Light-Matter Interfaces for Quantum Enhanced Technologies

19-23 Sept. 2021
Oxford,
United Kingdom

www.limquet.eu

International conference and workshop on quantum interfacing light and matter, new concepts and developments and applications in modern quantum technologies.

The conference will be held simultaneously at Christ Church, a 500-year old Oxford college and online, with numerous invited talks and presentations by the Early-State Researchers of the EU ITN LIMQUET.

More information is available at www.limquet.eu

Axel Kuhn
(University of Oxford, Local Organiser and Chair)

Stephane Guerin
(Université Bourgogne Franche-Comté, LIMQUET Coordinator)

Juan Rafael Alvarez
(University of of Oxford, Student Workshop Organiser)

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Conference Programme

LIMQUET 2021 School

All talks will be presented online at [zoom.us/my/limquet.2021] with passcode **Oxford**
All times are displayed in British Summer Time, GMT +01

Time	Monday 20	Tuesday 21	Wednesday 22	Thursday 23
07:30-09:00	**Breakfast**	**Breakfast**	**Breakfast**	**Breakfast**
08:45-09:00	Welcome (A.K.)			
09:00-09:45	Jakob Reichel	Gerhard Rempe	Hugues de Riedmatten	**Oxford Session:** Robert Taylor Jason Smith David Lucas Axel Kuhn
09:45-10:30	Mete Atatüre	Francisco Garcia Vidal	Charles S. Adams	
10:30-11:00	**Coffee break**	**Coffee break**	**Coffee break**	**Coffee break**
11:00-11:45	Jean-Pierre Hermier	Andrea Alberti	Morgan Mitchell	Juan Alvarez Cecilia Muldoon
11:45-12:30	Brahim Lounis	Jürgen Eschner	Stefanie Barz	John Dudley
12:30-13:45	**Lunch**	**Lunch**	**Lunch**	**Lunch**
13:45-14:30	Robert Nyman	Giovanna Morigi	Arno Rauschenbeutel	ESR talks
14:30-15:15	Michael Vanner	Christoph Becher	Almut Beige	Departure
15:15-15:45	**Coffee break**	**Coffee break**	**Coffee break**	
15:45-16:30	Thomas W. Ebbesen	Jon Goldwin	Tracy Northup	
16:30-17:15	Jean-Jacques Greffet	Astghik Saharyan Sergiy Stryzhenko Ana Micevic	Mouhamad Al-Mahmoud Corentin Pignot Mateja Prslja	
18:00-19:00	**Virtual Drinks and Discussions on Gather Town**			
		LIMQUET board meeting (17:30-19:00)		
19:00			**Drinks Reception**	
19:30	**Dinner**	**Dinner**	**Dinner**	

Session Chairs

Session Chairs are made co-hosts in Zoom in order to moderate questions during and after the presentations.
All times are displayed in British Summer Time, GMT +01

Monday 09:00-10:30 Axel Kuhn
Monday 11:00-12:30 Stéphane Guerin
Monday 13:45-15:15 Jean-Marc Merolla
Monday 15:45-17:15 Christophe Couteau

Tuesday 09:00-10:30 Matthias Keller
Tuesday 11:00-12:30 Mouhamad AL-MAHMOUD
Tuesday 13:45-15:15 Juan Alvarez
Tuesday 15:45-17:15 Thorsten Peters

Wednesday 09:00-10:30 Thomas Halfmann
Wednesday 11:00-12:30 Xiao Yu
Wednesday 13:45-15:15 Nikolay Vitanov
Wednesday 15:45-17:15 Slava Tzanova

Thursday 09:00-10:30 Ana Mićević
Thursday 11:00-12:30 Cécil Pham
Thursday 13:45-15:15 Axel Kuhn

Virtual Drinks and Discussions

Please install Gather Town (https://www.gather.town) on your computer. It allows us to walk around in a virtual landscape and gather for individual meetings in smaller groups. Very much like moving an avatar through an old-fashioned adventures computer game. All very experimental!

