

ULTRANARROW optical and spin transitions in ultrapure crystals

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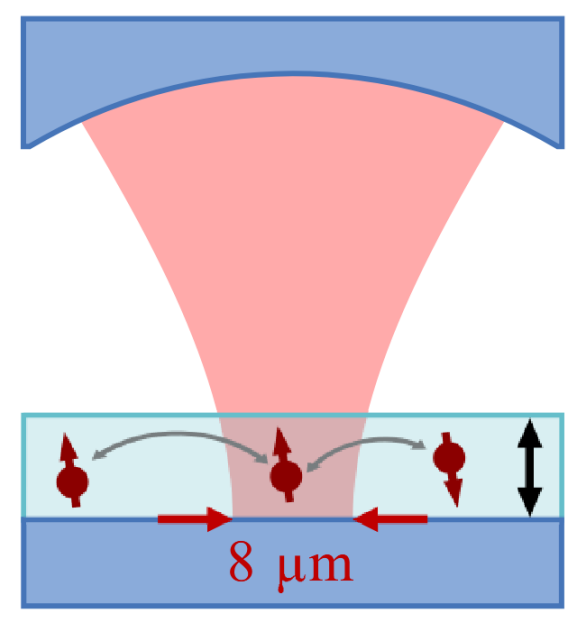
Project outline

Coherence is a key property of all quantum systems.

Achieving long coherence times requires **quantum systems that couple weakly to environmental perturbations and minimizing these perturbations as much as possible.**

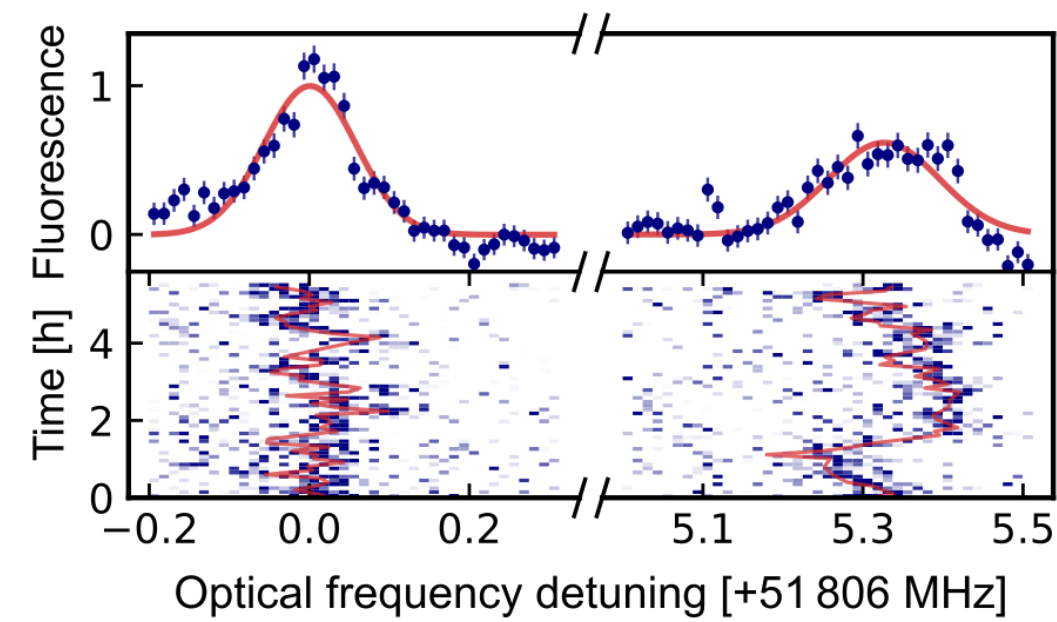
ULTRANARROW will explore the potential of a new materials platform: **rare-earth emitters in ultra-pure CaWO_4 crystals.**

Partner 1 : TUM (Coordinator)



Single Er dopants in membranes:

- Fabry-Perot resonators: Purcell effect enables efficient light-matter interaction and thus single-ion spectroscopy
- 10 μm membranes: Noise from interfaces is still low

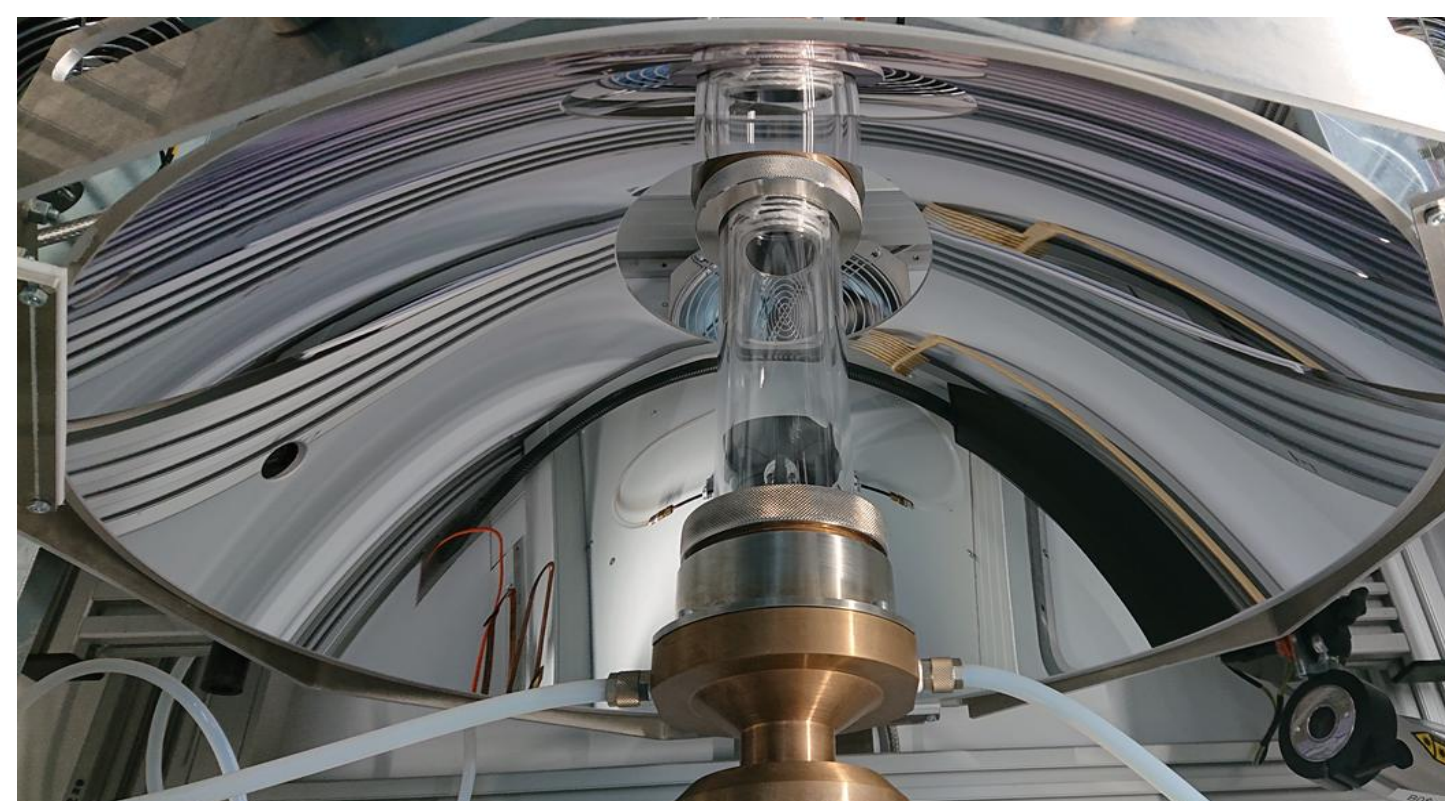


- Earlier work (left) used YSO crystals
- Spectral stability of individual emitters: 0.2 MHz
 - Best measured in any solid so far
 - Limitation: Nuclear spin bath
- Lower spin-bath density in CaWO_4 should enable a 100-fold improvement
- In ULTRANARROW: Systematic characterization of the remaining limitations

