Rare-Earth Ions for Quantum Information Workshop

16-17 Sep. 2025, Nice

Book of abstract

Tuesday 16th

9h00 - 9h45	Participants Arrival + Registration		
9h45 - 10h00	Jean Etesse	Univ. Côte d'Azur, CNRS	Welcome Speech
10h00 - 10h30	Emanuele Urbinati	Delft Univ.	Characterization of Single Erbium ion in Lithium Niobate for Quantum Network Applications
10h30 - 11h00	**Coffee Break**		
11h00 - 11h30	Michael Moull	Univ. Canterbury	Rare-earth ions in CaF2 for scalable quantum technologies
11h30 - 12h00	Mahsa Karimi	Univ. Calgary	Comparing the performance of practical two-qubit gates for individual 171-Yb ions in yttrium orthovanadate
12h00 - 13h30	**Lunch**		
13h30 - 14h00	Jaime Travesedo	CEA Saclay	High-resolution spectroscopy of single nuclear spins via microwave photon counting
14h00 - 14h30	Mayssane Selmani	TUM	Erbium crystals enhanced by Fabry-Pérot cavities
14h30 - 15h00	Vishnu Unni Chorakkunnath Evgenij Vasilenko	Karlsruhe IT	Optical and spin characterization of Eu3+ based organic molecular complexes for quantum information applications
15h00 - 15h30	Flora Segur	Thalès Research and Technology	Investigating inhomogeneous profile correlations between two optical transitions via SHB in Er:YSO
15h30 - 16h00	**Coffee Break**		
16h00 - 16h30	Sagar Kumar Seth	Univ. Chicago	Spin decoherence dynamics of Er3+ in CeO2 film
16h30 - 17h00	Shuping Liu	Heifei Nat. Lab.	Optical and spin coherent spectroscopy of Eu3+Y2O3 transparent ceramics
17h00 - 17h30	Akshay Karyath Luozhen Li	Univ. Geneve	Spectroscopic investigations of an excited-state transition in Tm3+:YAlO3
17h30 - 19h00	**Poster Session 1**		

20h00 -	**8:00 pm** **Conference Dinner**

Wednesday 17th

9h30 - 10h00	Zong Quan Zhou	USTC Hefei	A metropolitan-scale multiplexed quantum repeater with Bell nonlocality
10h00 - 10h30	Yuyang An	Nanjing Univ.	Quantum teleportation from telecom photons to erbium-ion ensembles
10h30 - 11h00	**Coffee Break**		
11h00 - 11h30	Steven Touzard	Majulab Singapore	Building Quantum networks of superconducting circuits mediated by telecom photons
11h30 - 11h50	Signe Seidelin	Institut Neel	Thermodynamical versus coherence properties in europium doped Y2SiO5 below 1K
11h50 - 12h10	Bess Fang	Observatoire Paris	Thermal-noise limits to the frequency stability of spectral hole referenced lasers using Eu:YSO crystals
12h10 - 13h30	**Lunch**		
13h30 - 14h00	Riku Fukumori	Caltech	Many-body physics and microwave-to-optical transduction with Yb doped crystals
14h00 - 14h30	Ujjwal Gautam	Univ. Calgary	Memory-assisted microwave-to-optical transduction
14h30 - 15h00	Markus Müller	Paul Scherrer Institut	Emergence of highly coherent two-level systems in a noisy, randomly doped rare-earth magnet
15h00 - 15h30	Ben Field	Univ. Syndey	Piezospectroscopic sensitivity of Erbium
15h30 - 16h00	**Coffee Break**		
16h00 - 16h20	Diana Kim	Chimie Paris	Strain engineering for Er3+ emitters coupled to Y2O3 membranes
16h20 - 16h40	Karolina Waszkowska		Coherent Optical and Spin Spectroscopy of 171 Yb3+:CaWO4 Crystals at Varying Dopant concentrations
16h40 - 17h00	Anatole Bach		Rare earth - Diamond Hybrid structures for quantum technologies
17h00 - 19h00	**Poster Session 2**		

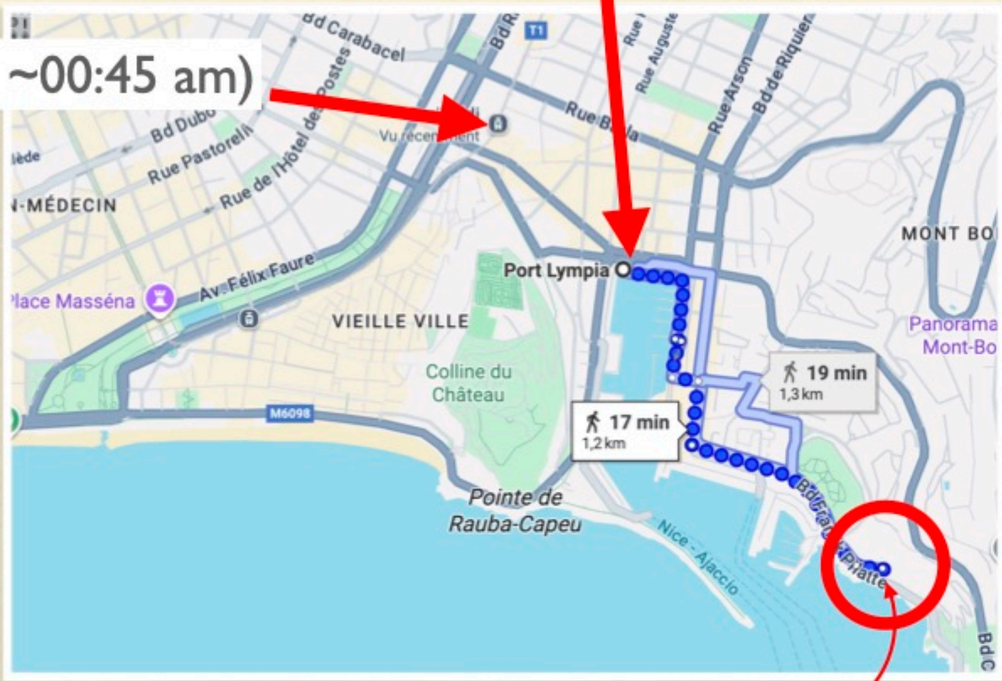
Thursday 18th

9h30 - 10h00	Georg Mair	Walther-Meissner-Institut Garching	Towards broadband coherent manipulation of rare-earth spins in CaWO4
10h00 - 10h30	Mickael Chan	Thalès Research and Technology	Toward highly efficient integrated quantum memories in rare-earth doped crystals
10h30 - 11h00	**Coffee Break**		
11h00 - 11h15	Alberto Rodriguez-Moldes	ICFO	Dynamically decoupled storage of single photons in a Pr3+ YSO quantum memory
11h15 - 11h30	Felicien Appas		Towards a functional quantum repeater link using Pr3+:YSO quantum memories
11h30 - 12h00	Mira Abu Yahia Erik Lundblad	Lund Univ.	Transportation-based quantum repeaters for global distribution of entanglement
12h00 - 13h30	**Closing remarks + Lunch**		
13h30 - 16h30	**Lab Tour**		

CONFERENCE DINNER

Tram 2 'Port Lympia' (last @11:10 pm)

Tram 1 'Garibaldi' (last @ ~00:45 am)



Where? Hôtel 'Le Saint Paul', 29 bd Franck Pilatte, 06300 NICE

When ? 16th of Sep., 8 pm

Contents

1 Talks

1.1 Tuesday 16th

Characterization of Single Erbium ion in Lithium Niobate for Quantum Network Applications

Emanuele Urbinati,[1] Luca Mastrangelo,[1] Yong Yu,[1] Gaia Da Prato,[1] Annalise Lennon,[1] WolfgangTittel,[2,3] and Simon Gröblacher [1]

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[2]*Department of Applied Physics, University of Geneva, 1211 Geneva, Switzerland*
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The realization of a rare-earth-ion-based quantum network requires the development of an on-demand source of single, indistinguishable photons. While rare-earth ions have shown significant promise for quantum memory and repeater applications, their viability as efficient single-photon sources remains to be fully demonstrated. In this work, we investigate the properties of individual erbium ions implanted in X-cut lithium niobate crystals. By integrating silicon photonic crystal cavities onto the crystal surface, we achieve coupling to single ions and characterize key photonic properties including brightness, purity and coherence. We present measurements under varying temperature, electric, and magnetic field conditions, offering insights into the suitability of this platform for scalable quantum networking.

Rare-earth ions in CaF_2 for scalable quantum technologies

M.D Moull[1,2,3], J.-P.R. Wells[1,2,3] and M.F. Reid[1,2,3]
[1]*The School of Physical and Chemical Sciences, University of Canterbury, PB4800 Christchurch 8140, New Zealand*
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[3]*Quantum Technologies Aotearoa, Dunedin, New Zealand*

Rare-earth ions (REI) doped into inorganic crystals are seen as a leading candidate for quantum information technologies that provide an interface between light and matter, such as quantum memories, transducers, and repeaters. They also provide an interesting alternative as high-density quantum processors via single-ion manipulation. Europium based systems have shown promising characteristics such as coherent storage with a six-hour timescale that has been demonstrated in electron-nuclear hyperfine states of europium ions in yttrium orthosilicate (YSO) [1].

4f - 4f transitions of REI's are electric dipole forbidden in the absence of mixing with opposite-parity configurations on the ion or ligands and are therefore weak compared to other systems. However, dipole moments can be modified by the Purcell effect in waveguides and cavities. For example, recent experiments have demonstrated single-ion detection of trivalent erbium ions in nanoparticles [2]. This limitation is compounded in the case of the relevant $^7F_0$ - $^5D_0$ transitions of trivalent europium systems. This transition relies on crystal-field mixing of $^7F_0$ with other multiplets, leading to typical branching ratios less than 1 percent. This has meant that even with Purcell enhanced dipole moments, single-ion detection of trivalent europium ions has not yet been achieved.

In some host systems, a combination of a large axial crystal-field and low-lying charge transfer states (CTS) result in the $^7F_0$ - $^5D_0$ transitions having greatly increased intensity. In some cases, so much so that it is the most intense transition. One of these such systems is the $C_{3v}(O^{2-})$ centre in CaF_2 where the oxygen charge compensation leads to a large axial crystal-field with a $^7F_0$ - $^5D_0$ dipole moment over a factor of three times greater than the same transition in YSO [3,4]. We have previously shown that we could model the equivalent site for erbium [5], and in this talk we will show that our crystal-field and intensity model is able to account for the effects induced by the low-lying CTS to accurately model the 4f - 4f transitions of this europium site. We will also discuss our work to scale this site from bulk crystal into nanoparticles that will be placed into a fibre optic based cavity with the hope of achieving single-ion detection of europium ions.

[1] M. Zhong, M.P. Hedges, R.L. Ahlefeldt, J.G. Bartholomew, S.E. Beavan, S.M. Wittig, J.J. Longdell, M.J. Sellars, *Nature* 517:177 (2015)
[2] C. Deshmukh, E. Beattie, B. Casabone, D. Serrano, A. Ferrier, P. Goldner, D. Hunger, H. de Riedmatten, *Optica* 10:1339 (2023)
[3] A. Silversmith, A. Radlinski, *Journal of Physics C: Solid State Physics* 18:4385 (1985)
[4] J. Bartholomew, Ph.D. thesis, Australian National University (2014)
[5] M. D. Moull, J. B. L. Martin, T. G. M. Newman, A. J. Jeffery, J. G. Bartholomew, J.-P. R. Wells, M. F. Reid, *Optical Materials X*, 24:100365 (2024)

Comparing the performance of practical two-qubit gates for individual ^{171}Yb ions in yttrium orthovanadate

M. Karimi[1], F. K. Asadi[1], S. C. Wein[1*] and C. Simon[1]
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Two-qubit gates such as Controlled-NOT (CNOT) gates are fundamental building blocks for quantum repeater protocols and distributed quantum computing. Solid-state rare-earth (RE) ion platforms have emerged as promising candidates for practical quantum computing due to their remarkable coherence properties. Whitin RE ions, ytterbium-171 ($^{171}Yb^{3+}$) ions stand out for their simple hyperfine structure and long nuclear spin coherence times, making them ideal spin qubits [1,2]. Among host materials, yttrium orthovanadate (YVO) offers high site symmetry and compatibility with nanophotonic cavity fabrication, enhancing its appeal for quantum hardware integration [3,4].

Despite recent progress, implementing efficient and high-fidelity CNOT gates between individual RE ions remains challenging. Addressing this, we theoretically investigate and compare three two-qubit gate schemes for individual Yb ions doped in YVO (Yb: YVO): (i) magnetic dipolar interactions, (ii) photon scattering off a cavity, and (iii) a photon interference protocol implemented with and without an optical cavity. We also develop a theoretical framework that incorporates noise effects to accurately compute gate and state fidelities.

Our analysis shows that the probabilistic photon interference approach achieves the best fidelity scaling with cooperativity and currently outperforms other schemes based on existing Yb: YVO technology. The photon scattering scheme offers near-deterministic operation but with slower gate speeds and less favorable fidelity scaling. The cavity-free magnetic dipolar interaction scheme enables fast, deterministic gates with moderate fidelity, contingent on close ion localization.

Beyond Yb: YVO, our theoretical tools are broadly applicable to other spin qubit platforms. These results provide critical guidance for experimental efforts aiming to realize CNOT gates between individual RE ions advancing the development of practical quantum computing [5].

[1] A. Tiranov et al., *Physical Review B,* **98**., 195110 (2018)
[2] J. M. Kindem et al., *Physical Review B,* **98**., 024404 (2018)
[3] J. M. Kindem et al., *Nature,* **580**., 201 (2020)
[4] C.-J. Wu et al., *Physical Review Applied,* **20**., 044018 (2023)
[5] M. Karimi et al., *arXiv:2410.23613* (2024)

High-resolution spectroscopy of single nuclear spins by microwave photon counting

J. Travesedo[1], Z. Huang[1], M. Debray[1], L. Pallegoix[1], P. Goldner[2], T. Chaneliere[3], S. Bertaina[4], D. Esteve[1], D. Vion[1], J. O'Sullivan[1], E. Flurin[1] and P. Bertet[1]
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[2] *Chimie ParisTech, PSL University, CNRS, Institut de Recherche de Chimie Paris, 75005 Paris, France.*
[3] *Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France.*
[4] *Aix-Marseille Univ. University of Toulon, IM2NP, 13013, Marseille, France.*

Recent demonstrations have highlighted the potential of single microwave photon counting as a powerful detection method for magnetic resonance experiments at the single-spin level [1, 2, 3]. In this work, we expand on this approach by performing high-resolution spectroscopy on a ^{93}Nb nuclear spin-9/2, addressed through a neighboring Er^{+3} electron spin impurity in a $CaWO_4$.

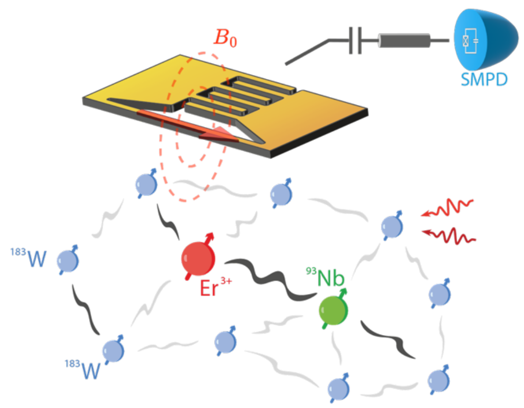

Figure 1: Scheme of experimental setup. A superconducting resonator is coupled to an Er^{3+} paramagnetic impurity, which in turn can address its proximal nuclear environment, which consists of a single ^{93}Nb and a bath of ^{183}W. Er^{3+} is measured via its fluorescence through an SMPD.

We generalize previously established readout, dynamic polarization, and spin-driving methods, originally developed for spin-1/2 nuclei, to high-spin nuclei.

Leveraging the long coherence of the ^{93}Nb spin, we achieve 1 Hz resolution on the nuclear transition frequencies. Through precise measurement and fitting of quadrupole-induced shifts in the ^{93}Nb-spin transition frequencies, we detect a distinct mismatch between the quadrupole tensors corresponding to the two electron-spin states We attribute this behaviour to an electron spin dependent quadrupole interaction whose origin lies in the mixing of Kramer's doublets under the application of an external magnetic field.

Additionally, we use Spin Echo DOuble Resonance (SEDOR) to measure both the Larmor frequency and magnetic dipole coupling between the ^{93}Nb spin and its neighboring nuclear spin environment, consisting entirely of ^{183}W with spin 1/2. We observe shifts in the Larmor frequency of up to 10,000 ppm between each other, which we tentatively attribute to chemical shifts induced by the presence of substituting Er^{3+} and ^{93}Nb species.

Moreover, using these ^{183}W spins as SEDOR probes, we measure their mutual couplings, with values as low as 77 mHz. Using these high-precision measurements of the inter-network coupling, we perform 3D reconstruction of their physical location in the crystal lattice.

[1] Z. Wang et al., *Nature*, **619**, 276–281 (2023)
[2] J. Travesedo et al, *Science Advances*, **11**, eadu0581, (2025)
[3] J. O'Sullivan et al, *Nature Physics,* in print, (2025). *Preprint : ArXiv:2410.10432*

Erbium crystals enhanced by Fabry–Pérot cavities

M. Selmani[1], A. Ulanowski[1], S. Rinner[1], J. Früh[1], F. Burger[1], F. Salamon[1], J. Schmitt, D. Lopriore[1], J. Pforr[1], N. Goel[1], A. Schäpers[1], B. Braumandl[1], A. Gritsch[1], K. Sandholzer[1], and A. Reiserer[1], Quantum Networks Group
[1]*Technical University of Munich, TUM School of Natural Sciences, Physics Department and Munich Center for Quantum Science and Technology (MCQST), Garching, Germany*

Erbium dopants are a promising platform for future quantum networks due to their coherent emission in the low-loss telecom band and their long spin coherence times. However, their intrinsically weak emission in both the optical and microwave domains poses a challenge for efficient control and detection. To overcome this, we employ high-Q resonators that enhance light–matter interactions [1] and enable precision spectroscopy down to the level of single emitters [2] and their surrounding nuclear spin environments [3,4].

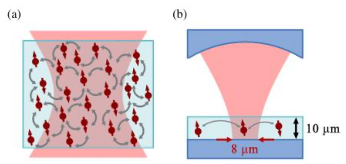

Figure 1. Spectroscopy of emitters at both a. ensemble and b. single ion scale embedded in a Fabry-Pérot cavity.

Thus, using optical echo envelope modulation (OEEM) [5], we recently investigated the superhyperfine interactions in an Er:YSO crystal embedded in a high-finesse Fabry–Pérot resonator. This configuration enables the observation of strong optical echoes even at ultra-low dopant concentrations, allowing us to resolve couplings to multiple nearby yttrium nuclear spins with unprecedented precision. These insights shed light on the structure of dense nuclear-spin environments and enable novel approaches to the detection and coherent control of individual nuclear spins in solids. Current efforts in this system focus on understanding and mitigating spectral diffusion.