Meeting space: https://gather.town/app/tB9m07S3uqiYGVjT/LIMQUET%202021
Password: Oxford

LIMQUET Board Meeting

Tuesday 17:30 - 19:00

Further information, agenda and Zoom link provided to PIs only.

Book of Abstracts

LIMQUET 2021 School

All talks will be presented online at zoom.us/my/limquet.2021 with passcode **Oxford**
Arrival and check-in in the afternoon/evening of Sunday 19 September for those attending the conference in person.

Monday, September 20th

07:30-08:45
Breakfast

08:45-09:00
Conference opening

09:00-09:45
Fiber Fabry-Perot cavities for quantum technologies
Jakob Reichel, *Laboratoire Kastler Brossel de l'ENS*

Light-matter quantum interfaces often involve a close encounter of foundational quantum science and cutting-edge technology. I will discuss properties of fiber Fabry-Perot cavities with laser-machined mirrors and how they come to bear in some recent applications such as the generation of spin squeezing for an atomic clock on a chip.

09:45-10:30
Mete Atatüre

10:30-11:00
Coffee break

11:00-11:45
Quantum plasmonics with a single emitter
Jean-Pierre Hermier,
Université Versailles Saint-Quentin-en-Yvelines, Université Paris-Saclay

Plasmons offer the possibility to confine light at sub-wavelength scales and to miniaturize photonic components. In the field of quantum optics, this property allows to enhance light-matter interactions. In this presentation, we will first briefly introduce the main properties of plamon resonances. We will give an overview of the field of quantum plasmonics and then focus on the coupling between a single quantum emitter and plasmonic structures. In the weak coupling regime, we will show that nanofabrication techniques allow to amplify the optical excitation, to increase the spontaneous emission rate but also to improve the emission directivity or to reduce the optical losses inherent to metallic structures. Finally, we will present some promising quantum plasmonic devices.

11:45-12:30

Tailoring the degree of entanglement of two coherently coupled quantum emitters

Brahim Lounis, *University of Bordeaux*

The control and manipulation of quantum-entangled non-local states is a crucial step for the development of quantum information processing. A promising route to achieve such states on a wide scale is to couple solid-state quantum emitters through their coherent dipole-dipole interactions. Entangling the electronic states of coherently interacting solid-state emitters is challenging since it requires both a coupling strength larger than the coherence decay rate, implying nanometric distances between the emitters, and quasi-degenerate optical transitions, detuned by less than their coupling strength. Single aromatic molecules embedded in well-chosen solid matrices at liquid helium temperatures are unique candidates to achieve this goal, as they have proven to be test-bench systems for quantum optics. Due to their random spatial distribution in the host crystal and the variety of local matrix environments that span their optical resonances within an inhomogeneous band, fulfilling the requirements of space and transition-frequency proximities of the molecules remains a challenge. Further challenges are to manipulate the degree of entanglement of pairs of molecules having frozen geometries and dipole orientations, and selectively address any quantum entangled state.

We use hyperspectral superresolution imaging in highly doped molecular crystals to reveal pairs of coupled fluorescent molecules. We demonstrate the manipulation of the degree of entanglement of coupled molecules through Stark shifts of their optical resonances. We achieve maximal entanglement with nearly pure subradiant and superradiant Bell states. We also show that delocalized molecular electronic states can extend over distances as large as 60 nm, which opens up attractive perspectives in terms of addressability. Interestingly, optical nanoscopy images of the entangled molecules unveil novel spatial signatures that result from quantum interferences in their excitation pathways.

12:30-13:45

Lunch

13:45-14:30

Phase transitions of light in a dye-filled microcavity

Robert Nyman, *Imperial College London*

Interactions between light and matter mediated by an optical resonator are familiar in quantum optics, but they also show behaviour from the statistical mechanics text book, such as a phase transitions.