Partner 2 : IKZ

Growth of CaWO_4 single crystals with very high purity and high structural quality using different growth methods:

- Crucible-free: optical floating zone technique (OFZ) and traveling solvent floating zone technique (TSFZ)
- Crucible based: top-seeded solution growth (TSSG) and Czochralski growth (Cz)



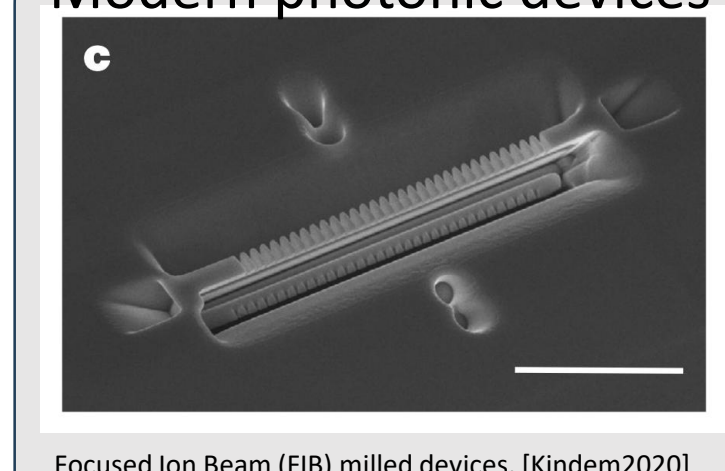
Vertical optical floating zone furnace

- Basic chemical and structural characterization of the grown crystals

Partner 3 : DUT

Next-gen nanophotonic devices in CaWO_4

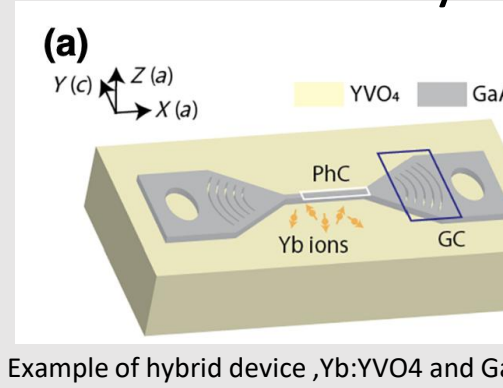
Modern photonic devices - FIB



- It works
- Lowers crystal purity and integrity
- Poor scalability and tunability

Alternative 1

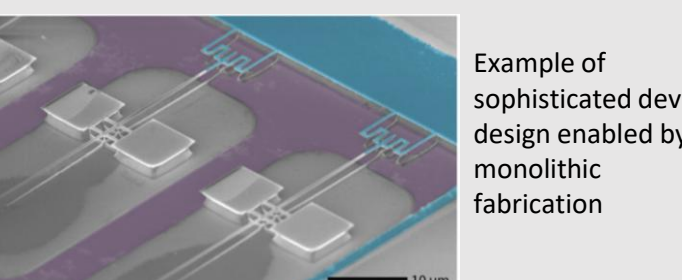
Silicon nitride hybrid devices



- Successful in similar platforms
- Scalable and tunable
- Preserves crystal purity and integrity
- Lower light-matter coupling