In parallel with our single-dopant experiments, we explore erbium ensembles as a platform for coherent microwave-to-optical photon conversion— a key functionality for establishing coherent links between remote quantum nodes. Using a novel hybrid resonator design [6], we have reached the ultrastrong coupling regime in the microwave domain, which, combined with high-Q optical cavities, will bring efficient and reversible quantum transduction within reach.

These results advance our understanding of spin–photon interfaces in solid-state systems and open a path towards scalable quantum architectures that combine microwave and optical control for future quantum networks.

[1] A. Reiserer et al., *Rev. Mod. Phys.* ***94*****, 041003** (2022)
[2] A. Ulanowski et al., *Science Advances.* ***8, eabo4538*** (2022)
[3] A. Ulanowski et al., *Adv. Optical Mater.*, **12, 2302897** (2024)
[4] A. Ulanowski et al., *PRX Quantum* **6, 020344** (2025)
[5] B. Car et al., *Phys. Rev. Letter* **120, 197401** (2018)
[6] RR. Mett et al., *J. Magn. Reson.,* **307:106585** (2019)

Optical and spin characterization of Eu^{3+}-based organic molecular complexes for quantum information applications

V. Unni C.[1], E. Vasilenko[1], N. Jobbitt[1], J. Hessenauer[1], T. Neumann[2], B. Brachnakova[1], S. Kuppusamy[1], M. Ruben[1], M. Seitz[2], D. Hunger[1]

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[2] *Eberhard Karls University of Tübingen, Tübingen, Germany*

Rare-earth ion (REI) doped solid-state materials are promising candidates for quantum information applications due to their good optical and spin coherences making them ideal for optically interfaced spin qubits. Europium (Eu^{3+}) is an REI that demonstrated exceptional optical [1] and spin coherences [2]. Europium-based organic molecular complexes are proposed as a novel material platform that offers extended flexibility to tune optical and spin transitions, to define precisely arranged multi-qubit systems, and eventually large-scale quantum registers.

As a first, we report on the optical detection of the two hyperfine transitions of the ground state of Eu^{3+} at 4.2 K in a molecular complex which has previously demonstrated excellent optical coherence [3]. We characterise the spin inhomogeneous lines of both hyperfine transitions. Additionally, we coherently drive the nuclear spins to observe Rabi oscillations and report a spin coherence time of 613 µs at 4.2 K. The spin coherence is extended with dynamical decoupling up to 2 ms.

Further, we report characterisation of additional organic complexes showing similar or better optical properties. We observe an improved branching ratio of >1% in two of these complexes while maintaining good optical coherence times.

[1] R. M. Macfarlane et al., Phys. Rev. Lett. 72, 2179 (1994)

[2] F. Wang et al., PRX Quantum 6, 010302 (2025)

[3] D. Serrano et al., Nature, 603, 241 (2022)

Investigating inhomogeneous profile correlations between two optical transitions via SHB in $Er^{3+}:YSO$

F. Segur[1,2], A. Louchet-Chauvet[1], S. Welinski[2] and P. Berger[2]
[1]*Institut Langevin, CNRS, ESPCI, Université PSL, Paris, France*
[2]*Thales Research and Technology, Palaiseau, France*

Inhomogeneous broadening results from local variations in the environment of emitters, such as strain, electric fields, or defects in the crystalline matrix. This phenomenon plays a crucial role in techniques that involve Rare-Earth Ion-doped Crystals (REICs) [1], [2]. In this study, we investigate whether the inhomogeneous broadening profiles of two distinct optical transitions can exhibit similarities. To achieve this, we use Spectral Hole Burning (SHB) on the well-known $Er^{3+}:YSO$ crystal, focusing on transitions $^4I_{15/2} \to {}^4I_{13/2}$ and $^4I_{15/2} \to {}^4I_{11/2}$ operating at 1.5µm and 980nm, respectively. By applying SHB to one transition and simultaneously monitoring the spectral response of the other, we reveal some correlations in the optical behavior of these two transitions.

This approach enables us to uncover hidden relationships between transitions that are not accessible through conventional spectroscopy. By revealing such correlations, our experiment provides new insights into the local environment and the dynamics of the atomic ensemble.

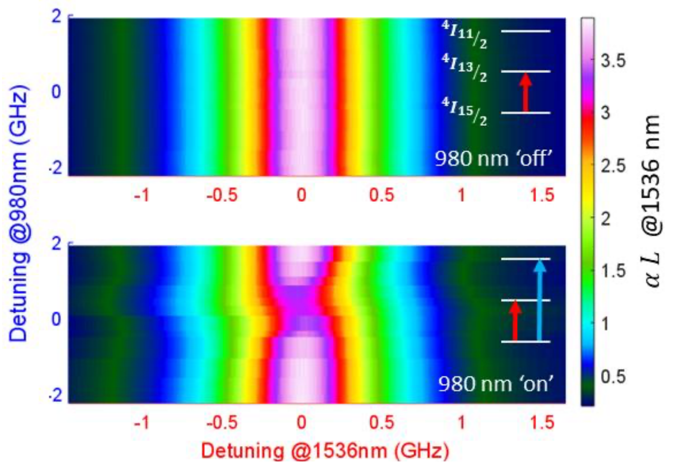

Figure: Optical absorption profile along the 1.5µm transition in $Er^{3+}:YSO$, without (top) or with (bottom) a preliminary pumping along the 980nm transition.

[1] M. Afzelius *et al.*, "Demonstration of atomic frequency comb memory for light with spin-wave storage," *Phys. Rev. Lett.*, vol. 104, no. 4, pp. 1–4, 2010, doi: 10.1103/PhysRevLett.104.040503.
[2] A. Louchet-Chauvet *et al.*, "Telecom wavelength optical processor for wideband spectral analysis of radiofrequency signals," *Laser Phys.*, vol. 30, no. 6, p. 066203, Jun. 2020, doi: 10.1088/1555-6611/ab88d9.

Spin decoherence dynamics of Er^{3+} in CeO_2 film

Sagar Kumar Seth,[1, 2] Jonah Nagura,[1] Vrindaa Somjit,[2] Aneesh Bapat,[1, 2] Xinhao Li,[3] Gregory D. Grant,[1, 2] Ignas Masiulionis,[1, 2] Xu Han,[3, 1] F. Joseph Heremans,[2, 4, 1] Giulia Galli,[1, 2, 5] David D. Awschalom,[1, 2, 4, 6] Supratik Guha,[1, 2, 4] and Jiefei Zhang[2,4]

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[6]Department of Physics, University of Chicago, Chicago, Illinois 60637, USA

Developing telecom-compatible spin-photon interfaces is essential towards realizing scalable quantum networks. Erbium ions (Er^{3+}) offer a unique combination of a telecom C-band optical transition and an effective spin-1/2 ground state. Erbium ions doped into bulk crystals such as $CaWO_4$, Y_2SiO_5, and YVO_4, have demonstrated milliseconds-long spin coherence times [1–4], enabling the demonstration of quantum technologies like microwave quantum memories [5]. However, bulk crystals pose limitations for device fabrication and integration. Therefore, the search for Er^{3+} spins in a solid-state host that simultaneously provides the ease of integration and exhibits lifetime-limited optical and spin coherence remains an open challenge.

To this end, we explore a new platform of Er^{3+}:CeO_2 films on silicon[6], offering low nuclear spin density (only 0.04% ^{17}O) and potential to host spins with long coherence [7]. The platform shows promising narrow optical homogeneous linewidth [8]. These, combined with its compatibility with silicon and controlled synthesis, make Er^{3+}:CeO_2 a compelling candidate for building opto-electrical quantum devices. We study the decoherence dynamics of Er^{3+} spins in this platform and demonstrate a 38.8 μs spin coherence time at ∼ 77 mK. The dominant decoherence process is spectral diffusion-induced Er^{3+} spin flips, primarily from Er-Er dipolar interactions, a strong process in CeO_2 due to its cubic crystal field symmetry. This finding is corroborated by both experimental observations and cluster correlation expansion calculations. We also discuss the possibility of further spectral diffusion suppression at lower temperatures and the effects of impurities, providing a route to enable millisecond-scale spin coherence times.

[1] M. L. Dantec et al., Sci. Adv., **7**, eabj9786 (2021).
[2] M. Raha et al., Nat. Commun., **11**, 1605 (2020).
[3] S. Welinski et al., Phys. Rev. Lett., **122**, 247401 (2019).
[4] T. Xie et al., Phys. Rev. B, **104**, 054111 (2021).
[5] S. Probst et al., Phys. Rev. B, **92**, 014421 (2015).
[6] G. D. Grant et al., APL Mater., **12**, 021121 (2024).
[7] S. Kanai et al., Proc. Natl. Acad. Sci. U.S.A., **119**, e2121808119 (2022).
[8] J. Zhang et al., npj Quantum Inf., **10**, 119 (2024).

Optical and spin coherent spectroscopy of Eu^{3+}:Y_2O_3 transparent ceramics

Shuping Liu[1,2], Miaomiao Ren[1,2], Wanting Xiao[1,2], Fudong Wang[1,2] and Manjin Zhong[1,2]

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Rare earth ions (REI) in solid materials are among the leading systems for quantum technology applications [1-2]. However, developing practical REI quantum devices with long-lived coherent states remains challenging due to great difficulties in growing high-quality REI materials and the incomplete understanding of their decoherence mechanisms. In this work, we report a long optical coherence time of 422 ± 11 μs for the $^7F_0 \rightarrow {}^5D_0$ transition, a lifetime exceeding 30 hours for the $^7F_0$ hyperfine spin states, as well as a spin coherence time of 183±71 ms in Eu^{3+}:Y_2O_3 optical ceramics. We identify for the first time the absence of TLS induced optical decoherence in such short-range-ordered crystals and a new decoherence mechanism caused by new kinds of perturbing magnetic centers below 1.5 K. Furthermore, we demonstrate coherent light storage over 5 μs by using the AFC protocol. These results provide a promising proof-of-principle demonstration of quantum memory using Eu^{3+}:Y_2O_3 optical ceramic system, highlighting its significant potential for practical quantum applications.

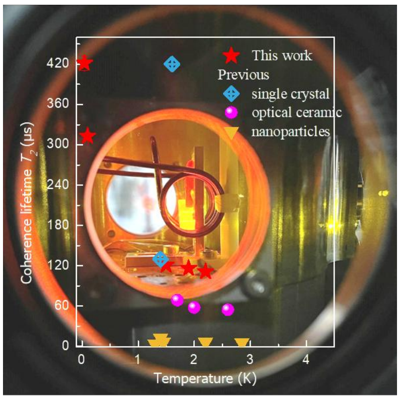

Figure 1: Experimental setup and the comparison of optical coherence times obtained in our work with various Eu^{3+}:Y_2O_3 nanoparticles [3], optical ceramics [4] and single crystals [5] that previously reported.

References:

[1] H. de Riedmatten, et al., *Nature*, **456**, 773 (2008).
[2] M. Zhong, et al., *Nature*, **517**, 177 (2015).
[3] S. Liu, et al., *ACS Nano*, **14**, 9953-9962(2020).
[4] N. Kunkel, et al., *Physical Review B*, **94**, 184301 (2016).
[5] R. M. Macfarlane, R. M. Shelby, *Optics Communications*, **39**, 169-171 (1981).

Spectroscopic investigations of an excited-state transition in Tm^{3+}: $YAlO_3$

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Despite extensive studies of ground-state transitions of rare-earth ions doped into inorganic crystals, excited-state transitions remain largely unexplored in the field of quantum information processing. In this work, we report spectroscopic and coherence properties of the excited-state transition between the lowest crystal field levels of the $^3F_4$ and the $^3H_4$ manifolds of thulium-doped yttrium aluminum perovskite (Tm:YAP) at cryogenic temperatures. The wavelength of this transition is at 1451.37 nm, which lies near the telecom C-band.

We find an inhomogeneous broadening of this transition of 1.29 GHz, and lifetimes of the higher-lying and lower-lying levels of 0.85 ms and 6.21 ms , respectively. We also
investigate spectral holes with varying magnetic fields from 0 to 2T, revealing hyperfine and superhyperfine structure. For coherence properties, we measure spectral hole widths as well as optical free induction decays (FID), yielding consistent results and a maximum optical coherence time of 1.1 μs when a 2T magnetic field is applied.

Our results suggest the possibility of exploiting excited-state transitions in REI doped crystals for applications of quantum information processing, including for single photon sources and quantum memory for light.

1.2 Wednesday 17th

A metropolitan-scale multiplexed quantum repeater with Bell nonlocality

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Existing metropolitan-scale quantum-repeater demonstrations have been confined either to single-photon entanglement [1] or to low-fidelity two-party entanglements [2], leaving nonlocality between far-separated atomic memories unobserved. I will report our recent realization of a metropolitan-scale multiplexed quantum repeater based on Eu:YSO memories deployed in the city Hefei. The heralded high-fidelity entanglement between two quantum memories separating by 14 km demonstrates a clear violation of the Bell inequality. I will also present photonic qubit storage exceeding five seconds, achieved in Eu:YSO at the ZEFOZ field.

[1] Jian-Long Liu et al., *Nature*, **629**, 579 (2024)
[2] Arian J. Stolk et al., *Sci. Adv.*, **10**, eadp6442 (2024)

Quantum Teleportation from Telecom Photons to Erbium-Ion Ensembles

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Quantum teleportation is one of the most important protocols in quantum communication and quantum information. The distribution of quantum states via quantum teleportation is a key ingredient for realizing the quantum internet. In order to integrate such quantum networks into existing fiber networks, entangled photons and quantum memories at telecom wavelength are necessary. Erbium is the ion of choice for this task, given that its optical transitions sit exactly within the C-band, offering the lowest photon loss in propagation.

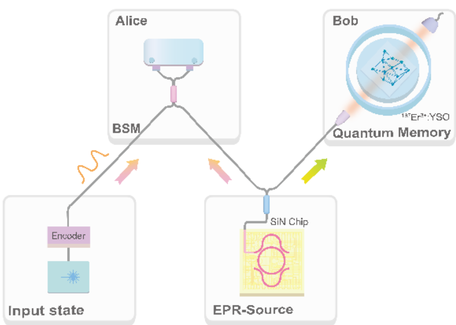

Figure 1: Quantum teleportation from telecom photons to erbium-ion ensembles.

Recently, $^{167}Er^{3+}$ ions have been identified as a promising candidate for an efficient, broadband quantum memory at telecom wavelength. However, to date, the quantum teleportation from telecom photons to a solid-state quantum memory based on $^{167}Er^{3+}$ ions, has remained elusive.

In this work, we experimentally demonstrate the quantum state teleportation from telecom photons to a solid-state quantum memory based on erbium-ion ensembles. Combining the naturally linewidth of the entangled photons generated from an integrated photonic chip and long life time of $^{167}Er^{3+}$ ions, we realize a storage time of more than 2 us. Using quantum-state-tomography and quantum-process-tomography protocols, we obtain an average quantum state fidelity of 81.8% and a quantum process fidelity of 73.6%, which significantly exceeds the classical bound.

[1] Y.-Y. An, Q. He, W. Xue, M.-H. Jiang, C. Yang, Y.-Q. Lu, S. Zhu, and X.-S. Ma, Quantum teleportation from telecom photons to erbium-ion ensembles, Phys. Rev. Lett., **135**, 010804 (2025).

Building Quantum Networks of Superconducting Circuits Mediated by Telecom Photons

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Quantum Technologies are meant to drive innovation in the future, with Quantum Computing, Communication, Networking and Sensing. Erbium ions in solid-state are poised to play an important role in the development of these platforms. Their Zeeman-split spin easily couples with standard superconducting circuits, and their optical transition naturally matches the telecom C-band (1550 nm). Researchers typically address either isolated ions or large ensembles, depending on the targeted technology. Single Erbium qubits display high coherence and can be networked through their optical degree of freedom, while large ensembles enable linear operations such as quantum memories and microwave-optical entanglement. The development of these applications depends critically on interfacing good Erbium hosts, such as the celebrated Calcium Tungstate, with powerful quantum technologies. In this talk, I will present our effort to interface highly-coherent Erbium ions with superconducting qubits, as well as with Lithium-Niobate on Insulator (LNOI) microring resonators.

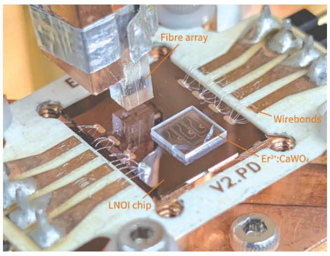

Figure 1 Close-up picture of a Lithium-Niobate on Insulator chip, bonded to $CaWO_4$, with wirebonded electrodes and with a fiber array

Our choice of LNOI is based on the availability of the materials in large format (beyond 6in wafers), known fabrication methods (Ar physical etch), and the availability of the electro-optic effect (in contrast with Si, SiN…). Our group successfully reproduced leading fabrication techniques of LNOI, reaching a Q-factor in excess of 10M, and successfully used direct bonding to couple to Erbium ions. Our work shows a clear path towards a cooperativity of 1 and beyond, with negligible internal losses.
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We also fabricated high-Q superconducting microwave resonators onto $CaWO_4$ and measured a strong collective coupling between our resonators and the ensemble of Erbium ions. This measurement is carried with quantum-limited Josephson Parametric Amplifiers, which can be leveraged towards generating entanglement between microwave photons and Erbium ions.

Finally, we have used our direct bonding technique to integrate $CaWO_4$ with Sapphire, so that our ensemble of Erbium ions can be made compatible with standard fabrication of Josephson junctions.

Thermodynamical versus optical coherence properties europium-doped Y_2SiO_5 below 1 K.

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Rare-earth doped crystals continue to play a central role in emerging quantum technologies, precision metrology, and optical signal processing, owing to their long-lived optical transitions. At sub-kelvin temperatures, the coherence properties of these materials can be significantly enhanced [1], but the underlying mechanisms limiting performance in this regime remain incompletely understood. In this work, we investigate the low-temperature behavior of a Czochralski-grown europium-doped yttrium orthosilicate (Eu:YSO) crystal, combining thermodynamic and optical measurements to assess its suitability for high-coherence applications [2].

We report heat capacity measurements down to millikelvin temperatures, which provide critical insight into the presence of two-level systems (TLS) — often associated with structural disorder — through a characteristic linear-in-temperature term. Such TLS might contribute to decoherence when phonon populations are suppressed below 1 K, potentially broadening homogeneous linewidths [3]. However, our heat capacity measurements allows us to place stringent upper bounds on the TLS contribution in our sample, confirmed by photon-echo lifetime measurements, which reveal a constant optical linewidth between 300 mK and 2 K.

Our findings suggest that Eu:YSO, when properly synthesized, exhibits minimal TLS-induced decoherence. This highlights not only the importance of careful crystal growth and characterization, but also the promise of ultralow-temperature operation for optimizing rare-earth based quantum devices. These results could be of particular interest to those developing these materials for quantum memories or frequency references.

[1] X. Lin, M. T. Hartman, B. Pointard, R. Le Targat, P. Goldner, S. Seidelin, B. Fang, and Y. Le Coq, *Anomalous subkelvin thermal frequency shifts of ultranarrow linewidth solid state emitters*, Phys. Rev. Lett. **133**, 183803 (2024).