Our experiments are based around liquid dye between two mirrors placed about 1 micron apart. We have two control main parameters: how hard we pump the matter, and how strongly the light is re-absorbed (effectively controlled by the cavity length). From both simulations and experimental data, I will show the phase diagram of light, how both between lasing (low re-absorption) and Bose-Einstein condensation (BEC, for strong re-absorption) regimes exist, as well as a multi-mode or fragmented condensate.

By controlling the density of states for light, we push the BEC regime so that threshold is found for as few as 7 photons. In doing so we use clustering algorithms to define a "fuzzy phase diagram" wherein phase transitions are broadened by the finite size of the system. We will also explore the dynamics and fluctuations around the mean of the transition, finding that lasing and BEC are stochastic not deterministic processes.

14:30-15:15

Brillouin optomechanics in whispering-gallery-mode microresonators: From strong coupling to single-phonon addition and subtraction operations

Michael R. Vanner, *Imperial College London*

Backward Brillouin scattering in whispering-gallery-mode micro-resonators offers an exciting avenue to pursue both classical and quantum optomechanics applications. Our team—the Quantum Measurement Lab (qmeas.net)—together with our collaborators, are currently utilizing this regime and the favourable properties it affords for non-Gaussian motional state preparation of the acoustic field. In particular, the high mechanical frequencies, strong optomechanical coupling, and low optical absorption and heating provide a promising route to overcome current hindrances within optomechanics. Three of our recent results in this area include: (i) the observation of Brillouin optomechanical strong coupling [1], single-phonon addition or subtraction to a thermal state of the acoustic field [2], and performing phase-space reconstruction of non-Gaussian states generated by single- and multi-phonon subtraction [3]. This talk will cover these three results, what they enable, and the broader direction of our lab including the prospects of this platform for quantum-memory applications.

[1] G. Enzian et al. Optica 6, 7 (2019).
[2] G. Enzian et al. Phys. Rev. Lett. 126, 033601 (2021).
[3] G. Enzian*, L. Freisem*, J. J. Price*, A. Ø. Svela* et al. arxiv:2103.05175 (2021).

15:15-15:45

Coffee break

15:45-16:30

New Properties of Matter in the Strong Coupling Regime

Thomas W. Ebbesen, *USIAS & ISIS, University of Strasbourg & CNRS, France*

Light-matter strong coupling can give rise to a multitude of physical effects through the formation of hybrid light-matter states that have been extensively studied. Over the past decade, its implications for molecular and material properties have been explored revealing much potential as a means for manipulating matter [1,2]. After introducing the fundamental concepts, examples of modified properties under strong coupling in the vacuum limit such as superconductivity, magnetism, charge and energy transport, and chemical reactivity will be given to illustrate this potential.

[1] F.J. Garcia Vidal, C. Ciuti, T.W. Ebbesen, Manipulating matter by strong coupling to vacuum fields, Science 373, eabd336 (2021)
[2] C. Genet, J. Faist, T.W. Ebbesen, Inducing new material properties with hybrid light-matter states, Physics Today 74, 42-48 (2021)

16:30-17:15
Emission and scattering by interacting identical atoms
Jean-Jacques Greffet, *Université Paris-Saclay*

In the first part of the talk, I will consider resonant light scattering by a subwavelength ensemble of identical atoms. While N noninteracting atoms would scatter N2 more than a single atom, we find that N interacting atoms scatter less than a single atom. We analyse this counterintuitive effect in terms of collective modes resulting from the light-induced dipole-dipole interactions [1].

In the second part of the talk, I will discuss single-photon emission and storage. We start with a one-dimensional atom which consists in a single two-level system (TLS) in a cavity with a large Purcell factor so that emission takes place in the cavity mode with high probability. However, a large Purcell factor is detrimental for long-time memory storage. We propose to replace the TLS by a pair of strongly coupled TLSs [2]. The resulting antisymmetric state is subradiant state and its decay rate can be tuned by controlling a detuning between the two TLS. As a result, the pair of atoms can be viewed as an effective TLS with a tuneable decay rate. We discuss the potential of this system to generate time-shaped single photons and to implement a quantum memory.