Alternative 2

Etched monolithic devices

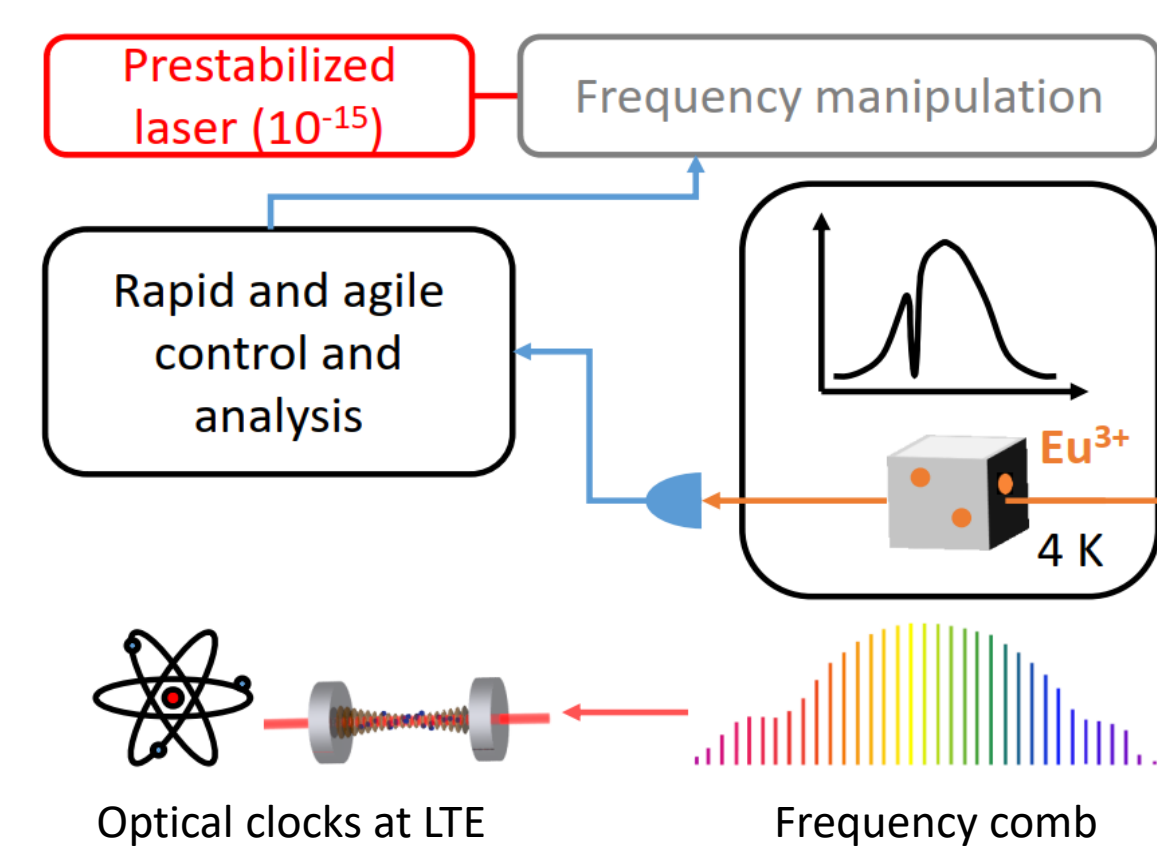


- Strong light-matter coupling
- Scalable and tunable
- Less intrusive than FIB
- More exploratory than hybrid devices