[2] T. Klein, C .Marcenat, D. Serrano, P. Goldner, M. T. Hartman, B. Fang, Y. Le Coq, S. Seidelin, *Thermodynamics versus Coherence in Ultra Narrow Linewidth Optical Solid State Emitters*, **arXiv:2504.21422** (2025).

[3] X. Lin, M. T. Hartman, P. Goldner, B. Fang, Y. Le Coq, S. Seidelin, *Homogeneous linewidth behavior of narrow optical emitters at sub-kelvin temperatures*, Appl. Phys. Lett. **126**, 054101 (2025).

Thermal-noise limits to the frequency stability of spectral hole referenced lasers using Eu:YSO crystals

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Techniques in frequency stabilization of lasers to fixed-spacer optical cavities have advanced to the point where the ultimate frequency stabilities are limited by thermal noise for standard cavity configurations at room temperature. In early experiments, laser stabilization via spectral-hole burning (SHB) has been shown to be a promising alternative.

We report our investigations of the thermal-noise limits to frequency stability in spectral holes. and compile known material parameters for a typical system used in SHB experiments (Eu^{3+}:Y_2SiO_5) to make numerical estimates for the fundamental thermal-noise induced frequency instability in spectral-holes for the liquid-helium temperature and dilution temperature cases [1]. We also report cryogenic mechanical loss measurements, which is a crucial parameter allowing us to estimate an upper limit for the Brownian thermal noise [2].

Our findings indicate that Eu^{3+}:Y_2SiO_5 could be a promising candidate for future ultra-stable laser applications.

[1] M. T. Hartman et al., "Thermal-noise Limits to the Frequency Stability of Burned Spectral Holes", *APL* in press (2025).

[2] N. Wagner et al., "Temperature-dependent mechanical losses of Eu^{3+}:Y_2SiO_5 for spectral hole burning laser stabilization", *APL Materials*, **13,** 061107 (2025).

Microwave-to-optical transduction and many-body physics with $^{171}Yb^{3+}$ in YVO_4

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Coherent, low-noise conversion of microwave single photons to the optical domain is a promising pathway for entangling remote superconducting qubits via room-temperature links. In working towards this goal, we design systems with strong coupling between microwave cavities and rare-earth ion ensembles, often requiring dense atomic packing or large collective cooperativity. These conditions naturally give rise to direct or cavity-mediated interactions between the atoms, which are not only of fundamental interest for studying many-body physics, but also essential to understand and control for realizing practical quantum technologies. In this talk, I will present our recent progress on microwave-to-optical transduction using $^{171}Yb^{3+}$-doped crystals, focusing on both transduction performance and many-body physics enabled by these systems.

We first discuss our work with $^{171}Yb^{3+}:YVO_4$, where we achieve high doping levels (~400 ppm) while maintaining narrow inhomogeneous linewidths: ~100 MHz optically and ~150 kHz for the spin transition. Due to the large optical absorption, we employ a planar superconducting microwave cavity with a small mode volume. This design allows us to use a minimal crystal volume to prevent over-absorption while achieving a spin-resonator cooperativity exceeding unity. The resulting transducer demonstrates device efficiency around 1%, added noise of approximately 1.2 quanta, a bandwidth of 500 kHz, and kHz-level repetition rates. [1]

Beyond transduction, these platforms offer rich opportunities for exploring many-body physics. In YVO_4, we have used an optical cavity to demonstrate cavity-mediated dissipative dynamics, observing coherent-induced transparency (CIT) and superradiance. [2] More recently, we have observed direct spin flip-flop interactions between Yb ions in the spin domain. Leveraging the coherent nature and tunability of these interactions, we apply Hamiltonian engineering to control the system dynamics and observe signatures of a discrete time crystal. [3]

[1] T. Xie, R. Fukumori, J. Li, A. Faraon, *Nature Physics*, **21**, 931-937 (2025)
[2] M. Lei, R. Fukumori, … A. Faraon, *Nature* 617, 271-276 (2023)
[3] M. Lei, R. Fukumori, … A. Faraon, https://arxiv.org/abs/2408.00252 (2024)

Memory-assisted microwave-to-optical transduction

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Microwave-to-optical quantum transducers will enable coherent interconnection between distant superconducting quantum devices. Ongoing explorations with several platforms have shown promising results reaching the single-photon levels. However, in all these demonstrations, the elimination of noise due to intense pump pulses remains a challenge. Moreover, none of the demonstrations have shown on-demand quantum transduction with storage capabilities, which could be a way to mitigate noise associated with the pump pulses. Here, we integrate a quantum memory protocol with transduction in a three-level atomic system to demonstrate on-demand retrieval of transduced signals. Among the different approaches for transduction and quantum memory, rare-earth ion-doped crystals, due to their coherence properties, inhomogeneous broadenings, and strong effective second-order nonlinearities are promising candidates. We use a 5 ppm doped Yb:YSO crystal at 30 mK temperature due to its zero-first-order Zeeman (ZEFOZ) transitions at zero magnetic fields. We achieve on-demand transduction assisted by memory with 0.45 (0.2) noisy photons in the detection window at a storage duration of 460 (700) µs. Further, multimode transduction capacity is demonstrated, utilizing the spin and optical inhomogeneous broadenings.

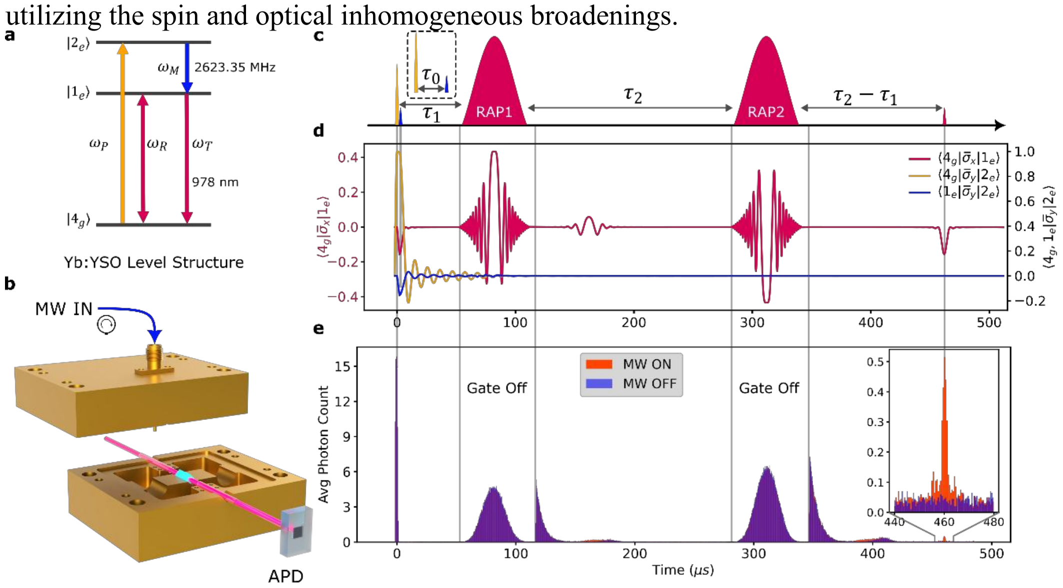

Figure 1: ***Protocol Sequence****.* ***(a)*** *Relevant three-level system in Yb:YSO with excited state spin transition showing respective color-coded transitions used in* ***c****.* ***(b)*** *Experimental setup showing Yb:YSO crystal (cyan) kept at the centre loop of a 3D loop-gap resonator. SMA antenna pin couples MW in and out via an isolator. A pair of grin lenses are used for optical coupling through the crystal.* ***(c)*** *Schematic of pulse sequence. Intense pump pulse (yellow) is followed by a weak coherent microwave pulse (blue) after a time τ_0. RAP1 and RAP2 pulses (red) of duration τ_R are applied after τ_1 from the pump pulse and after τ_2 from RAP1 respectively. Transduced optical echo (red) is emitted at $\tau_2 - \tau_1$ from RAP2. Total storage time is $\tau_2 + \tau_R$.* ***(d)*** *Simulated evolution of relevant coherences excited by the corresponding color pulses. Coherence in $\langle 4_g|\bar{\sigma}_x|1_e\rangle$ is a result of two-pulse excitation which is then rephased with RAP1 and RAP2.* ***(e)*** *Histogram of 200-cycle average transduced optical photon counts with 500 ns bin-width. Tall bar at $t = 0$ is the leaked part of the pump pulse. Leaked RAP1 and RAP2 are seen in the gate off windows. Decaying counts after the RAP pulses are the corresponding free-induction decay. Transduced echo is visible when the microwave is on. (Inset) Zoom-in view around the transduced echo showing signal versus the noise floor.*

[1] J. O'Sullivan et al., *Physical Review X,* **12.4**, 041014 (2022)
[2] T. Xie et al., *Nature Physics,* 1-7 (2025)
[3] L. Nicolas et al., *npj Quantum Inf* **9**, 21 (2023)

Emergent quantum coherence in random rare earth magnets probes slow quantum dynamics

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Local excitations in magnetic materials are usually highly incoherent, since they dephase very quickly due to mutual interactions. However, there are interesting exceptions to this common lore. Our joint experimental and theoretical study of the random rare-earth magnet $LiY_{1-x}Tb_xF_4$ [1] reveals that a combination of hyperfine interactions, external magnetic fields and substantial disorder allows excitons on pairs of Tb sites to retain coherence for remarkably long times, as they can be well shielded from the dominant decoherence channels.

Figure 1: Pairs of rare earth ions are highly coherent despite their noisy environment

The remaining decoherence turns out to probe the slow dynamics in the neighborhood of these degrees of freedom, which thus act as quantum sensors.
This is particularly interesting as a means to probe the nearly many-body localized dynamics of strongly disordered dipolar magnets.
The dephasing of similar excitons in much denser, strongly correlated materials (e.g. $Tb_2Ti_2O_7$ [2]) opens a new route to studying interactions and correlations.

[1] A. Beckert et al., *Nat. Phys.,* **20**, 472, (2024).

[2] R. Mankowsky et al., *Nat. Comm.,* **15**, 7183 (2024).

Piezospectroscopic sensitivity of Erbium

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A quantum memory using the extremely long-lived coherence time of the rare-earths, offers a unique way to overcome the photon loss of traditional transmission methods [1]. By storing large numbers of photonic modes, transporting the memory to the destination, and reading out the states with high efficiency, such a quantum memory has applications in quantum communication and fundamental science. With coherence times approaching one day [2], there is the opportunity to reduce photon transmission loss for distances over 100 km by at least an order of magnitude compared to fibre or satellite communication.

There are many challenges to be overcome to implement a useful memory for transporting photons. In this paper, we explore one limitation: the effect that stress, arising from vibration or acceleration, will have when the memory is moved. In this talk we discuss measurements of the piezo-spectroscopic stress tensor of Er^{3+}:Y_2SiO_5.

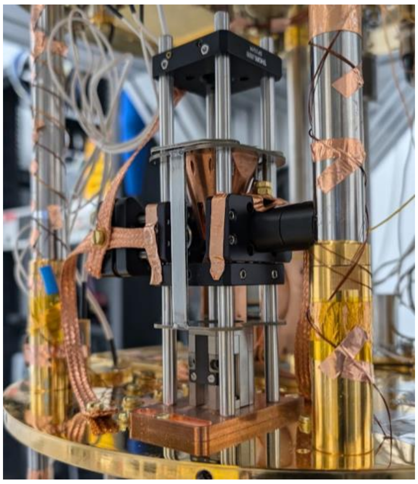
Figure 1. Stress apparatus. A nanopositioner is used to lower a series of weights onto the sample, which is probed by a double-pass laser absorption measurement.

We use a method similar to that described by Seidlin et. al. [3,4], whereby a narrow spectral feature is prepared using optical pumping and its shift observed as a function of weight resting on the sample. This method allows both high frequency resolution as well as a well calibrated source of strain on the sample. We will discuss the modifications to [3,4] to allow operation at <1 K in a closed cycle cryostat.

During the course of these measurements, we have observed spectral holes with lifetimes exceeding 100 s at a non-zero magnetic field below 1 mT. This regime [5] is of particular interest as it is readily accessible using small permanent magnets, and has been found to be temperature insensitive up to 4 K.

[1] J. Bland-Hawthorn, et al., "Quantum memories and the double-slit experiment: implications for astronomical interferometry," J. Opt. Soc. Am. B, 38, 7, 2021.
[2] F. Wang, et al., "Nuclear Spins in a Solid Exceeding 10-Hour Coherence Times for Ultra-Long-Term Quantum Storage," PRX Quantum, 6, 1, 010302, 2025.
[3] S. Zhang, et al., "Inhomogeneous response of an ion ensemble from mechanical stress," Phys. Rev. Research, 2, 1, 013306, 2020.
[4] N. Galland, et al., "Mechanical Tunability of an Ultranarrow Spectral Feature of a Rare-Earth-Doped Crystal via Uniaxial Stress," Phys. Rev. Applied, 13, 4, 044022, 2020.
[5] S. R. Hastings-Simon et al., "Zeeman-level lifetimes in Er^{3+}:Y_2SiO_5," Phys. Rev. B, 78, 8, 085410. 2008,

Strain engineering for Er^{3+} emitters coupled to Y_2O_3 membranes

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To propel the rapid development of quantum networks, establishing a reliable spin-photon interface for distributed quantum computing is crucial. One approach is through incorporating single-atomic defects in the solid state such as with rare-earth ions (REIs)[1]. REIs are strong emergent contenders due to their narrow and coherent transitions in both the optical and microwave domains[2]. Among the REIs, Erbium Er^{3+} and Ytterbium Yb^{3+} ions are of particular interest for interfacing with superconducting circuits through their electronic spin degrees of freedom. Moreover, their optical and spin coherent properties[3] in the near infrared and telecom bands and the possibility of nanophotonic integration make them a strong candidate for achieving scalable spin-photon interfaces. In our work, we have fabricated suspended thin-film microstructures of various geometries doped with Er^{3+} ions housed in a Y_2O_3 polycrystalline matrix. The thin-films are deposited via double-liquid injection chemical vapor deposition (DLI-CVD) directly on silicon. We observe a strain-dependent shift in the wavelength of the Er^{3+} ion emission coupled to the suspended microstructures of up to 80 GHz, exhibiting Er^{3+} : Y_2O_3 thin films as a promising platform for hybrid optomechanical coupling[4,5]. Ultimately, with this work we envision heterogeneous integration of the strain-free films with nanophotonic platforms such as silicon-on-insulator (SOI) or lithium niobate-on-insulator (LNOI) directly by fabrication or with transfer printing techniques for interfacing the REI spin and optical coherent properties. This brings novel functionalities on a chip, allowing implementation of integrated quantum memories and optical-to-microwave quantum transduction.

[1] L. Yang *et al,* Controlling single rare earth ion emission in an electro-optical nanocavity, *Nat. Commun.* **14**, 1718 (2023).

[2] T. Zhong, P. Goldner, Emerging rare-earth doped material platforms for quantum nanophotonics, *Nanophotonics*, **8**, 11, (2019).

[3] A. Ortu *et al.,* Simultaneous coherence enhancement of optical and microwave transitions in solid-state electronic spins, *Nat. Mat.* **17** (8), 671–675 (2018).

[4] K. Mølmer *et al.,* Dispersive coupling between light and a rare-earth-ion–doped mechanical resonator, *Phys. Rev.* A **94** (2016).

[5] R. Ohta *et al.* Rare-Earth-Mediated Optomechanical System in the Reversed Dissipation Regime, *Phys. Rev. Lett.* **126** (2021).

Coherent Optical and Spin Spectroscopy of $^{171}Yb^{3+}$:$CaWO_4$ Crystals at Varying Dopant Concentrations

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[3] *CNRS, Aix Marseille Univ, Université de Toulon, Institut Matériaux Microélectronique et Nanosciences de Provence, IM2NP, 13013 Marseille, France*

Quantum memories are essential building blocks of quantum technologies, especially in quantum communication and quantum computing systems. They allow to store quantum information, carried by single photons, and retrieve it on demand [1]. This is especially important for synchronizing quantum operations and extending communication distances in quantum networks. Rare-earth ion-doped crystals offer an advantageous combination of long-lived optical and spin coherence, narrow inhomogeneous broadening, and compatibility with integrated photonic structures [2-4].

Among rare-earth ions, ytterbium-171 isotope ($^{171}Yb^{3+}$) is particularly advantageous due to its simple hyperfine structure, with nuclear spin of I = 1/2 and magnetically insensitive clock transitions at zero or low magnetic fields. Moreover, the optical transition between $^2F_{7/2}(0)$ ground state and the $^2F_{5/2}(0)$ excited state occurs near 973 nm, a wavelength compatible with existing photonic technologies [5-7]. When embedded in low-nuclear-spin hosts like calcium tungstate ($CaWO_4$), these ions offer a favorable environment for preserving quantum coherence over long timescales [8].

In this work, we investigate the coherent optical and spin properties of $^{171}Yb^{3+}$:$CaWO_4$ crystals at varying dopant concentrations. First, we performed spectral hole burning (SHB), focusing on the orthorhombic D_2 site symmetry, a crystallographic site not explored in earlier studies [8]. We extracted hyperfine splittings in both ground and excited states and observed long-lived spectral holes. We then concentrated on the comparison with lower-doped crystal, where reduced ion-ion interactions are expected to improve coherence properties. Optical absorption measurements revealed narrower inhomogeneous linewidths, and spin coherence times up to 0.23 s were observed, confirming excellent spin stability in this host. Finally, we implemented the Atomic Frequency Comb (AFC) quantum memory protocol, demonstrating suitability of this platform for time-multiplexed quantum storage. Our results represent an advancement in exploring and optimizing the $^{171}Yb^{3+}$:$CaWO_4$ crystal for various quantum technologies including ensemble-based memories and microwave-to-optical transducers, and integrated single ion spin-photon interfaces.

[1] Z.-Q. Zhou et al., *Laser Photon. Rev.*, **17**, 2300257 (2023).
[2] M. Le Dantec et al., *Sci. Adv.*, **7**, 51 (2021).
[3] M. Businger et al., *Nat. Commun.*, **13**, 6438 (2022).
[4] A. Ruskuc et al., *Nature*, **602**, 408–413 (2022).
[5] S. Welinski et al., *Phys. Rev. X*, **10**, 031060 (2020).
[6] M. Businger et al., *Nat. Commun.*, **13**, 6438 (2022).
[7] L. Nicolas et al., *npj Quantum Inf.*, **9**, 21 (2023).
[8] A. Tiranov et al., *arXiv:2504.01592* (2025).

Rare earth-diamond hybrid structures for quantum technologies

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Nitrogen-vacancy (NV^-) centers in diamond offer a mature platform for quantum sensing, owing to their long spin coherence times and optically addressable ground state. Nevertheless, their emission in the visible range, combined with spectral diffusion, limits their scalability and integration in photonic and telecommunication devices.