[1] N.J. Schilder, C. Sauvan, Y.R.P. Sortais, A. Browaeys and J.-J. Greffet, Near-Resonant Light Scattering by a Subwavelength Ensemble of Identical Atoms, Phys.Rev.Lett. 124, 073403 (2020).
[2] I. Shlesinger, P. Senellart, L. Lanco and J.J. Greffet, Time-frequency encoded single-photon generation and broadband single-photon storage with a tunable subradiant state, Optica 8, 95 (2021).

18:00-19:00
Virtual Drinks and Discussions on Gather Town

19:30-22:30
Dinner

Tuesday, September 21st

07:30-09:00
Breakfast

09:00-09:45
Memory-enabled quantum networks: Repeater
Gerhard Rempe, *Max Planck Institute of Quantum Optics*

Quantum light-matter systems as information-processing modules constitute an ideal toolbox for future long-distance quantum communication and distributed quantum computation networks [Daiss et al., Science 371, 614 (2021)]. Incorporating optical fiber technology has additional advantages such as miniaturization and complex architectures [Niemietz et al., Nature 591, 570 (2021)]. Against this backdrop, single atoms in optical cavities have been used, e.g., as passive heralded quantum memories and non-destructive qubit detectors that can speed up a plethora of quantum communication protocols [Distante et al., Physical Review Letters 126, 253603 (2021)]. Most recently, optical cavities have been loaded with two individually addressable atoms in order to implement a random-access quantum memory and a scalable quantum-repeater node for secure quantum key distribution [Langenfeld et al., Physical Review Letters 126, 230506 (2021)]. The talk will discuss challenges and present achievements towards memory-enabled quantum networks.

09:45-10:30
A theoretical perspective on Molecular Polaritonics
Francisco Garcia Vidal, *Autonomous University of Madrid*

When the interaction between light and excitons in matter is strong enough, the photon and matter components mix to create hybrid light/matter states, called polaritons. Traditionally, their hybrid character has been used to achieve new functionalities in which polaritons are utilized as dressed photons. However, over the last ten years, it has become clear that the strong coupling regime can be used in organic materials with an alternative purpose: to significantly modify molecular properties and dynamics by dressing the excitons [1]. Under strong coupling conditions, energy transport in organic materials can be enhanced [2-6] and the energy landscape of the organic molecules can be altered in such a way that photochemical reactions [7-10] and even ground-state chemical reactions [11,12] can be modified.

In this talk I will present our main results in the search for developing an accurate theoretical approach to Molecular Polaritonics, able to capture the complexity of both the internal structure of organic molecules [13] and the electromagnetic fields associated with the nanophotonic structures [14,15] in which molecular polaritons emerge.

[1] Francisco J. Garcia-Vidal, Cristiano Ciuti, and Thomas W. Ebbesen, Science 373, eabd0336 (2021).
[2] Johannes Feist and Francisco J. Garcia-Vidal, Physical Review Letters 114, 196402 (2015).
[3] Carlos Gonzalez-Ballestero et al., Physical Review B 92, 121402 (R) (2015).
[4] Carlos Gonzalez-Ballestero, et al., Physical Review Letters 117, 156402 (2016).
[5] Francisco J. Garcia-Vidal and Johannes Feist, Science 357, 1357 (2017).

