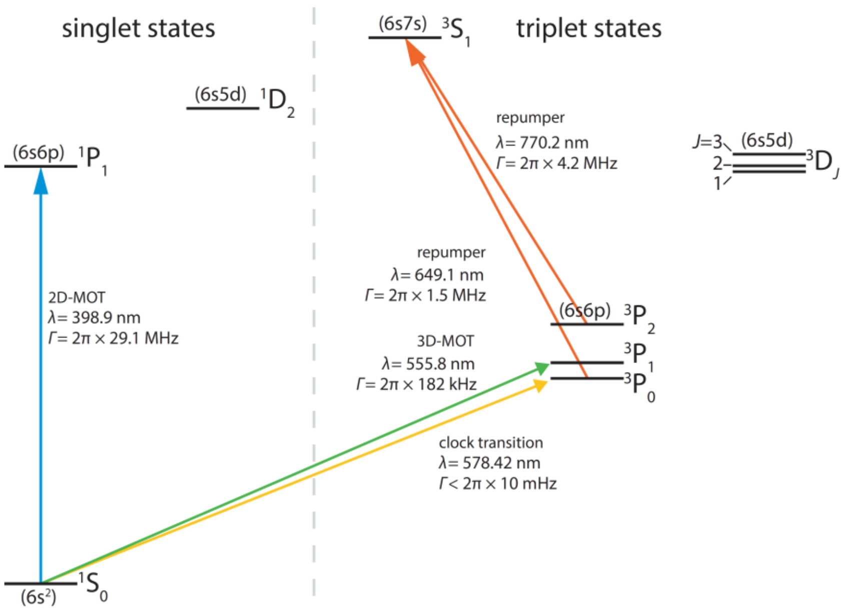
M2 internships/PhD topics in 2022:

- [Cold Rydberg atoms for thermometry in optical clocks]()

A new project at SYRTE: transportable Ytterbium optical lattice clock

REFIMEVE+ network and international links to NMIs





Goals of the project

- Transportable Ytterbium lattice clock
- Atomic clocks are sensitive to the local gravitational potential (**gravitational time dilation**): the clock will be used to refine the cartography of the geopotential
- Quantum sensor capable of measuring the potential, **no classical equivalent**
- More sensitive than existing techniques (satellite of levelling measurements)
- Will exploit the REFIMEVE + optical fiber network (dissemination of a 1542 nm reference)

M2 internships/PhD topics/Post doc positions in 2022:

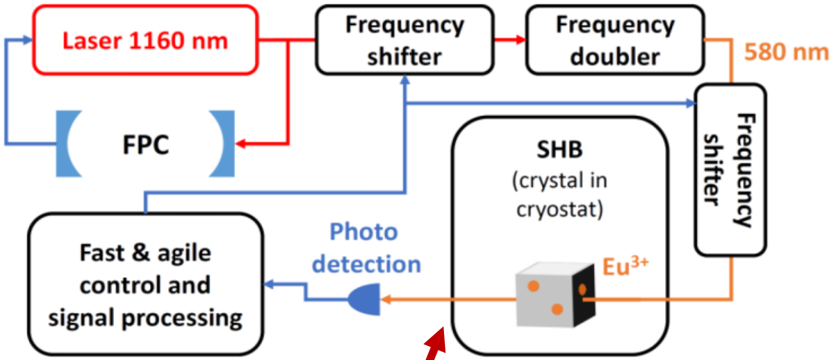
- Starting project with various tasks:
  - Assembly of a 2D-MOT+3D-MOT trapping architecture (lasers at 399 nm + 556 nm)
  - Design of an optical lattice in ultra high vacuum
  - Clock laser at 578 nm, with transfer of spectral purity from 1542 nm via a frequency comb
  - Control and automating in Python

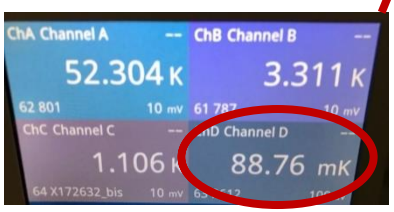
Post doc position Design of a high stability transportable Yb lattice clock applied to geodesy

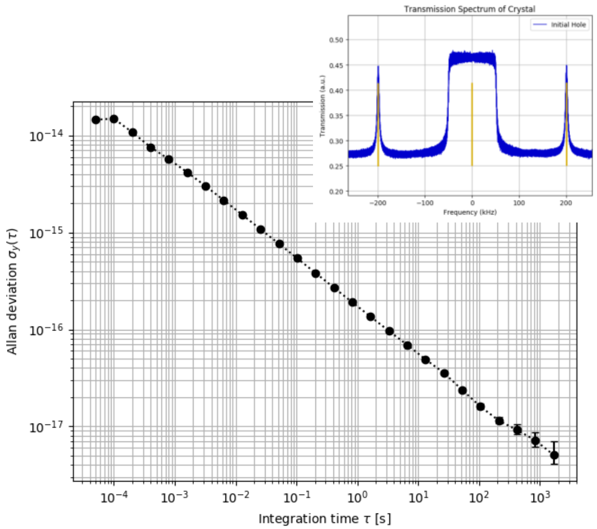
Post doc position Ultrastable oscillator for atomic clocks at the Quantum Projection Noise limit

M1 or M2 internship 1542 nm ultrastable laser for probing an ensemble of atomic clocks

Spectral Hole Burning : microscopic frequency reference







An **alternative approach** in ultra-stable optical frequency reference :

- Narrow optical transition at 580 nm in $Eu^{3+}:Y_2SiO_5$ (expect ~122 Hz homogeneous line width)
- Crystal at cryogenic temperatures (4 K down to sub 1 K) : many ions → large signal to noise ratio ; long life time → arbitrary but quasi permanent structure
- Objective : low 10^{-17} or below at 1 s, with fundamental limits unknown but to be explored
- Applications :
  - Spectral purity to be transferred to optical clocks at SYRTE
  - Acceleration sensitivity to be explored in optomechanics
  - Test bed to explore classical and quantum correlations between groups of ions

Proposals in 2022

M2 internship/PhD :

- Sensitivity to temperature < 1 K
- Multimode laser frequency stabilization
- Correlations between spectral holes

M1 internships :

- Interferometric cancellation of path length induced frequency noise
- Digital electronic and programming tools of TF metrology