Rare-earth (RE) ions, by contrast, feature optically stable, atom-like transitions with sub-GHz linewidths, including the 1.5 µm telecom band transition of Er^{3+}. However, Er^{3+} cannot be incorporated into the diamond lattice due to fundamental chemical incompatibility, preventing direct integration. To address this, we introduce a thin-film-based architecture [1] in which RE ions and NV^- centers can be brought into close proximity while preserving their coherence properties. By harnessing RE-NV^- interactions, these hybrid structures may lead to new functionalities that combine the unique properties of both centers.

Er^{3+}:Y_2O_3 thin films are deposited by chemical vapor deposition onto diamond substrates hosting shallow NV^- ensembles created by focused ion beam implantation [2]. We demonstrate that the Y_2O_3 overlayer enhances NV^- spin coherence times, suggesting a reduction in surface-induced decoherence mechanisms. Concurrently, optical spectroscopy of Er^{3+} ions at cryogenic temperatures reveals an inhomogeneous linewidth of 8 GHz for the Y_1 - Z_1 transition at the C_2 site, consistent with high crystalline quality. These results establish RE-doped oxide films on diamond as a viable platform for hybrid quantum devices, enabling new functionalities in spin–photon interfaces and integrated quantum networks.

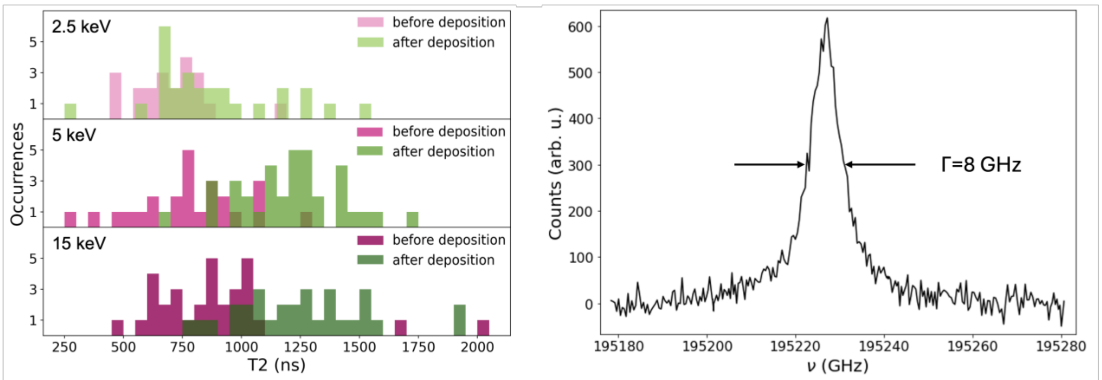

Figure 1: (Left) Spin coherence times of NV^- centers before and after Y_2O_3 thin film deposition for implantation energies of 2.5, 5, and 15 keV. (Right) Photoluminescence excitation spectrum of the Er^{3+} Y_1 - Z_1 transition at the C_2 site in Y_2O_3 at 3.5 K.

[1] I.G. Balas et al., *Adv. Optical Mater*, **12**, 2401487 (2024)
[2] J. Al Yahya et al., *to be published*.

1.3 Thursday 18th

Towards broadband coherent manipulation of rare-earth spins in $CaWO_4$

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The spin states of rare-earth ions doped into crystals offer a promising platform for quantum memories due to their long coherence times and frequency compatibility with superconducting quantum circuits. We investigate dilute ensembles of Er^{3+} and Yb^{3+} ions in $CaWO_4$ crystals at millikelvin temperatures using broadband electron spin resonance spectroscopy with superconducting coplanar waveguides, enabling precise mapping of their zero-field and low-field spin transition spectra. Hyperfine and quadrupolar interactions (arising from the $I = 7/2$ nuclear spin of ^{167}Er and the $I = 1/2$ of ^{171}Yb) give rise to a rich microwave spectrum below 4 GHz, from which we identify Zero First-Order Zeeman (ZEFOZ) shift transitions. Figure 1 shows such broadband spectrum of natural abundance erbium with the external magnetic field applied along the crystalline c-axis. By measuring the coherence properties of individual hyperfine spin transitions, we find Hahn echo coherence times of tens of microseconds to milliseconds. Our broadband spectroscopy approach thus enables not only the fitting of the full spin Hamiltonian but also the identification and validation of long-lived spin transitions, representing a crucial step towards coherent control and the implementation of rare-earth-based quantum memories.

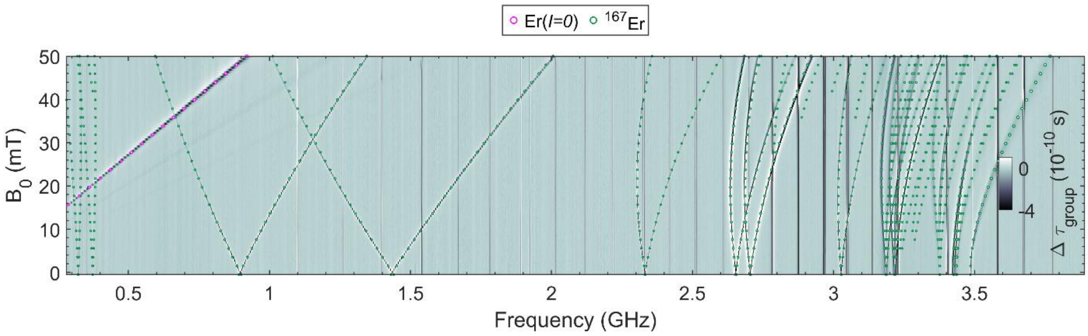

Figure 1: Broadband ESR spectroscopy of Er:$CaWO_4$. Fitting of low-field hyperfine transitions by the effective spin Hamiltonian allows for the determination of the characteristic material parameters entering the Hamiltonian.

We acknowledge support by the German Research Foundation via Germany's Excellence Strategy (EXC-2111- 390814868) and the German Federal Ministry of Education and Research via the project QuaMToMe (Grant No. 16KISQ036).

Toward highly efficient integrated quantum memories in rare earth doped crystals

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Rare-earth (RE) doped crystals are a promising platform for quantum memories. At cryogenic temperatures, they exhibit narrow optical transitions and long hyperfine coherence time[1], while maintaining large inhomogeneous absorption lines, allowing for higher degrees of multiplexing. However, current storage experiments in bulk RE-doped crystal show limited efficiency for long storage time due to low absorption [2] and poor light-matter interaction strength, particularly because of free space beam divergence when optically long samples are required[3]. Using waveguides in RE-doped crystals is a promising solution to enhance memory performance: contrary to free-space propagation, the optical Rabi frequency stays constant along the waveguide. Structure length can then be easily extended to match the desired absorption depth needed to reach maximum storage efficiency [3]. The waveguide form-factor also eases scalability, as arrays of fibers can be cryogenically coupled to arrays of integrated memories, enabling high spatial multiplexing and technological scaling up [4]. For this reason, various techniques for fabricating integrated quantum memories in RE ensembles have been explored, such as Femtosecond Laser Machining, Ion-beam Etching or integration with the Lithium Niobate platform [4]. These techniques show different compromises between conserving bulk performances, coupling with surface ions via evanescent fields [5], optimization difficulty and versatility to accommodate complex functions, such as couplers, curvatures or cavities .

In this talk, we present a new solution for getting integrated photonic stuctures in the RE-doped material. We report on the fabrication of single-crystalline Y_2SiO_5 (YSO) waveguides based on YSO/glass heterostructure adhesion [6], with the final carving step being performed with dicing or dry-etching. This process can provide a promising solution to the issues encountered in integrated memories. Those structures, made directly from bulk crystals, are designed to preserve the bulk properties as the injected light interacts with deeply nested ions less sensitive to external perturbations. It also serves as a foundation for more complex integrated photonic structures. We describe our recent progress on the different steps of the fabrication method, with a particular emphasis on polishing, bonding, flatness measurement as well as dry-etching results. Relevant methods and results will be highlighted from our recent paper [7]. Additionally, we will showcase the optical characterization of ridge waveguides with the

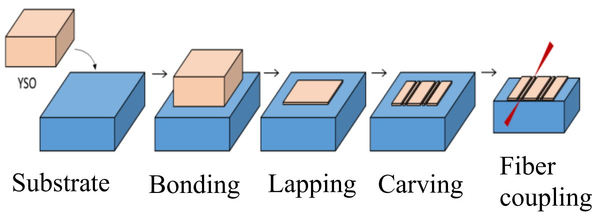

Figure 1: Fabrication process flow of crystalline waveguides

carving step performed using high precision dicing. Spectroscopy at low temperatures in crystalline waveguides is currently in progress. Finally, a theoretical discussion on the improvement of integrated quantum memories for spin-wave AFC, regarding temporal multiplexing in particular will be held.

[1] M. Zhong et al., *Nature*, **517**, no 7533, p. 177- 180, (2015).
[2] Y. Ma et al., *Nat. Commun*., **12**., 2381 (2021)
[3] M.Afzelius et al., *Phys.Rev.A,* **79**., 052329 (2009)
[4] Jing et al., *Appl. Phys. Rev.* **11.**, 031304 (2024)
[5] Ourari et al., *Nature* **620**, no 7976, p. 977-981 (2023)
[6] A.Talneau et al., *Physica status solidi (a)*, **221**, no 5, 2300718 (2024)
[7] A.Talneau et al., J. Vac. Sci. Technol. A **43**, 043002 (2025)

Dynamically decoupled storage of single photons in a Pr3+:YSO quantum memory

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The realization of large-scale quantum networks requires the distribution of entanglement over large distances [1]. Such quantum networks will rely on quantum memories to store entanglement while it is distributed over the full quantum network [2]. The realization of an efficient, yet long-lived and multimode memory is one of the challenges this architecture proposes. Solid-state quantum memories offer an intrinsically multimode storage in many degrees of freedom [4], and can be made highly efficient when embedded in a cavity [5]. However, the achievable communication distance is bounded by the storage time, that needs to exceed the photon travel time over the network links. In this talk I will present an important step towards a long-lived quantum memory, showing the first dynamically decoupled storage of single photons in an atomic ensemble, specifically on a Pr-doped YSO crystal.

Dynamical decoupling is a technique used to increase the spin coherence by dynamically correcting for the decoherence induced by the spin inhomogeneous broadening and spectral diffusion. It consists on a series of RF pulses sent during the storage of the photon in the spin state, that effectively decouples it from its environment, thus allowing for longer storage times. This has been demonstrated in using attenuated pulses in other rare-earth species, where storage times in the millisecond range were achieved [6]. In this work, we prove dynamically decoupled storage of heralded single photons generated by SPDC source. At 90µs of storage time in the spin state we show a second-order cross-correlation $g^{(2)}_{DD}$ of 4.8±0.4, and remained above the non-classical bound of 2 for 160µs of storage time. This is the longest storage of single photons recorded in a Pr-doped crystal, and the first dynamically decoupled storage of single photons in any atomic ensemble. This opens the way for long distance entanglement with high rates, and is a significant step towards a real quantum network.

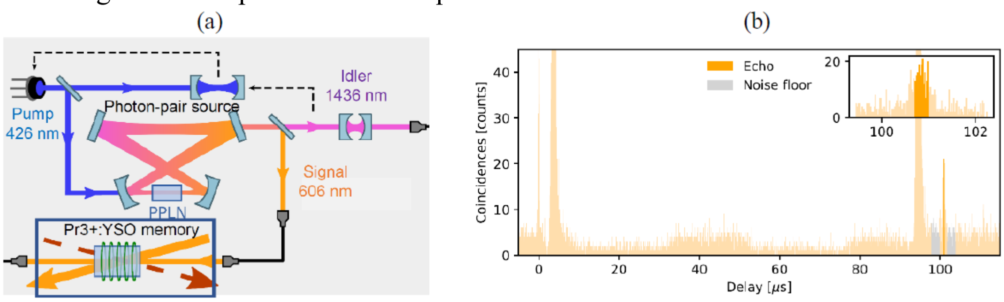

Figure 1: (a) Sketch of the setup used in the experiment, involving a cavity-enhanced SPDC photon pair source and a quantum memory inside a cryostat. A coil surrounding the memory sends the RF pulses necessary for dynamical decoupling (b) Spin-wave echo of dynamically decoupled single photons stored in a solid-state quantum memory.

References

[1] Duan, LM., Lukin, M., Cirac, J. et al. Nature 414, 413–418 (2001).
[2] Lago-Rivera, D., Grandi, S., Rakonjac, J.V. et al. Nature 594, 37–40 (2021).
[3] Ortu, A, Rakonjac, J.V. et al. Quantum Science and Technology 7.3: 035024 (2022).
[4] Duranti, Stefano, et al. *Optics Express* 32.15: 26884-26895 (2024).
[5] Ortu, A., Holzäpfel, A., Etesse, J. & Afzelius, M. npj Quantum Inf 8, 29 (2022).

Towards a functional quantum repeater link using Pr3+:YSO quantum memories

F. Appas[1], A. E. Rodríguez-Moldes[2], J. Hänni[1], A. Das[1], L. Feldmann[1], M. Teller[1], S. Grandi[1], H. de Riedmatten[1,2]

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Future quantum networks will rely on the distribution of entanglement between distant matter quantum nodes [1]. Physical requirements for operating in a quantum network include heralding at telecom wavelengths, high heralding rate, resilience against optical losses, multimode operation, on-demand read-out of the stored entanglement and encoding in a functional basis. In that regard, rare earth-doped crystals are prominent candidates for quantum network nodes thanks to their large multiplexing capacity in several degrees of freedom [2], long spin/optical coherence times [3,4] and high storage efficiency [5].

In this work, we present ongoing progress towards functional entanglement between solid-state multimode quantum memories (QM) based on praseodymium-doped crystals heralded by cavity-enhanced SPDC photons at telecommunication wavelengths. We demonstrate a dual-rail quantum node architecture where photons generated by a cavity-enhanced SPDC source are successively stored in two spatial modes of the QM with the use of beam displacers (BD) and fast switching Pockel cells (PC). We operate the dual mode QM in on-demand spin-wave storage and measure signal/idler cross-correlations well above 2 for both modes, compatible with non-classical correlations. Together with the high heralding rates (510 cps) of the SPDC sources [6], our architecture represents a promising route to the realization of practical quantum repeater links.

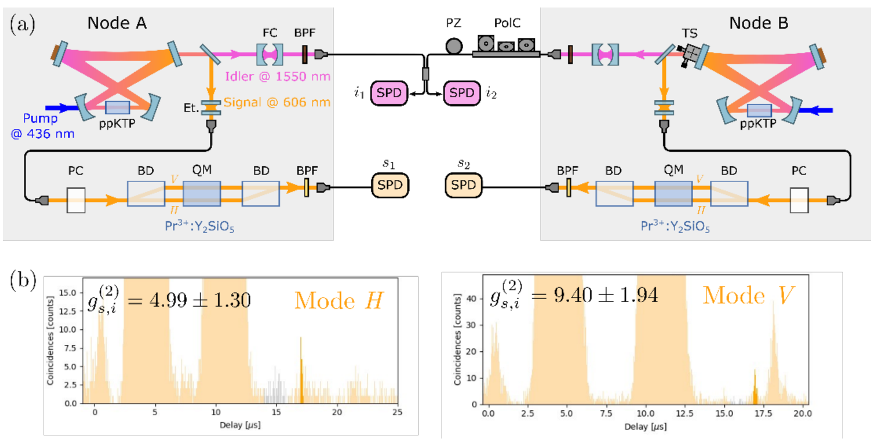

Figure 1. (a) Experimental setup for functional quantum repeater link architecture. (b) Measured signal-idler cross correlation for both modes of the dual-rail spin-wave QM at node A.

References:
[1] Duan, LM., Lukin, M., Cirac, J. et al. Nature 414, 413–418 (2001).
[2] Teller, M., et al. npj Quantum Inf 11, 92 (2025).
[3] Ortu, A., Holzäpfel, A., Etesse, J. & Afzelius, M. npj Quantum Inf 8, 29 (2022).
[4] E. Rodriguez-Moldes, A et al., *in preparation*
[5] Duranti, S. et al. Opt. Express, OE 32, 26884–26895 (2024).
[6] Hänni, J. et al. arXiv.2501.04131 (2025).

Transportation-Based Quantum Repeaters for Global Distribution of Entanglement.

E. Lundblad[1], M. Abu Yahia[1], A. Walther[1], A. Kinos[1], and L. Rippe[1]
[1]*Lund University, Lund, Sweden*

Rare-earth ions are considered strong candidates for quantum repeaters, which are essential components in achieving distributed quantum computing and a global quantum cryptography network. However, realizing such a network in practice remains a challenge due to the large number of repeater nodes required for long-distance communication, particularly in fiber-based schemes. Here, we propose a scheme for entanglement distribution based on the physical transportation of qubits in a satellite. We show that it is possible to create a link of entangled EPR pairs between the satellite and a ground station using heralded entanglement generation. With the satellite traveling to a new destination, a second link can be generated at a new ground station, allowing us to establish a link between the ground stations themselves using deterministic entanglement swapping. The possible rate of distributing entanglement is discussed, taking realistic losses of free-space communication into account.

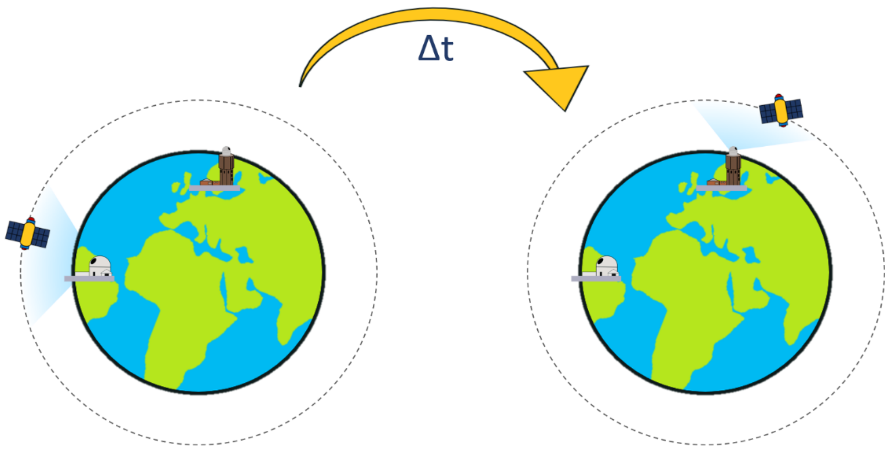

Figure 1: A quantum repeater network for distributing entanglement between two ground stations. First, a link is generated between the satellite and one of the ground stations through heralded entanglement generation. The satellite travels to a new station and a second link is established with the satellite. Through deterministic entanglement swapping of the links, the two ground stations become entangled.

2 Posters

2.1 Tuesday 16th: Singles and Materials

Characterization of Single Erbium ions in Lithium Niobate for Quantum Network Applications

Luca Mastrangelo,[1] Annalise Lennon,[1] Emanuele Urbinati,[1] Gaia Da Prato,[1] Yong Yu,[1] and Simon Gröblacher [1]

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The realization of a rare-earth-ion-based quantum network requires the development of an on-demand source of single, indistinguishable photons. While rare-earth ions have shown significant promise for quantum memory and repeater applications, their viability as efficient single-photon sources remains to be fully demonstrated. In this work, we investigate the properties of individual erbium ions implanted in X-cut lithium niobate crystals. By integrating silicon photonic crystal cavities onto the crystal surface, we achieve coupling to single ions and characterize key photonic properties including brightness, purity and coherence. We present measurements under varying temperature, electric, and magnetic field conditions, offering insights into the suitability of this platform for scalable quantum networking.