[6] Rocío Sáez-Blázquez et al., Physical Review B 97, 241407(R) (2018).
[7] Javier Galego et al., Physical Review X 5, 041022 (2015).
[8] Javier Galego et al., Nature Communications 7, 13841 (2016).
[9] Javier Galego et al., Physical Review Letters 119, 136001 (2017).
[10] Rui E.F. Silva et al., Nature Communications 11, 1423 (2020).
[11] Javier Galego et al., Physical Review X 9, 021057 (2019).
[12] Clàudia Climent et al., Angewandte Chemie International Edition 58, 8698 (2019).
[13] J. del Pino et al., Physical Review Letters 121, 227401 (2018).
[14] Johannes Feist et al., Nanophotonics 10, 477 (2021).
[15] I. Medina et al., Physical Review Letters 126, 093601 (2021).

10:30-11:00
Coffee break

11:00-11:45
Matter waves at their quantum speed limit
Andrea Alberti, *Universität Bonn*

How fast can a quantum system evolve between two states? This question is not only important for its basic nature, but it also has far-reaching implications on future quantum technologies. There are two well-known limits on the maximum evolution rate, named after their discoverers—Mandelstam–Tamm and Margolus–Levitin. Despite their fundamental character, only the Mandelstam–Tamm limit has been so far investigated and exclusively in effective two-level systems.

In this talk, I will report on a recent experimental study [1] where we test both limits in a multi-level system by following the motion of a single atom in an optical trap using fast matter wave interferometry. Our measurements reveal a crossover between the two quantum speed limits, depending on the energy distribution of the quantum state. We find a striking difference between a two-level and a multi-level system—excitations of a multi-level system do not saturate the speed limit but, unexpectedly, produce a small, universal deviation from it.

In the second part of my talk, I will address the related question, what is the fastest route — the quantum brachistochrone—to transport an atom between distant states. We demonstrate [2] coherent transport of an atomic matter wave over a distance of 15 times its size in the shortest possible time. Because of the large separation between the two sites, the two limits above fail to capture the relevant time scale. In contrast, we show that quantum optimal control provides solutions to the quantum brachistochrone problem.
Our results, establishing quantum speed limits beyond the simple two-level system, are important to understand the ultimate performance of quantum computing devices and related advanced quantum technologies.

[1] G. Ness, M. R. Lam, W. Alt, D. Meschede, Y. Sagi, and A. Alberti, "Observing quantum-speed-limit crossover with matter wave interferometry," (2021), arXiv:2104.05638 [quant-ph]
[2] M. R. Lam, N. Peter, T. Groh, W. Alt, C. Robens, D. Meschede, A. Negretti, S. Montangero, T. Calarco, and A. Alberti, "Demonstration of Quantum Brachistochrones between Distant States of an Atom," Phys. Rev. X 11, 011035 (2021)

11:45-12:30
Jürgen Eschner, *Universität des Saarlandes*

12:30-13:45
Lunch

13:45-14:30
Giovanna Morigi, *Universität des Saarlandes*

14:30-15:15
Interfacing of tin-vacancy spin qubits in diamond
Christoph Becher, *Universität des Saarlandes*

For many applications in the field of quantum information processing stationary qubits are required, providing long-lived spin coherence and suitable level schemes for coherent control and efficient optical read out. In addition, transferring the spin information to indistinguishable single photons is necessary e.g. to distribute entanglement in quantum networks.

Color centers in diamond, more specifically the group-IV-vacancy centers, have emerged as promising candidates among solid state qubits. They exhibit favourable features such as individually addressable spins with long coherence times and bright emission of single, close to transform limited photons. Recent experiments have shown that the negatively charged tin-vacancy center (SnV) [1] exhibits a large ground state orbital splitting resulting in the suppression of phonon induced dephasing processes of the spin states, allowing for long spin coherence times at conveniently achievable cryogenic temperatures (>1K) [2]. Among its good spectral qualities such as bright single photon emission and transform limited linewidths [3,4] the indistinguishability of the emitted single photons remains a missing cornerstone to be demonstrated.