Long term goals

- Strong ion-light coupling
- Full photonic integration

Partner 4 : LTE / CNRS



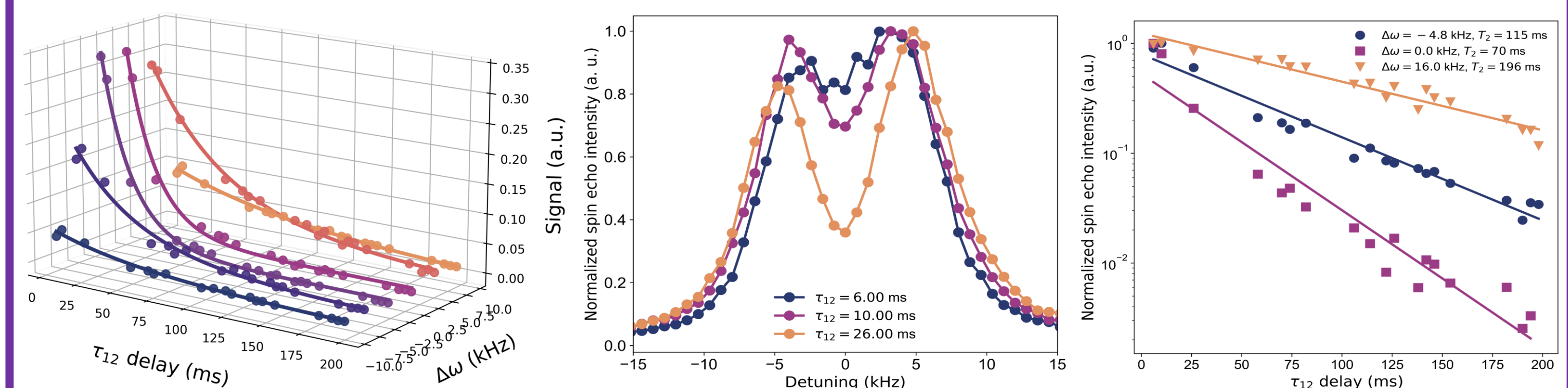
Notable results on Eu:YSO

- Laser frequency stabilization at 4×10^{-16} at 1 s, limited by detection noise and vibration, further improvement of detection
- Study of unilateral strain induced line shifts and broadenings
- Study of the influence of a static electric field (Stark effect)
- Study of temperature-pressure coupled environment and dilution environment
- Study of thermal noise limit

Contribution to ULTRANARROW using Eu:CaWO

- Spectroscopic characterization
- Demonstrating laser frequency lock relevant for frequency metrology

Partner 5 : IRCP / CNRS



$^{171}\text{Yb}^{3+}$:

- Paramagnetic isotope with nuclear spin of $I = 1/2$.
- Main site of $\text{Ca}^{2+} \rightarrow \text{Yb}^{3+}$.
- Optical transition $^2F_{7/2}(0) \rightarrow ^2F_{5/2}(0)$ @973.16 nm.
- Intra-4f transitions with narrow natural linewidths.
- Long-lived spin states due to weak interaction with CF.
- Excellent for optical and spin qubit implementations.

Results:

Excellent coherence performance of $^{171}\text{Yb}^{3+}:\text{CaWO}_4$:

- spin coherence times up to **150 ms**,
- optical coherence times up to **0.75 ms**.

High crystalline quality: very narrow optical and spin inhomogeneous linewidths.

Modelling of the concentration.

Implementation

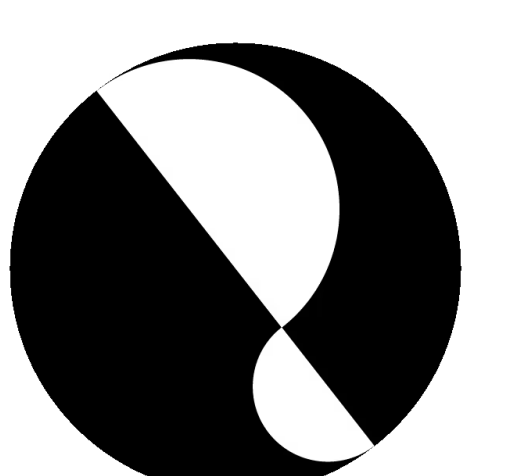
Objectives:

- 1) Minimizing the concentration of perturbing defect centres by growing crystals with ultra-high purity
- 2) Optimizing the post-growth fabrication of devices to maintain the bulk crystal properties
- 3) Improving the stability of the cryogenic setups in terms of vibrations, temperature, electric and magnetic fields
- 4) Identifying transitions where the REIs are least susceptible to remaining fluctuations

ULTRANARROW will thus determine and push the **ultimate limits of the coherence and spectral stability** of quantum emitters in solids and investigate first quantum applications



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