Exploring the Limit of Spectral Stability of Erbium Dopants

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Second-long spin coherence [1], photon emission in the minimal-loss window of optical fibers and the potential for high scalability make erbium dopants in solids an exceptional candidate for a future quantum networks platform [2].

In this approach, an interaction between remote erbium spins will be mediated by photons. This requires the emitters to exhibit 1) lifetime-limited optical coherence, 2) spin coherence times that far exceed the optical lifetime, 3) coherent control over the optical and spin states, 4) a spectral stability sufficient to emit indistinguishable photons, and 5) highly efficient photon outcoupling.

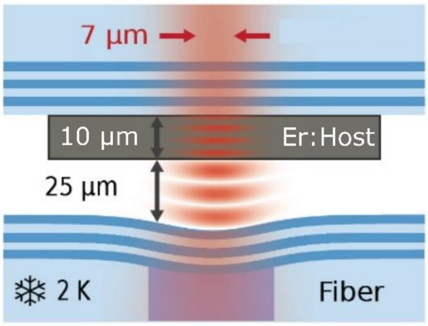

Figure 1: Schematic view of erbium-doped host membrane in tunable high-finesse Fabry-Perot resonator. Due to the large distance of the emitters from interfaces, unprecedented spectral stabilities can be achieved.

To meet these requirements, we use tunable high-finesse Fabry-Perot resonators [3], in which we spectrally resolve and manipulate the electron spin of hundreds of individual erbium dopants [4], and control nuclear spin states of ^{167}Er with coherence times exceeding 0.2 seconds [5].

Our Fabry-Perot design enables Purcell-enhancement-factors of currently up to 120 [4]. While this value is smaller than what can be achieved in nanophotonic resonators [6], the larger distance of the emitters from interfaces reduces perturbations and allows us to achieve spectral lines that are much narrower than those of other solid-state emitters. Our recent progress on this topic will be presented in this poster.

The excellent coherence properties of erbium nuclear spins and record-narrow spectral lines combined with recent advances in entanglement generation with rare earth emitters [7, 8] mark a significant step forward for rare-earth-based, long-distance quantum networking experiments.

[1] M. Rancic, M. P. Morgan, R. L. Ahlefeldt & M. J. Sellars, *Nat. Phys.*, **14**, 50-54 (2018).
[2] A. Reiserer, *Rev. Mod. Phys*. **94**, 041003 (2022).
[3] B. Merkel, A. Ulanowski & A. Reiserer, *Phys. Rev. X,* **10**, 041025 (2020).
[4] A. Ulanowski, J. Früh, F. Salamon, A. Holzäpfel & A. Reiserer, *Adv. Optical Mater.,* **12,** 2302897 (2024).
[5] A. Ulanowski, J. Früh, F. Salamon & A. Reiserer, *in preparation*.
[6] S. Ourari, Ł. Dusanowski, S.P. Horvath et al., *Nature* **620**, 977–981 (2023).
[7] A. Ruskuc, C. J. Wu, E. Green et al., *Nature* **639**, 54–59 (2025).
[8] M. T. Uysal, Ł. Dusanowski, H. Xu et al., *Phys. Rev. X,* **15**, 011071 (2025).

Single-photon emitters based on thulium-doped lithium niobate

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We investigate trivalent thulium ions embedded in a lithium niobate crystal (Tm^{3+}:LN) as a platform for deterministic single-photon emission at 795 nm and 1450 nm wavelengths with the aim of later implementing them in a quantum repeater protocol. We Purcell-enhance the photon emission at each transition using nanocavities that we fabricate in the cleanroom.

For the 1450 nm transition, we fabricate nanocavities in Silicon-on-Insulator (SOI) chips that are then placed on top of a bulk LN crystal with a pick-and-place technique. Then, via edge-coupling with a lensed fiber, we inject light into the cavities designed with a cavity-mode extending to the LN crystal and thereby coupling to the Tm^{3+} ions near the Si-LN interface. Early results include Purcell-enhanced emission at 1450 nm with cavities of loaded quality factors near $6 \cdot 10^4$ (measured on the SOI chip).

On the other hand, for the 795 nm transition, we cannot use Si as the material for the nanocavities because the photons would get absorbed. Therefore, we fabricate the cavities directly in thin-film LN-on-Insulator (LNOI) chips that have been doped with Tm^{3+} by ion implantation. Then, we couple light into them via evanescent coupling using a fiber that has been inverse-tapered with hydrofluoric acid and glued to the LNOI chip. Early results include simulations of the LN cavities and their nanofabrication.

We believe our early results show that Tm^{3+} ions are promising as a platform for single-photon emission at wavelengths suitable for fiber-based (1450 nm) and free-space-based (795 nm) quantum networks.

As future work we will characterize the single photon sources with Hanbury-Brown and Twiss setups for the single-photon purity measurements, and Hong-Ou-Mandel setups to measure the indistinguishability of the single-photons.

Towards interacting single rare-earth ions

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Rare earth ion-doped crystals constitute a promising platform for quantum information processing and networking [1]. They feature exceptional spin coherence times to store information, narrow optical transitions to act as an interface to optical photons, and possibilities to realize quantum gates between single ion qubits through electric dipole interactions. Recent results have shown single rare earth ions in the Purcell-enhanced regime to be excellent spin-photon interfaces [2-4], but the detection of a controlled interaction between two such single ions remains elusive.

We present our work towards detecting the first controlled interaction between single rare earth ions. Our system consists of a praseodymium-doped yttrium oxide nanoparticle placed inside of an open fiber cavity in a closed-cycle cryostat. The large electric dipole moment of the praseodymium transition, combined with the small ion-ion separations enabled by the nanoparticle's small size (70nm diameter), results in interactions which we predict will be strong enough to detect directly as shifts in each ion's optical spectrum.

In a previous experiment we detected single erbium ions in our nanoparticle-cavity system [5]. Since then we have realized major upgrades to the experiment, mainly consisting of a new nanopositioner design which improves the stability of the cavity (2.5 pm RMS down from 30 pm) and allows for operation at lower temperature (1.65K down from 6.5K). This new design also allows for MHz-rate tuning of the cavity length, enabling temporal shaping of the emitted photons.

In this poster we will give an overview of the rare earth ion quantum computing architecture, which motivates the need for controlled ion-ion interactions. A description of our fiber cavity and nanoparticle system will be given, along with quantitative analysis estimating the interaction strength between ions and an outline of the methods we will use to find pairs of interacting ions. Finally, we will include an outlook on the novel experimental capabilities unlocked by our new positioner.

[1] Kinos et al, *Preprint arXiv:2103.15743* (2021)
[2] Ourari et al, *Nature,* **620** (2023)
[3] Kindem et al, *Nature,* **580** (2020)
[4] Ulanowski et al, *Advanced Optical Mater,* **12** (2024)
[6] Deshmukh et al, *Optica,* **10** (2023)

Hybrid Magnon-Spin Ion Systems for Quantum Transduction Between Microwaves and Optics

T. Riederer[1], J. Attenberg[1], L. Flajšman[1] and S. van Dijken[1]
[1]*Aalto University, Espoo, Finland*

Quantum networks represent a frontier in information processing and distribution, offering transformative opportunities and rigorous tests of quantum theory. Quantum computers are connected via quantum interconnects within these networks. However, the full potential of quantum networks is limited by challenges in transporting quantum information using microwave photons. Pioneering experiments have established connections between microwave photons and long-distance, optical fiber-guided telecom photons [1-3]. However, current approaches lack the fidelity, scalability, and versatility required for large-scale quantum networks.

We aim to develop an on-chip platform that converts microwaves into optical photons using magnons as a bridge between the two. To achieve this, we will build an innovative hybrid quantum system that couples erbium-ion spins to magnons within a low-loss yttrium iron garnet (YIG) optomagnonic cavity.

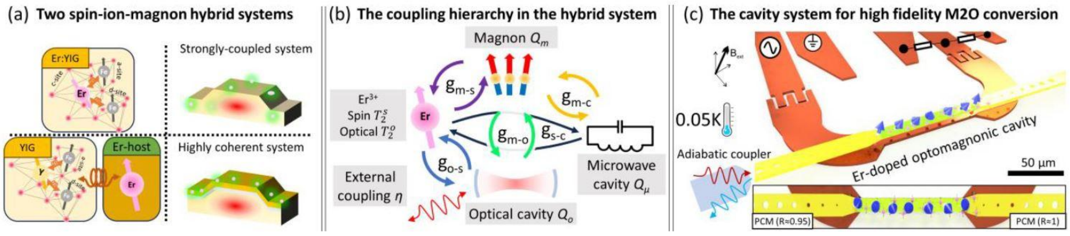

Figure 1: Project overview (a) Two different Er:YIG systems, that will be explored. Erbium-doped YIG for strong coupling as well as an Er-host layer on top of YIG for highly coherent systems. (b) Coupling hierarchy of the Er:YIG optomagnonics cavity. (c) Final Er:YIG microwave-to-optics transducer.

The tunable and scalable nature of this system is achieved by integrating low-loss magnons, an optical cavity, erbium ions, and a microwave cavity into a single device. If successful, this project will mark a major milestone in quantum information science, paving the way for quantum interconnects that enable secure, efficient, and long-distance communication and information processing within quantum networks.

[1] Na Zhu et al. "Waveguide cavity optomagnonics for microwave-to-optics conversion". In: *Optica* 7 (2020), p. 1291.

[2] Jake Rochman et al. "Microwave-to-optical transduction with erbium ions coupled to planar photonic and superconducting resonators". In: *Nature Communications* 14 (2023), p. 1153.

[3] Reed W Andrews et al. "Bidirectional and efficient conversion between microwave and optical light". In: *Nature physics* 10 (2014), p. 321.

Novel ytterbium-based molecular materials for quantum information applications

Jannis Hessenauer[1], Robin Wittmann[1], Antara Das[1], Nicholas Jobbitt[1], Timo Neumann[2], Barbora Brachnakova[3,4], Michael Seitz[2], Mario Ruben[3,4], David Hunger[1,3]
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[2] *University of Tübingen, Institute of Inorganic Chemistry, Germany*
[3] *Karlsruhe Institute for Technology, Institute for Quantum Materials, Germany*
[4] *Karlsruhe Institute for Technology, Institute of Nanotechnology, Germany*

Ytterbium ions in solid state hosts are excellent candidates for the implementation of a spin-photon interface, a key building block of quantum networks, due to their excellent coherence properties and easily accessed electronic spin degree of freedom. Pioneering experiments have demonstrated remote entanglement of two ytterbium ions via a photonic link [1]. Recently, it has been shown that rare earth centres can retain their excellent coherence properties when integrated into organic molecules [2]. Hereby, their optical and spin properties sensitively depend on the coordinating ligands. This can be harnessed to engineer and boost the optical and spin properties, such as coherence times and optical branching ratios, promising a deterministic, bottom-up design approach.

However, ytterbium ions specifically suffer from non-radiative decay mechanisms caused by the high-energy vibrational modes introduced by the organic ligands, thereby reducing the quantum efficiency. This can be alleviated by chemical techniques such as deuteration [3].

In this poster, we present a thorough investigation of multiple ytterbium-based molecular systems via laser spectroscopy at cryogenic temperatures. Therefore, we develop a fully fibre-coupled cryogenic measurement setup with a centimetre-sized footprint. We observe narrow optical inhomogeneous lines and large optical depths. Furthermore, we find strong indication for the formation of multiple clusters of ytterbium ions, demonstrating the potential of laser spectroscopy for probing the sample homogeneity. Finally, we systematically compare the excited state lifetimes and compare them to the structure of the surrounding organic ligands, where we find correlations consistent with phonon-assisted non-radiative decay channels introduced by high frequency C-H oscillators. This may serve as an important starting point for a more sophisticated ligand design leading to higher quantum efficiencies, a key requirement for an efficient spin-photon interface.

[1] Ruskuc, A., *et al.* Multiplexed entanglement of multi-emitter quantum network nodes. *Nature* **639**, 54–59 (2025).
[2] Serrano, D., *et al.* Ultra-narrow optical linewidths in rare-earth molecular crystals. *Nature* **603**, 241–246 (2022).
[3] Kreidt, Elisabeth, Christian Kruck, and Michael Seitz. "Nonradiative deactivation of lanthanoid luminescence by multiphonon relaxation in molecular complexes." *Handbook on the physics and chemistry of rare earths*. Vol. 53. Elsevier, 2018. 35-79.

Optimizing diamond surface to grow quantum grade rare earth oxide thin films

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Rare-earth (RE) doped oxides find applications in a broad range of areas from photonics to quantum technologies [1]. They can be produced in various forms, including thin films, which offer the possibility of complex stacked architectures, and wafer scale processing. Diamond is an established photonic platform material but its dissimilarity with oxides makes it challenging to use as a substrate for deposition. In this work, we investigated surface treatments to improve the quality of Y_2O_3 thin films deposited on diamond substrates using Direct Liquid Injection Chemical Vapor Deposition (DLI-CVD) [2][3]. We studied the crystalline quality of our films by doping the very first nanometers of the films with RE ions and recording their luminescence.

We studied two different doping schemes. The first one was the well-known Yb-Er co-doping [4] which shows visible luminescence from infrared excitation through energy transfer. The second one was Tb^{3+} doping, which has a favorable energy level scheme and can show ms excited state lifetimes even at high doping concentrations.

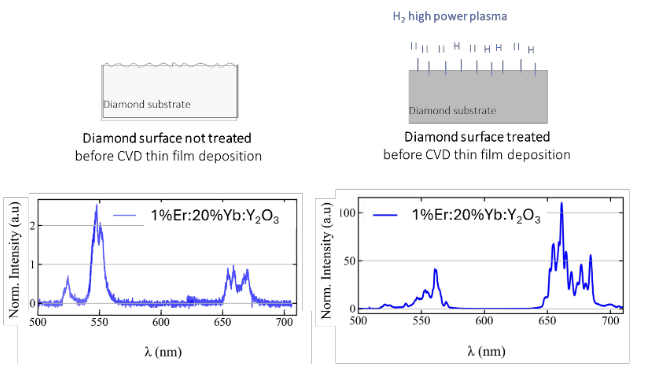

Figure 1 - Photoluminescence spectra of Er,Yb doped Y_2O_3 without and with diamond surface treated

Prior to deposition, the single crystal diamond substrate was treated with a high-power hydrogen plasma that aimed at modifying and reconstructing its surface. In both cases, we observed that RE luminescence close to the interface was clearly dependent on diamond surface treatment, either in terms of emission spectra, lifetimes, or intensity. This allowed us to achieve similar optical properties to those recorded on thicker films or bulk crystals, evidencing improved crystalline quality. This opens the way to the development of rare earth-diamond hybrid materials that could combine both systems properties through interactions at the interface.

[1] Goldner, P., Adv. Quant. Tech., in press
[2] Harada, N. et al., Mater. Adv. 2022, 3 (1), 300–311.
[3] I. G. Balașa, et al. Adv. Opt. Mat. 2024, 2401487.
[4]Auzel, F. C. R. Acad. Sci., 263.14 (1966): 819.

Progress in Europium-Doped Y_2O_3 Thin Films for Quantum Applications

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Thin films provide nanoscale confinement along with compatibility with photonic and microwave architectures, making them ideal candidates for chip-scale quantum devices. In this work, we report recent progress on Eu^{3+}-doped thin films grown by chemical vapor deposition [1,2]. We have explored several approaches for the fabrication of epitaxial $Y_2O_3:Eu^{3+}$ thin films. Epitaxy was achieved on silicon by introducing an MBE-grown Y_2O_3 buffer layer [2], as well as by using oxide crystals such as Yttria-Stabilized Zirconia (YSZ) as substrates [3]. These epitaxial thin films exhibit sub-megahertz optical homogeneous linewidths below 2 K, characterized by spectral hole burning, representing a tenfold improvement compared to previous reports on the same material.

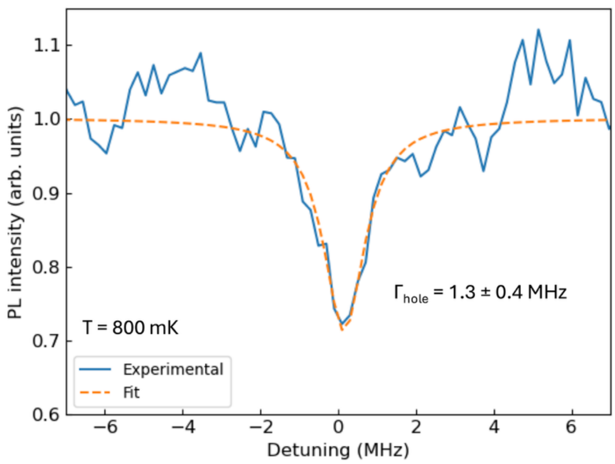

Figure 1: Spectral hole burn on the $^5D_0$ - $^7F_0$ transition of Eu3+ for an epitaxial Y_2O_3 thin film

To gain insight into the remaining optical dephasing mechanisms, we studied the power and temperature dependence of the homogeneous linewidth, as well as the impact of post-deposition annealing.

[1] T. Zhong and P. Goldner, “Emerging rare-earth doped material platforms for quantum nanophotonics,” *Nanophotonics* **8** (11), 2003–2015, (2019).
[2] D. Serrano et al. *Nanophotonics* **14** (11), 1809-1815 (2025).
[3] A. Blin et al. *Applied Physics Reviews* **12** (1), (2025)

Purcell enhancement and spectroscopy of europium-based molecular materials coupled to a microcavity

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Rare-earth-doped solid-state materials are an attractive option for the realisation of quantum registers given their long coherence and compatibility with current telecommunication infrastructure [1]. However, the low oscillator strengths present in such systems limits the ability to create efficient devices. Rare-earth-based organic molecules offer a solution to this problem through engineering the optical and spin properties with synthetic chemistry, which in turn allows for the possibility to produce multi-qubit systems within a single molecule, and self-assembly to construct large qubit registers.

We report on the integration of multiple europium-based molecular complexes into a fibre-based Fabry-Pérot microcavity. Such a configuration allows for further enhancement of the emission rate via the Purcell effect [2]. In particular, the binuclear complex $[Eu(btfa)_3]_2bpm$ [3], which has shown a branching ratio of 1.35%, and a promising optical coherence time of 2.0 μs at 500 mK, was successfully dissolved in PMMA and integrated into the microcavity. A two-fold reduction in the optical lifetime was measured, corresponding to a 167-fold enhancement of the coherent 580 nm transition, which is equivalent to an enhanced branching ratio of ~70%. Furthermore, the emitter linewidth was determined to be ~200 MHz through the use of transient spectral hole burning.

Moreover, work is underway to integrate single crystals of $Eu(dbm)_3bipy$ into the microcavity [4]. This molecule has shown a similar branching ratio of ~1.3%, and an optical coherence time of 300 ns at 4.2 K. Crystals were grown from a saturated solution and showed surface roughnesses of <1 nm rms over an area equal to that of the cavity mode (~5 μm^2).

[1] A. Kinos et al., arXiv:2103.15743 (2021)
[2] C. Deshmukh et al., Optica, **10**, 1339 (2023)
[3] R. Ilmi et al., J. Mater. Chem. C, **8**, 9816 (2020)
[4] H.-Y. Wong et al., Inorg. Chem., **56**, 5135–5140 (2017)

Spectroscopic investigations of an excited-state transition in Tm^{3+}: $YAlO_3$

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Despite extensive studies of ground-state transitions of rare-earth ions doped into inorganic crystals, excited-state transitions remain largely unexplored in the field of quantum information processing. In this work, we report spectroscopic and coherence properties of the excited-state transition between the lowest crystal field levels of the $^3F_4$ and the $^3H_4$ manifolds of thulium-doped yttrium aluminum perovskite (Tm:YAP) at cryogenic temperatures. The wavelength of this transition is at 1451.37 nm, which lies near the telecom C-band.

We find an inhomogeneous broadening of this transition of 1.29 GHz, and lifetimes of the higher-lying and lower-lying levels of 0.85 ms and 6.21 ms , respectively. We also investigate spectral holes with varying magnetic fields from 0 to 2T, revealing hyperfine and superhyperfine structure. For coherence properties, we measure spectral hole widths as well as optical free induction decays (FID), yielding consistent results and a maximum optical coherence time of 1.1 μs when a 2T magnetic field is applied.

Our results suggest the possibility of exploiting excited-state transitions in REI doped crystals for applications of quantum information processing, including for single photon sources and quantum memory for light.

Toward Er-Doped Fiber and Rare-Earth Molecular Crystals in Quantum Networks

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Erbium-doped silica fibers (EDFs) are promising candidates for fiber-based quantum networks due to their emission wavelength, which aligns with the telecom band where optical fibers exhibit minimal loss. Their availability, ease of use, and compatibility with existing fiber infrastructure make them especially attractive. In this work, we use spectral-hole burning (SHB) and photon-echo techniques to investigate spin lifetime and optical coherence properties of the erbium ions in EDFs. SHB measurements targeting the Zeeman sublevels of the $^4I_{15/2}$ ground state at ultralow temperatures and under varying magnetic fields reveal three distinct spin-relaxation components, including one with spin lifetimes exceeding 9 hours at ~7 mK [1]. While earlier studies struggled to account for all decay components at higher temperatures [2], our model successfully describes all decay components using a unified framework based on spin flip-flop interactions, direct coupling to two-level systems (TLSs), and Raman-type processes. In addition, two-pulse photon-echo (2PPE) measurements of the $^4I_{13/2} \leftrightarrow {}^4I_{15/2}$ optical transition revealed an effective homogeneous linewidth of approximately 8 kHz at ~7 mK and 0.09 T—an improvement of over two orders of magnitude compared to earlier results at 700 mK [3]. Three-pulse photon-echo (3PPE) measurements further reveal that TLS-induced decoherence is significantly suppressed below ~100 mK, underscoring the potential of EDFs for long-lived quantum memory applications.

In parallel, we explored rare-earth molecular crystals, including $[Ln(C_5H_7O_2)_3(C_{12}H_8N_2)]$ with Ln = Er, Tm, and Eu, as alternative platforms for quantum storage. Optical spectroscopy revealed narrow inhomogeneous broadening in Er-containing samples, approximately 4 GHz for the stoichiometric crystal. We also observed long lifetimes of the entire population (not just spectral hole lifetimes) in both Er and Tm complexes, measured to be 1.759 ± 0.227 s and 3.943 ± 0.138 s at ~500 mK, respectively. We attribute these extended lifetimes to slow re-thermalization of the sample as it cools, a behavior likely caused by phonons becoming trapped within the large molecules and unit cells of the organic crystal. Unlike in inorganic hosts, this phonon trapping delays energy transfer to the surrounding lattice, an effect that can be mitigated by cooling with a liquid helium bath or using helium gas exchange. We further examined the temperature dependence of inhomogeneous broadening to evaluate phonon contributions, and Zeeman measurements under applied magnetic fields yielded an average g-factor of 3.23 for Er ions in our Er complex. Similar studies on other RE-based complexes, including Eu- and Yb-containing complexes, are ongoing, emphasizing the broader potential of molecular platforms in quantum technologies [4]. Together, these results highlight the strengths of inorganic fiber systems and molecular platforms for applications in quantum technologies.

[1] M. Bornadel et al., *Phys. Rev. Applied,* **24**, 014030 (2025)
[2] E. Saglamyurek et al., *Phys. Rev. B,* **92**, 241111(R) (2015)
[3] L.Veissier et al., *Phys. Rev. B,* **94**, 195138 (2016)
[4] D. Serrano et al., *Nature,* **603**, 241–246 (2022)

Zeeman Spectroscopy of Charge-Compensated Er^{3+} Sites in $CaWO_4$ under Vector Magnetic Fields

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The rare-earth-doped crystal Er:$CaWO_4$ has recently emerged as a promising material for quantum networks, combining the telecom-band optical transitions of Er^{3+} with favorable spin properties in a low-symmetry host lattice [1 - 3]. While the well-known axial Er^{3+} site in $CaWO_4$ has been studied extensively, our previous work identified three additional, lower-symmetry sites likely originating from charge compensation mechanisms involving neighboring Ca^{2+} vacancies [4].

In this work, we perform polarization-resolved optical absorption measurements on bulk Er:$CaWO_4$ under vector magnetic fields to study the Zeeman splitting of these sites. The axial site (site 1) exhibits a single symmetric Zeeman-split transition pattern aligned with the crystal axes, consistent with its S_4 symmetry. In contrast, sites 2 and 3 reveal more complex spectra: each shows two sets of transitions that interchange under 90° rotations around the crystal c-axis, indicative of lower-symmetry [5-7], for instance, rhombic-like environments with misaligned principal axes. An example measurement set under a-polarization is shown in Figure 1. From these patterns and measurements at different temperatures, we could extract projective g-factors in the a-b and b-c planes for site 2. A corresponding EPR signal confirms the optically predicted ground-state g-factor. Our results provide strong evidence for distinct Er^{3}–vacancy complexes and offer insight into their symmetry and local structure.

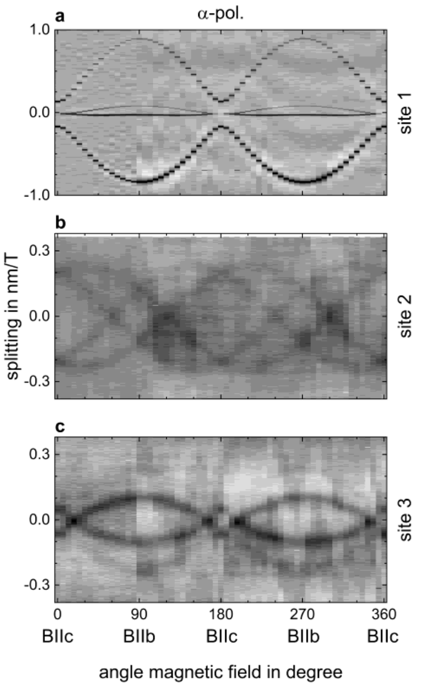

Figure 1: Symmetry of Zeeman-split transitions of sites 1 - 3 in the b-c plane measured in α-polarization. Site 1 is measured at 0.6 T at 1.76 K, site 2 and site 3 are measured at 0.5 T at 10 K.

[1] M. Le Dantec et al, *Sci. Adv.*, **7**, 51 (2021)
[2] S. Ourari et al., *Nature*, **620**, 977-981 (2023)
[3] M. T. Uysal et al., PRX, 15, 011071 (2025)
[4] F. Becker et al., PRM, **9**, 076203 (2025)
[5] R. W. Kedzie and M. Kestigian, APL, **3**, 86 (1963)
[6] U. Ranon and V. Volterra, PR, **134**, A1483 (1964)
[7] W. B. Mims and R. Gillen, J. Chem. Phys., **47**, 3518 (1967)

On-chip Photonic and Superconducting Circuits for Erbium^{3+} Ion Property Analysis

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Erbium (Er^{3+}) ion-doped yttrium orthovanadate (YVO) crystals, combined with silicon waveguides, have demonstrated significant potential for on-chip microwave-to-optical transduction [1]. Other host materials, such as calcium tungstate (CaWO), also show promise as efficient platforms for quantum memory applications [2] and microwave-to-optical transduction [3, 4].

In this contribution, we present innovative fabrication techniques designed to streamline the characterization of various on-chip coupling strategies for Er^{3+} ions across different host materials. A stamping transfer process [5] for silicon waveguides allows rapid prototyping using standard silicon wafers. We efficiently transfer silicon waveguide structures, utilizing a PDMS stamp with a precision stacker, commonly used for 2D material transfer. Combined with inverse design grating couplers [6], this method enables fast characterization of different platforms. These grating couplers, designed for simultaneous transfer with waveguides, are arranged in arrays held together by a transfer structure.

Additionally, we introduce a macroscopic microwave split-ring resonator, fabricated on a printed circuit board, for Er^{3+} spin control. This resonator, optimized for a second-harmonic resonance frequency of 5.236 GHz with a full-width half-maximum of 24.08 MHz, achieves a measured total quality factor of 217. The design allows for rapid modifications to accommodate different host materials and manage restricted cryostat space, as well as varying sample dimensions and orientations.

The integration of on-chip photonics enables the investigation of quantum memory applications using photonic crystal cavities to enhance memory efficiency. Combined with on-chip superconducting microwave resonator, we can explore spin control and transduction [7], advancing the capabilities for quantum technologies.

[1] J. Rochman, et al., *Nat. Commun*, **Vol. 14**, (2023)
[2] M. Le Dantec et al., *Sci. Adv.*, **Vol. 7, Nr. 51**, (2021)
[3] J. G. Bartholomew et al., *Nat. Commun*, **Vol. 11, Nr. 1**, (2020)
[4] T. Xie et al., *Phys. Rev. B*, **Vol. 104, Nr. 5**, (2021)
[5] A. M. Dibos, et al., *Phys. Rev. Lett.*, **Vol. 120, Nr. 24**, (2018)
[6] C. Lalau-Keraly, et al., *Opt. Express*, **Vol. 21**, (2013)
[7] N. Lauk et al., *Quantum Sci. Technol.*, **Vol. 5, Nr. 2**, (2020)

Spectroscopic Investigations of Eu^{3+} Ions in $EuCl_3 \cdot 6H_2O$ Crystal Doped with Er^{3+} ions

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[2] *International Quantum Academy, and Shenzhen Branch, Hefei National Laboratory, Shenzhen, 518048, China*
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Rare-earth ions (REIs) in solids are promising candidates for various quantum information processing technologies due to their long coherence times [1,2]. In comparison to REIs at extremely low concentrations, stoichiometric rare-earth single crystals exhibit greater absorption depth and inhomogeneous broadening. Notably, the $^7F_0 \rightarrow {}^5D_0$ transition of Eu^{3+} in $EuCl_3 \cdot 6H_2O$ single crystals exhibits an exceptionally long coherence time [3]. Additionally, substituting host Eu^{3+} ions in $EuCl_3 \cdot 6H_2O$ with other REIs introduces spatial variations in the positions of surrounding Eu^{3+} ions, giving rise to satellite lines in the spectrum [4]. However, few information about optical coherence of ions in satellite lines have shown so far. Here, we present spectroscopic investigations of Eu^{3+} ions in an Er^{3+}-doped $EuCl_3 \cdot 6H_2O$ single crystal. Fluorescence spectroscopy reveals that the satellite lines exhibit inhomogeneous broadening similar to that of the pure sample. In the sub-Kelvin regime, photon echo measurements show that the optical coherence time of the satellite lines is not significantly affected. However, at temperature >2K, significant decoherence of Eu^{3+} ions is observed, attributed to Orbach spin relaxation in the doped Er^{3+} ions. Following the results of stimulated photon echoes, clear echo modulation suggests strong ion-ion interactions between Er^{3+}-Eu^{3+} ion pairs. Based on our measurements of the electron Zeeman g-factor of the Er^{3+} ions, we observe a lifetime-limited optical coherence time at the external magnetic angle corresponding to the maximum g-factor, which we attribute to the 'frozen core'. These results demonstrate the potential of Er^{3+}: $EuCl_3 \cdot 6H_2O$ as a platform for photonic quantum technologies.

[1] M. Guo, S. Liu, W. Sun, et al., *Frontiers of Physics*, **18**, 21303 (2023).
[2] M. Zhong, M. Hedges, R. L. Ahlefeldt, et al. *Nature* **517**, 177–180 (2015).
[3] R. L. Ahlefeldt, N. B. Manson,and M. J. Sellars, *J. Lumin.* **133**, 152 (2013).
[4] R. L. Ahlefeldt, D. L. McAuslan, J. J. Longdell, et al., *Phys. Rev. Lett.* **111**, 240501(2013).

Phase-sensitive time-reversal for radiofrequency signals using a rare-earth-doped crystal

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Time reversal is a powerful method that enables wave focusing in complex media. Originally developed in the 1990s for acoustic waves, it has led to major advances in fields such as medical imaging, targeted therapy, geophysics, and underwater communications. More recently, this concept has been extended to radiofrequency (RF) waves, paving the way for numerous applications in dynamic, uncontrolled environments (urban, industrial, etc.).

One of the main obstacles to the actual implementation of time reversal in the RF domain is the high latency induced by conventional digital processing, especially for wideband signals, making it impossible to adapt to rapid changes in the environment. A promising alternative is a fully analog approach, particularly when based on microwave photonics, which offers very high bandwidth and low losses.

We present a fully analog architecture capable of performing phase-sensitive time reversal of optically carried RF signals. This approach relies on the photon echo mechanism in rare-earth-ion-doped materials, and directly exploits the "$-t$" term in the photon echo amplitude. Unlike earlier methods based on optical dispersion [1–3], this architecture enables the reversal of phase- and frequency-modulated signals, which is crucial for wave refocusing applications. We demonstrate this by time-reversing RF pulse trains with arbitrary modulations such as FSK and PSK (see Fig. 1) [4]. The system supports signals lasting several microseconds with latency under one millisecond, suitable for real-time dynamic scenarios. Although our use of a frequency-agile laser [5] should enable GHz-scale bandwidths, instantaneous spectral diffusion currently imposes a strong limitation to ~50MHz.

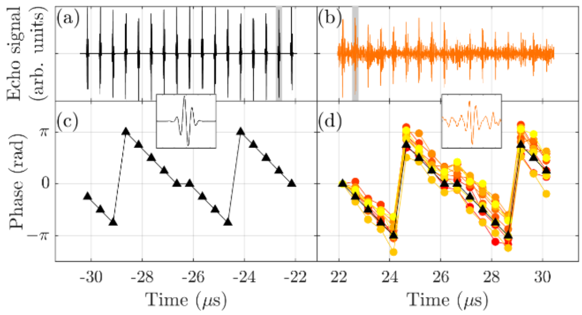

Figure 1: Time reversal of an 8 μs PSK pulse sequence, where each pulse has a 50 ns duration. (a) Input signal. (b) Example of output signal obtained experimentally by heterodyne detection. (c) Phase of each pulse in the input signal. (d) Measured phase of the output signal, obtained by numerical demodulation of each pulse. The experiment is repeated 10 times to assess its reproducibility.

This work represents an important step toward low-latency analog devices for processing and focusing RF signals in complex environments. By eliminating the need for digitization and being compatible with complex modulations, this approach opens new perspectives in communications, radar, and even imaging.

[1] H. Linget et al., *Opt. Lett.* **38** 643-645 (2013).
[2] F. Coppinger, A. S. Bhushan, and B. Jalali. *Electronics Letters* 35, 1230-1232 (1999).
[3] J. Zhang, and J. Yao, *IEEE Trans. Microw. Theory Tech.* **63,** 2166-2172 (2015).
[4] T. Llauze et al., *Opt. Lett.*, in press (2025).
[5] T. Llauze et al., *Appl. Opt.*, **63**, 5192-5202 (2024).

Towards photon-assisted spin relaxation in Ho: $LiYF_4$

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We investigated the hyperfine structure of Ho^{3+} ions in $LiY_{1-x}Ho_xF_4$ via broadband electron paramagnetic resonance spectroscopy. Our results shed new light on the thermally activated quantum tunneling responsible for low-temperature staircase-like magnetization curves of the compound [1]. Hyperfine interaction has important effects on the magnetic ordering [2,3,4] and spin dynamics [5] of Rare-earth materials. Manipulation of hyperfine transitions thus opens many possibilities for the study and applications of these spin systems.
Here, we present our efforts in demonstrating electronic spin relaxation in $LiY_{1-x}Ho_xF_4$ induced by hyperfine pumping.

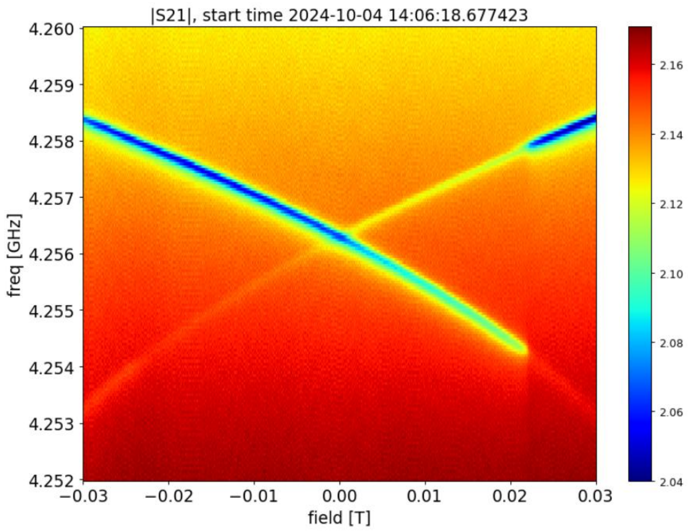

Figure 1: Thermally activated quantum tunneling enables fast spin relaxation, which manifests in an abrupt change in the intensities of spectroscopical lines.

[1] R. Giraud et al., *Phys.Rev.Lett.*, **87**, 057203 (2001).
[2] H. M. Rønnow et al., *Science,* **308**, 5720 (2005).
[3] J. A. M. Paddison, et al., arXiv:1908.03530 (2019)
[4] S. L. Chamberlain, et al., *Journal of Physics and Chemistry of Solids*, **67**, 710 (2006)
[5] C. Paulsen, et al., *Nature Communication* , **10**, 1509 (2019)

Damage-free detection of rare-earth magnetism via ultrashort X-ray free-electron laser pulses

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Diffraction-before-destruction schemes, enabled by ultrashort X-ray free-electron laser (FEL) pulses, have led to unrivaled structural refinements using serial femtosecond crystallography. This raises an opportunity to extend the approach to not only outrun structural photoinduced damage but also heating and alterations to electronic orders. We report on an ultralow-temperature vectormagnet setup that has recently become available at the SwissFEL Cristallina-Quantum endstation, highlighting the advantage of a brilliant, ultrafast X-ray source to measure fragile quantum-manybody states essentially at the base temperature of a dilution refrigerator.

Traditionally, neutron scattering has been the main technique to study electronic interactions in magnetic materials, such antiferromagnetism of $LiErF_4$ [1]. Though, exceptional improvements in terms of brilliance and coherence of accelerator-based photon sources, such as synchrotrons and X-ray FELs, have elevated X-ray scattering as a complementary technique. It offers elemental sensitivity from resonance effects of electronic transitions, and the ability to probe small sample volumes – down to tens of nanometer spotsize and atomic monolayers. A shortcoming of synchrotron-based X-ray experiments is the constant heat load from the incident photon beam that effectivley precludes measurements at sub-Kelvin temperatures – hence we turn to X-ray FELs that allow for pulsed experiments.

As part of the commissioning of the SwissFEL Cristallina-Quantum setup we have used single X-ray FEL pulses for resonant magnetic X-ray scattering at the Er L_3-edge (8.35 keV), showing that antiferromagnetic order of $LiErF_4$ can be detected at sample temperatures as low as $T = 35$ mK before the onset of beam heating. Moreoever, the character of the magnetic signal can be tuned via vector magnetic fields, *e.g.* to lift the degeneracy of magnetic domains, and directly monitered via the X-ray signal. This proof-of-principle demonstration of electronic diffraction-before-destruction opens the door for damage-free inspection of dense rare-earth systems, as well as application in the time domain to image coherently driven spin ensembles.

[1] C. Kraemer *et al.*, Science, **336**, 1416 (2012)

Quantum Gravity Detection Methods Using Rare-earth-ions

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In an attempt to better describe unique gravitational environments such as black holes, several models of quantum gravity have been derived. Among the different models, a reoccurring concept is the need for quantum gravity corrections to Heisenberg's uncertainty principle. However, due to the difficulty of probing cosmological objects, many experimental setups are limited to probing low mass objects where the magnitude of the proposed effect is significantly reduced. New, more sensitive measurements are therefore needed to be able to probe the effect at a scale where it is theoretically relevant. By utilizing a previous idea for a dispersive coupling between a probing light field and a mechanically oscillating cantilever doped with rare-earth-ions, we propose a scheme for measuring this effect in the Planck mass regime. The experimental setup, the physical parameters for an implementation, as well as the expected measurement accuracy is discussed.

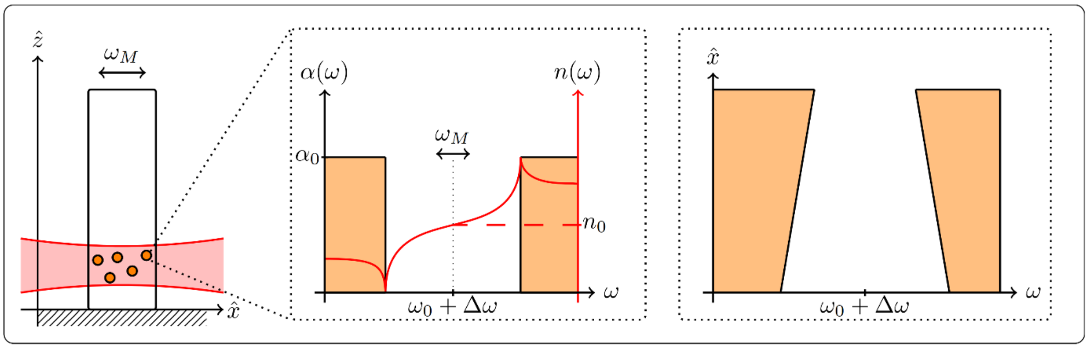

Figure 1: Mechanically oscillating cantilever doped with rare-earth-ions interacting with a probing light field (left). Spectral hole oscillating with the cantilever, changing the refractive index affecting the probing field (center). Spatially asymmetric spectral hole width creating the desired coupling between the probing field and the cantilever (right).

2.2 Wednesday 17th: Memories, Metrology and Microwaves

Special Hole Burning in Eu:YSO for Low-frequency Acceleration Sensing

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Rare-earth ions embedded in rare-earth ion-doped crystals (REICs) exhibit remarkable atomic coherence and couple efficiently to strain within the host matrix [1]. This combination enables access to parametric regimes and sensitivity levels that are unattainable with current technologies [1-3].

REICs experience inhomogeneous broadening due to local lattice distortions caused by the size difference between dopant and host ions. Spectral hole burning (SHB), which creates narrow spectral features through selective depletion of specific dopant ion populations using narrow-linewidth lasers, allows to overcome the inhomogeneous broadening and fully exploit the coherence of rare-earth ions [4].

By leveraging the high strain sensitivity of REICs along with the advantages of SHB, it is promising to develop high-performance, cryo-compatible inertial accelerometers in the form of inertial strain gauges, with sensitivity approaching ~1 ng/√Hz over a ~100 kHz bandwidth. In particular, Eu:YSO crystals support ultra-narrow, long-lived spectral holes, making them ideal for long-timescale sensing.

We report recent experimental progress on SHB in Eu:YSO crystals at cryogenic temperatures. On one front, we investigate optimal burning parameters and test various doping concentrations to achieve the narrowest possible spectral holes. On another, we study the strain-mediated coupling between the ions and the host matrix by characterizing the spectroscopic response of the crystal to externally induced strain from a loaded test mass. These results inform the optimization of SHB protocols and crystal properties for high-sensitivity inertial sensing, laying the foundation for the first demonstration of quasi-continuous, ultra-sensitive acceleration detection using REICs.

[1] C. W. Thiel et al., *J. Lumin.*, **131**., 353 (2011)
[2] A. Louchet-Chauvet et al., *Phys. Rev. Applied,* **20**, 054004 (2023)
[3] R. Ohta et al., *Phys. Rev. Lett.*, **132**, 036904 (2023)
[4] R. M. Macfarlane, *J. Lumin.*, **45**, 1 (1990)

Sub-K Special Hole Burning in Eu:YSO for Laser Frequency Stabilization

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As basic building blocks for quantum devices, ultra-stable lasers have a profound impact on various fields. Longer laser coherence times enhance the performance of quantum sensors, computers, communications, and optical clocks. Although optical lattice clocks have accomplished significant high-precision measurements, they often fall short of their quantum projection noise limits due to dead times during atom preparation: the instability in the laser frequency introduces stochastic fluctuations during the interrogation of atomic transitions (Dick effect). High-resolution optical clock comparisons are crucial for evaluating their accuracy and could lead to a redefinition of the SI second based on optical transitions [1].

However, the most common technique for achieving ultra-stable lasers, the Pound-Drever-Hall method with Fabry-Perot cavities, faces thermal noise limitations of the cavities. To overcome these constraints, alternative methods such as Spectral Hole Burning (SHB) in rare-earth-doped crystals (REICs) have been explored. Indeed, REICs experience inhomogeneous broadening due to local lattice distortions caused by the size difference between dopant and host ions. An SHB protocol, which creates narrow spectral features through selective depletion of specific dopant ion populations using narrow-linewidth lasers, allows to overcome the inhomogeneous broadening and fully exploit the coherence of rare-earth ions. At cryogenic temperatures, Eu:YSO crystal exhibit persistent Spectral Holes a few kHz narrow and with a lifetime up to 10 h, at 4 K [2], making it a high-precision frequency reference, ideal for intermediate-timescale sensing.

We report recent experimental progress on SHB in Eu:YSO crystals at specific sub-K dilution temperature setpoints that cancel the thermal sensitivity of the hole frequency [3]. The latest recorded performances on our experiment reach a fractional frequency stability of 4.10^{-16} at 1 s [4], which is close to the perfomance of the reference cavity at LTE. Therefore, a second SHB setup is needed for our future stability comparisons. On one front, we continue to further improving the laser frequency lock onto spectral holes, by cancelling frequency noise induced by the crystal displacement. We use a Michelson interferometer to measure and reject the path length fluctuations from the crystal to a reference plane on the optical bench. On another, due to the change in the optical setup, we investigate hole burning parameters to achieve optimal spectral hole linewidth and discriminant for frequency locking. In addition, we explore a group delay measurement technique via phase modulation to enhance the precision on the pointing of the center of spectral holes. This should help removing slow frequency drifts due to asymmetric burning of the hole while it is probed by the laser.

[1] S. Bize. *The unit of time: Present and future directions*. Comptes Rendus, **20**, 153 (2019)
[2] F. Könz et al., Phys. Rev. B, **68**, 085109 (2003)
[3] X. Lin et al., Phys. Rev. Lett., **133**, 183803 (2024)
[4] X. Lin, PhD Thesis, *Ultra-stable laser with spectral hole burning and multi-channel probing,* Université Paris Sciences et Lettres (2024)

A deployed fiber link for quantum networking in Hefei

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We report the deployment and preliminary characterization of a metropolitan fiber link in Hefei for quantum networking applications. The link connects multiple nodes intended for quantum communication and the interconnection of quantum nodes [1]. It leverages existing fiber infrastructure and is designed to support both time-bin and polarization qubit transmission. Initial measurements on channel loss and polarization stability indicate that the link is compatible with quantum memory interfaces and entanglement distribution schemes, providing a versatile platform for ongoing experimental exploration in scalable quantum networking.

[1] X. Liu et al., *Nature Communications*, **15**, 8529 (2024)

Efficient integrated quantum memory using waveguide cavity

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Scalable implementation of quantum networks and photonic processors demand integrated photonic quantum memories with high efficiency, yet current integrated systems have been limited to storage efficiencies below 27.8% [1]. Cavity-enhanced quantum memory is a universal method to improve memory efficiency, especially with the sample with low absorption like rare-earth ion (REI) doped crystals.

However, the former demonstrations of efficient cavity-enhanced quantum memory are all in bulky systems. Furthermore, their efficiencies are limited by cavity linewidth and intra-cavity loss [2-3]. Here, we demonstrate highly efficient integrated quantum memories based on REI-doped crystals coupled with waveguide-based cavities (WGC) fabricated using femtosecond lasers. After carefully optimization of the fabrication process, we achieve an ultralow propagation loss of 0.1 dB/cm. The narrow cavity linewidth caused by slow light effect is mitigated using an absorption-enhanced spectral hole-burning protocol.

With the improvements above, we achieve an efficiency of 80.3(7)% at the storage time of 1 μs, and on-demand retrieval at 7 μs using the Stark-modulated atomic frequency comb protocol. This WGC quantum memory not only breaks the efficiency record of integrated quantum memory, but also is the most efficient quantum memory based on REI-doped crystals.

[1] Liu, C. et al., *Phys. Rev. Lett*. **125**, 260504 (2020)
[2] Sabooni, M. et al., *Phys. Rev. Lett*. 110, 133604 (2013)
[3] Duranti, S. et al. *Opt. Express* 32, 26884–26895 (2024)

Efficient Integrated Spin-Wave Quantum Memory

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Spin-wave quantum memory, capable of long-lived storage and on-demand retrieval of quantum states, is pivotal for practical applications in scalable quantum networks [1,2]. The storage efficiency of spin-wave quantum memory is a key performance merit, as higher efficiency directly boosts the rate of entanglement distribution in quantum repeaters. Although optical impedance-matched cavities have been employed to improve efficiency [3,4,5], realizing a highly efficient spin-wave quantum memory remains challenging. Previously, using 200-μm-thin membranes of Eu^{3+}:Y_2SiO_5 coupled with fiber-based microcavities, we have achieved a 2-μs storage efficiency of 69.8(1.6)% for telecom-heralded single photons. In this study, we advance the platform by adopting a more integrated architecture featuring 100-μm-thin membranes of Eu^{3+}:Y_2SiO_5 coupled with fiber-based microcavities, and implement a control field in a non-collinear geometry, aiming to achieve an efficient spin-wave quantum memory with extended storage lifetime.

[1] M. Afzelius, C. Simon, H. de Riedmatten, and N. Gisin, Phys. Rev. A **79**, 052329 (2009).
[2] T.-X. Zhu et al., Natl. Sci. Rev. , **11**, nwae161 (2024).
[3] P. Jobez et al., New J. Phys. **16**, 083005 (2014).
[4] M. Sabooni et al., Phys. Rev. Lett., **110**, 133604 (2013).
[5] S. Duranti et al., Opt. Express , **32**, 26884 (2024).

Efficient solid-state quantum memory for telecom-heralded single photons

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Scalable quantum networks require quantum repeaters based on terrestrial fiber-optic networks and quantum memories [1]. Storage efficiency is a key metric for evaluating quantum memory performance, and improving it can significantly boost the rate of quantum entanglement distribution and remote quantum communication. However, all previous demonstrations of efficient solid-state quantum memories [2, 3], easily integrated for practical applications, are implemented with attenuated coherent pulses rather than entangled quantum photons. Here, we demonstrate the efficient storage of single photons with the heralding photon at the telecom C-band using 200-μm-thin membranes of Eu^{3+}:Y_2SiO_5 integrated with fiber-based microcavities (FBC). Heralded single-photon generation is achieved via cavity-enhanced nondegenerate spontaneous parametric down-conversion, producing photon pairs at 580 nm and 1537 nm. These telecom-heralded 580-nm single photons are stored in the FBC quantum memory with a storage efficiency of (69.8±1.6)% at 2 μs and temporal multiplexing capability. Our work provides a direct practical interface for long-distance quantum networks.

[1] X. Liu et al., *Nature*, **594**, 41–45 (2021)
[2] M. P. Hedges et al., *Nature* **465**, 1052–1056 (2010)
[3] S. Duranti et al., *Opt. Express* **32**, 26884–26895 (2024).

Entanglement storage in a highly multimode $^{171}Yb^{3+}:Y_2SiO_5$ quantum memory

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Quantum repeaters would allow for the distribution of entanglement between remote nodes at a faster rate than via direct distribution of a photon pair, by exploiting single photon storage in quantum memories. A promising memory platform is an absorptive solid-state quantum memory based on an ytterbium-doped Y_2SiO_5 crystal, of which an inhomogeneously broadened optical transition is shaped into a broadband atomic frequency comb (AFC) [1,2].

We generate time-energy entangled pairs of 1550/979 nm photons via spontaneous parametric down conversion and demonstrate single-photon storage of the 979 nm photon with a storage time of 125 us in our 250 MHz-bandwidth $^{171}Yb^{3+}:Y_2SiO_5$ AFC memory, corresponding to a temporal multimode capacity of more than 10’000. The 1550 nm photon is sent through a 25 km fiber delay line, and we obtain a normalized 1550/979 cross-correlation of 60 for a 12.5 ns mode duration, well above the classical limit of 2. Furthermore, we verify the preservation of the time-energy entanglement between the 1550 nm photon and the reemitted 979 nm photon by observing two-photon quantum interference via a Franson-type setup with 96% visibility, and performing a full Bell test, violating the Clauser–Horne–Shimony–Holt inequality with parameter S=2.67(4) by more than 16 standard deviations, mostly limited by multipair generation. In addition, we performed a Bell test using a 979 nm photon stored for 63 us in our quantum memory, and a flying telecom photon sent for a 28 us-long trip to a remote location 5.66 km away from the quantum memory, obtaining S=2.66(4).

[1] M. Afzelius et al., *Phys. Rev. A* ***79****, 052329* (2009)
[2] M. Businger et al, *Nat Commun 13, 6438* (2022)

Frequency-stabilised membrane external-cavity surface-emitting laser emitting at 995 nm for Pr:YSO quantum memories

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Implementing the off-resonant cascaded absorption (ORCA) quantum memory protocol [1] in Pr:YSO enables the use of 1550 nm signal photons (targeting the $^3H_4 \leftrightarrow {}^3F_3$ transition), compatible with the mature, relatively low loss telecom infrastructure, making quantum networks a reality. While narrow linewidth, telecom band sources with high powered amplification is relatively commonplace, the systems required for the control field in this implementation require a far less served 995 nm emission to target the $^3F_3 \leftrightarrow {}^1D_2$ transition. Typically, tapered amplifiers are used for this amplification at this wavelength, but they suffer from extremely asymmetric output beam profiles resulting in loss from poor coupling efficiencies into single-mode fibres. Having sufficient powers of both wavelengths also permits the generation of 606 nm via sum-frequency conversion for addressing the $^3H_4 \leftrightarrow {}^1D_2$ transition for writing atomic frequency combs (AFCs) [2] with spectral hole burning. Combining with a ladder memory protocol, longer, quasi-on demand, noise free quantum memory can be achieved. Both protocols require overcoming the losses in the system that are intrinsic to acousto-optic modulators used for temporally and spectrally shaping the light.

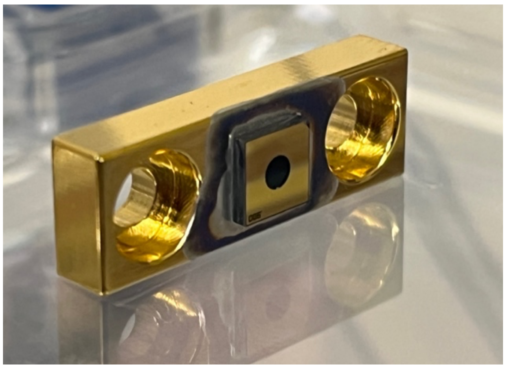

Figure 1: MECSEL gain chip from 21 Semiconductors GmbH, soldered to a gold-plated copper sub mount.

Membrane external-cavity surface-emitting lasers (MECSELs), consist of an optically pumped, semiconductor quantum-well gain structure sandwiched between two heat-spreaders [3]. An evolution of the semiconductor disk laser, the mirror in which such gain chips are typically grown on top of is discarded, allowing for higher output powers thanks to the superior thermal management. The resulting system is compact, achieves high output powers while retaining excellent beam quality, tunability, and narrow instantaneous linewidth. Furthermore, removing the bonded reflectors allows for greater flexibility in cavity design, enabling exploration of novel laser physics, such as in-plane, coherent, waveguide lasing arrays [4] and bi-frequency operation through structured external cavity mirrors [5]. Here, we present our development of an actively stabilised MECSEL system for 995 nm generation, where we aim to demonstrate the technology's first integration into a complex, quantum optics experiment.

[1] K. T. Kaczmarek et al., *Phys. Rev. A,* **97**, 042316 (2018)
[2] M. Afzelius et al., *Phys. Rev. A,* **79**, 052329 (2009)
[3] H. Kahle et al., *Optica,* **3**, 1506-1512 (2016)
[4] J. R. C. Woods et al., *Opt. Express*, **30**, 32174-32188 (2022)
[5] J. Daykin et al., *PLoS ONE*, **18**, 7 (2023)

Global-scale quantum networking using hybrid-channel quantum repeaters with relays based on a chain of balloons

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Global-scale entanglement distribution is the foundation of quantum networks, but is challenging to achieve due to the unavoidable losses in communication channels[1]. Terrestrial fiber-based quantum repeaters place high demands on the performance of quantum memory, while the recent proposals about satellite-assisted free-space channels lack short-term feasibility and flexibility.

Here, we propose a global-scale quantum networking scheme called the hybrid quadruple-link quantum repeater (H4QR), based on hybrid-channel quantum repeaters that combine ground-based quantum repeaters and a novel backbone channel of balloon-based aerial relays. Servers are interconnected globally via a chain of balloons, while clients link to local servers through fiber connections, facilitating rapid client switching and network scalability.

For the balloon-based aerial relays, we demonstrate for the first time that atmospheric disturbances[2,3] in balloon-based channels can be effectively mitigated by optimizing beam waist positions and employing a series of adaptive optics systems, which boosts the channel efficiency to -21 dB over a 10,000 km distance, outperforming satellite-based relays by 12 dB with the same device parameters.

Finally we simulate our scheme, with state-of-the-art Eu^{3+}:Y_2SiO_5 quantum memories and mature entanglement sources based on spontaneous parametric down-conversion, demonstrating an entanglement distribution rate[4] in the sub-Hertz range between clients separated by 10,000 km. This approach offers a practical path toward global quantum networking in the near future.

[1] Neumann, S. P. et al., *Nature Communications* **13**, 6134 (2022).
[2] Scriminich, A. et al., *Quantum Science and Technology* **7**, 045029 (2022).
[3] Karakosta-Amarantidou, I. et al., *Physical Review Research* **7**, 023199 (2025).
[4] Collins, O. A. et al, *Physical Review Letters* **98**, 060502 (2007).

High heralding efficiency c-SPDC source compatible with telecommunication networks and a $^{151}Eu^{3+}$:Y_2SiO_5 quantum memory

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Quantum repeaters using multimode quantum memories enable the heralding of entanglement between long-distance nodes at a faster rate than direct distribution of a photon pair state [1]. To work in the regime with the fewest losses , one of the photons must be at telecom C-band wavelength, while the other one photon must be compatible with the memory. Rare earths ions in solid state crystals are promising platforms for optical quantum memories, and in particular $^{151}Eu^{3+}$: Y_2SiO_5 is extremely interesting thanks to its uniquely long spin coherence times, which can reach hours in some experimental configurations under magnetic field [2]. It is possible to shape one of the optical transitions into an atomic frequency comb (AFC) [3]: therefore, the other photon of the pair must be at 580 nm.

We designed a photon pairs source based on spontaneous parametric down-conversion (SPDC), that will convert a 422 nm pump photon into pairs of 580 nm and 1552 nm photons, respectively referred to as signal and idler, through a periodically poled potassium titanyl phosphate crystal (ppKTP). Because SPDC photons have linewidiths several order of magnitude higher than the bandwidth of the memory, we can embed the SPDC crystal inside a cavity in order to engineer the linewidth, reducing the latter to the order of the memory linewidth. The other requirement of the cavity is to increase the heralding efficiency of the source, which is the probability to measure a signal photon after the detection of the idler photon. To do so, we reduce the losses inside the cavity, which are mainly introduced by the crystal. The final design of the cavity is in the bow-tie configuration, with a narrow angle (10°) to correct the astigmatism of the beam and facilitate the collection of the generated photons. The expected heralding efficiency is of 66%, which accounts for the escape efficiency of the photons from the cavity (94%) and the collection efficiency of the signal photons (70%). The source will be locked to the memory transition frequency, since this resonance is crucial for any practical application.

After the characterization of the source, we will need to interface the generated photons with the memory for single-photon storage with the high efficiency previously demonstrated in the group [4], and to show the preservation of the time-energy entanglement between the telecom photon and the stored 580 nm photon.

[1] C. Simon et al., *Phys. Rev. 98*, 190503 (2007)
[2] Y. Ma et al., *Nat. Commun.* **12**, 2381 (2021)
[3] M. Afzelius et al., *Phys. Rev. A* **79**, 052329 (2009)
[4] J. Chen et al., *Quantum Science and Technology* **10**, 025060 (2025)

Optical coherence and hyperfine structure of the $^7F_0 \leftrightarrow {}^5D_0$ transition in Eu^{3+}:$CaWO_4$

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Rare-earth ions doped in crystals with low nuclear-spin densities are highly promising candidates for quantum technology applications [1-5]. In this study, we investigated the spectroscopic properties of the $^7F_0 \leftrightarrow {}^5D_0$ optical and the hyperfine transitions of Eu^{3+} ions in a $CaWO_4$ crystal, where the nuclear spin arises solely from the ^{183}W isotope, with a natural abundance of 14% [6]. At a temperature of 3 K, we experimentally identified four distinct crystal field environments for Eu^{3+} ions in a 0.1 at.% Eu^{3+} doped $CaWO_4$ crystal. The optical coherence properties of Eu^{3+} ions in these environments were characterized. Additionally, we resolved the hyperfine structures in the $^7F_0$ ground state and $^5D_0$ excited state, and determined the $^7F_0$ ground state lifetimes using spectral hole burning techniques. These findings highlight the significant potential of Eu^{3+}:$CaWO_4$ for optical quantum memory applications.

[1] M. T. Uysal, M. Raha et al., *PRX Quantum*, **4**, 010323 (2023).
[2] S. Kanai, F. J. Heremans et al., *Proc. Natl. Acad. Sci. USA*, **119(15)**, 1-8 (2022).
[3] M. Dantec, M. Rani et al., *Sci. Adv*, **7**, eabj9786 (2021).
[4] M. T. Uysal, L. Dusanowski et al., *PRX*, **15**, 011071 (2025).
[5] F. Becker, C. L. Curtin et al., *Phys. Rev. Materials*, **9**, 076203 (2025).
[6] P. Garbacz, W. Makulski et al., *Chem. Phys*, **498-499**, 7-11 (2017).

Precise spatial confinement of optical excitation by STIRAP variations in Pr:YSO

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We experimentally demonstrate precise spatial confinement of optical excitation by STIRAP in a Pr:YSO crystal. The size of the excitation region is far smaller than the diameter of the driving laser pulses and, under optimised conditions, even exceeds the diffraction limit at 300 nm. To probe such small optical excitation volumes, we developed a STIRAP autocorrelation technique. The experimental results show excellent agreement with numerical simulations (see Fig. 1 (left)). In an extension of the project and beyond conventional STIRAP, we also applied a novel scheme based on tripod-STIRAP to demonstrate coherent preparation of spatially highly confined, long-lived two-dimensional excitation patterns in Pr:YSO (see Fig. 1 (right)) which is not possible by other means. Our work proves that STIRAP and its variants are a powerful tool to spatially confine optical excitations, in principle with arbitrary resolution even below the diffraction limit. The findings are of relevance for quantum computing, e.g., to suppress cross-talk between neighboured qubits, or applications in classical high-resolution microscopy.

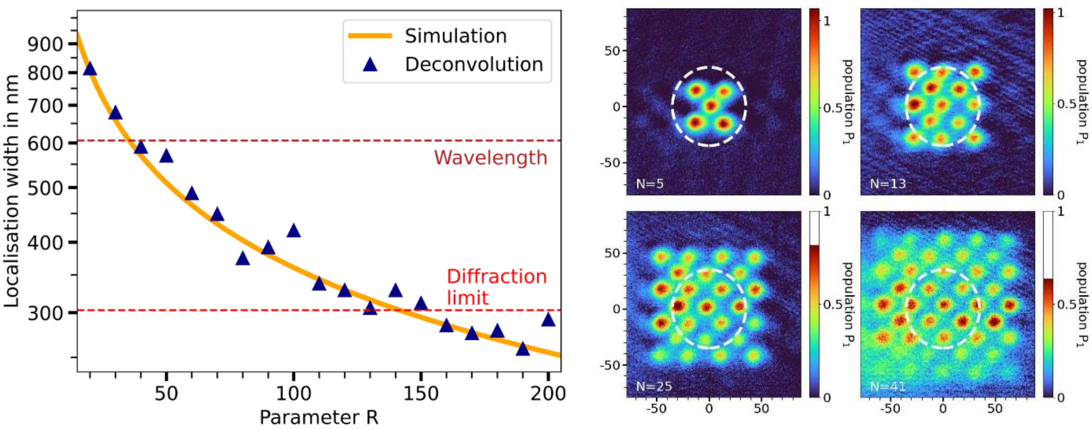

Figure 1: (left) Spatial width of the optical excitation region (FWHM) in Pr:YSO driven by STIRAP, vs. ratio of pump and Stokes Rabi frequencies $R = \Omega_P^2/\Omega_S^2$, i.e. essentially the ratio of laser intensities. We compare the experimental results from the autocorrelation measurements (blue triangles) to a numerical simulation (orange line). Though the laser beam diameter is large with w = 13 µm STIRAP enables confinement of the excitation region far below the laser beam diameter and even below the diffraction limit around 300 nm. (right) Two-dimensional grids of optical excitation driven by tripod-STIRAP. The data show preparation of 5, 13, 25 and 41 excitation cells well below the diameter of the driving laser beam (dotted white line).

Progress towards a second long high efficiency AFC quantum memory

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Future quantum communication networks rely on quantum memories in quantum repeater to overcome signal loss. Important parameters to maximize for quantum memories are the storage time, storage efficiency, multi-modality, and fidelity. In this work, we demonstrate light storage based on atomic frequency combs (AFC) in a Pr^{3+}:Y_2SiO_5 crystal, employing zero first order Zeeman shifts (ZEFOZ) and dynamical decoupling. In a first experiment, we measured storage efficiencies greater than 5% at storage times of 2.5 s (see Figure 1) below. This is already an improvement of nearly one order of magnitude in both storage efficiency and storage time in comparison to previous AFC experiments (0.5% at 0.5 s by the group of M. Afzelius).

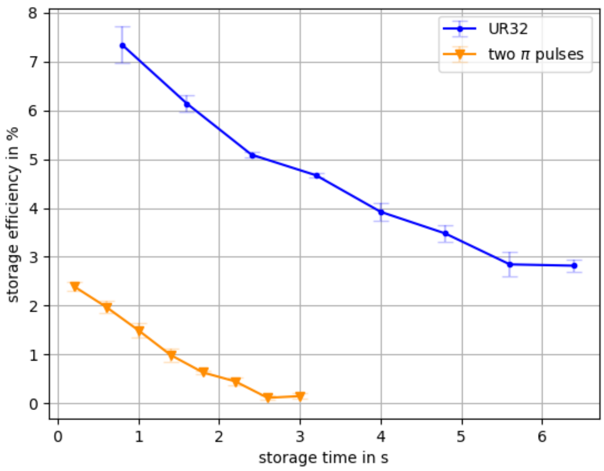

Figure 1. Light storage efficiency over storage time at ZEFOZ with two π-pulse *rephasing (orange) and the error-correcting rephasing sequence UR32 (blue).*

Quantum storage of photonic qubits for 5.6 seconds

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Photonic quantum memory works by mapping photonic qubits onto the quantum states of a storage medium, allowing them to be retrieved on-demand after a controlled delay. Rare-earth-doped crystals are regarded as promising candidates for such memories due to their favorable properties. However, their optical quantum memory implementations currently exhibit storage lifetimes of only about 20 milliseconds at the single-photon level. In our work, we use $^{151}Eu^{3+}:Y_2SiO_5$ crystal to achieve on-demand photonic quantum storage with a storage time of 5.6 seconds and a storage efficiency of 8.17%. Additionally, we demonstrate time-bin qubit storage and verify that its fidelity exceeds the classical threshold. This long-lived quantum memory not only presents distinct advantages in multi-photon quantum communication, but also shows great potential for realizing mobile photonic quantum memory.

Quiet Echoes: A Noiseless Quantum Memory in Er^{3+}:Y_2SiO_5

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Photon echo-based protocols offer a natural route to optical quantum memories, thanks to their intrinsic multimode capacity and compatibility with solid-state ensembles. However, conventional two-pulse photon echo (2PE) schemes are fundamentally limited by gain and spontaneous emission arising from population inversion. To overcome this, rephasing-based protocols such as the revival of silenced echo (ROSE) [1] and, more recently, the four-level noiseless photon echo (NLPE) [2] have been proposed to preserve the benefits of optical rephasing while eliminating inversion-induced noise.

We present the first demonstration of the NLPE protocol in erbium-doped yttrium orthosilicate (Er^{3+} :Y_2 SiO_5). Initial characterization has shown a write time of 175.8 μs and a spin-wave storage time of 22.1 μs. A peak memory efficiency of 15% was measured, limited primarily by polarisation mismatch between the counter-propagating control pulses. The retrieved echo exhibits high temporal fidelity with the input, and noise analysis confirms suppression of the primary echo, in agreement with theoretical expectations for noiseless operation.

[1] Damon, Vianney, et al. "Revival of silenced echo and quantum memory for light." New Journal of Physics 13.9 (2011): 093031.

[2] Ma, You-Zhi, et al. "Elimination of noise in optically rephased photon echoes." Nature Communications 12.1 (2021): 4378.

Ridge Architectures in Y_2SiO_5 for Quantum Memory

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Quantum memories represent fundamental building blocks for quantum information technologies, enabling coherent storage and faithful retrieval of quantum states. Rare-earth-ion-doped crystals distinguish themselves through exceptional coherence times [1] and remarkable multimode storage capacity [2], yet practical implementation requires overcoming the fundamental limitation of inefficient light-matter interactions in bulk systems due to poor spatial overlap between optical mode and active ion ensembles. Ridge waveguide architectures address this challenge by confining optical fields within the active medium, achieving enhanced interaction strength while providing homogeneous electromagnetic field distribution throughout the waveguide length. This integrated photonic approach unlocks spatial multiplexing capabilities through parallel waveguide channels on single substrates. The architecture enables fully integrated quantum photonic systems combining sources, waveguides, memories, and detectors on a single platform, facilitating simultaneous processing of multiple independent quantum signals for scalable quantum information systems.

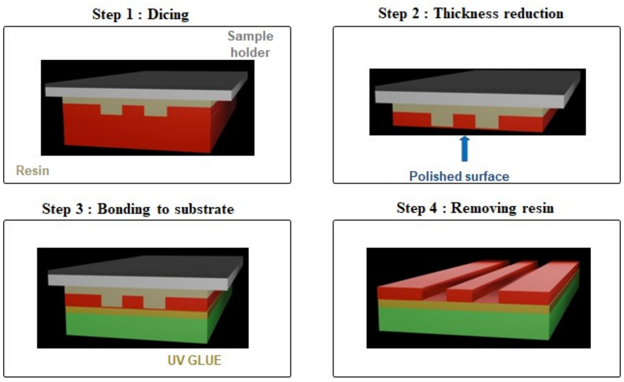

Figure 1: Fabrication protocol of ridge waveguides

This work addresses the critical challenge of fabricating integrated ridge waveguides in $Pr^{3+}:Y_2SiO_5$ crystals. Through simulations, we first determine optimal waveguide dimensions that maximize coupling efficiency with the active medium while ensuring compatibility with standard optical fibers.

We developed a fabrication protocol that implements four sequential steps, as illustrated in the figure. This purely mechanical approach eliminates any potential alterations that could compromise the crystal's intrinsic characteristics. Cryogenic spectroscopic experiments also demonstrate that this protocol successfully maintains fundamental spectroscopic characteristics, including absorption linewidth properties and Zeeman splitting behavior.

In this poster, we present the complete fabrication methodology and demonstrate manufactured waveguides achieving dimensions of up to 4 mm in length with 15 µm width and 30 µm thickness. The fabricated waveguides and their initial optical characterization establish the viability of this mechanical fabrication approach for quantum memory applications

[1] M. Zhong et al., Nature 517, 177 (2015). https://doi.org/10.1038/nature14025

[2] A. Seri et al., Phys. Rev. Lett. 123, 080502 (2019). https://arxiv.org/abs/1902.06657

Low-vibration cryostat towards high-performance quantum memories in a rare-earth ion-doped crystal

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Quantum memories have been an active research in quantum optics, for they are essential for quantum information processing. One of the most prominent platforms is rare-earth ion-doped crystals, used with the atomic frequency comb (AFC) protocol [1]. To reach the highest coherence times, these crystals need to be cooled down at cryogenic temperatures (~3 K), but current state-of-the-art commercially available closed-cycle systems suffer from inevitable vibrations, caused either by mechanically moving pieces or gas turbulences. Such vibrations induce detrimental piezospectroscopic shifts, that hinder the preparation of fine population structures, as required for the AFC protocol [2].
We present here the development of a cryostat whose architecture is designed for minimizing vibration propagation between the cold head and the sample. The body of the cryostat, the radiation shieldings as well as sample pieces were all machined in order to achieve high precision adjustment in the space-constrained environment of the cryostat, where the final currently operating version is shown in Figure 1. Our realization aims at being simultaneously low vibration, compact as well as modular, while reaching a base temperature below 4 K. The key vibration isolation feature is a mechanical decoupling between the cold head part and the experimental chamber via elastic vacuum connection and via the use of copper braids for thermal connection.
We estimate the performances of the cryostat by two means. The first means consists in burning a narrow hole in the inhomogeneously broadened absorption line of a praseodymium-doped yttrium orthosilicate (Pr:YSO) crystal. By monitoring in real time the hole width and position, we assess the effect of vibration on spectral features. With our setup we reach hole widths of 20 kHz, monitored with a free-induction decay (FID) protocol, for durations of the order of 400 ms, as shown in Figure 2. The second characterization means consists in implementing the AFC protocol in the Pr:YSO crystal for storage of coherent states of light, for storage durations ranging between 2 and 70 µs. By fitting the exponential decay of the efficiency η as a function of the storage time τ, we reach a coherence time T_2 of 88 µs, already at the level of state-of-the-art values.

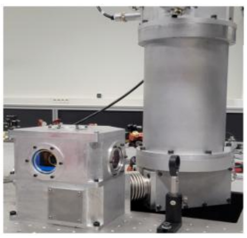

Figure 1: The cryostat chamber (left) and the cold head housing (right)

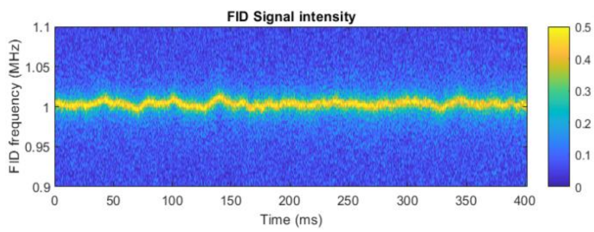

Figure 2: Spectral hole position tracking using FID protocol

[1] M. Afzelius, C. Simon, H. de Riedmatten, and N. Gisin, "Multimode quantum memory based on atomic frequency combs", Physical Review A 79, 052329 (2009)

[2] A. Louchet-Chauvet, R. Ahlefeldt and T. Chanelière "Piezospectroscopic measurement of highfrequency vibrations in a pulse-tube cryostat", Rev. Sci. Instrum. 90, 034901 (2019).

A solid-state quantum memory array at the single-photon level

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Long-distance quantum communication relies on quantum repeaters to overcome signal loss and decoherence. In a quantum network with repeater architecture, distant nodes are entangled through entanglement swapping, which is heralded by a classical signal. However, the entanglement rate is constrained by the travel time of heralding signals used in these repeaters. Multi-mode quantum memories address this limitation as successive entanglements attempts are generated in a multiplexed fashion. In this poster, we present a solid-state quantum memory array with 10 individual controllable memory cells. By combining spatial and temporal multiplexing, we demonstrate on-demand storage at the single photon level in 60 and 250 modes. We measure nonclassical correlations between AFC memories and telecom photons across all 10 spatial modes of average $g^{(2)}$=34(4).

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