By means of Hong-Ou-Mandel interferometry we here investigate the indistinguishability of single photons consecutively emitted by an off-resonantly excited single SnV-center. We find high Hong-Ou-Mandel visibilities, being a direct measure for high indistinguishability of the single photons. We compare the experimental results with the predictions of a theoretical model [5] and extract the magnitude of spectral diffusion potentially affecting single photon indistinguishability in the present system.
For realizing an efficient spin–photon interface we present a planar optical antenna based on two silver mirrors coated on a thin (sub-µm) single crystal diamond membrane. Employing off-resonant excitation, we show a six-fold enhancement of the collectible photon rate from single SnV centers, yielding detection rates of up to half a million photons per second [6].

[1] Iwasaki T. et al., Phys. Rev. Lett. 119, 253601 (2017).
[2] Debroux R. et al., arXiv:2106.00723 (2021).
[3] Trusheim M. E. et al., Phys. Rev. Lett. 124, 023602 (2020).
[4] Görlitz J. et al., New J. Phys. 22, 013048 (2020).
[5] Kambs B. and Becher C., New J. Phys. 20, 115003 (2018).
[6] Fuchs P. et al., APL Photonics 6, 086102 (2021).

15:15-15:45
Coffee break

15:45-16:30
Cold-atom Ring Laser
Jon Goldwin, *University of Birmingham*

I describe our experiments with a laser comprising cold atoms in an optical ring cavity. In the absence of pumping light, the atom-cavity system operates in the collective strong coupling regime of cavity QED. When the column density of atoms exceeds a threshold value, the magneto-optically trapped atoms undergo a transition to lasing without the need for any additional fields. The laser exhibits random switching between clockwise and anti-clockwise modes as well as a controllable breaking of symmetry between the two directions. Hanbury Brown-Twiss interferometry below the lasing threshold shows the coherence time can be extended by two orders of magnitude via a combination of gain and group index. Our current work aims to exploit this system to demonstrate cavity-assisted magnetometry in both passive and active (lasing) modes of operation.

16:30-16:45
Light-matter interaction in open cavities with dielectric stacks for quantum information processing with single photons
Astghik Saharyan, *Université de Bourgogne Franche-Comté (LIMQUET ESR)*

We evaluate the exact dipole coupling strength between a single emitter and the radiation field within an optical cavity, taking into account the effects of multilayer dielectric mirrors. Our model allows one to freely vary the resonance frequency of the cavity, the frequency of light or atomic transition addressing it and the design wavelength of the dielectric mirror. The coupling strength is derived for an open system with unbound frequency modes. For very short cavities, the effective length used to determine their mode volume and the lengths defining their resonances are different, and also found to diverge appreciably from their geometric length, with the radiation field being strongest within the dielectric mirror itself. Only for cavities much longer than their resonant wave- length does the mode volume asymptotically approach that normally assumed from their geometric length.

16:45-17:00
Four-wave mixing with Rubidium-87 in a hollow-core fiber
Sergiy Stryzhenko, *Technische Universität Darmstadt (LIMQUET ESR)*

Four-wave mixing (FWM) is a nonlinear optical process that enables generation of photon pairs which can be used for quantum communication protocols. Such biphoton sources have been demonstrated for hot and cold free-space atomic ensembles where full control over the laser fields' polarization is possible.
We here discuss an implementation of such FWM process inside a hollow-core fiber filled with cold Rubidium-87 atoms. Although good mode matching is easily achieved in such fiber, the relative polarizations of the laser fields cannot be chosen arbitrarily.

This talk will be focused on simulating these experiments using the rotating wave and the Weisskopf-Wigner approximation. The simulation takes into account all Zeeman sublevels and predicts the polarization states of the generated biphotons.

17:00-17:15
Universal electro-optic modulator
Ana Micevic, *QuBIG GmbH (LIMQUET ESR)*

Phase, amplitude, and polarization modulation of laser light play a significant role in the area of quantum computation and quantum cryptography. Electro-optic modulators allow for external modulation of laser light without affecting its linewidth and stability. Combining all three types of modulation in one device could reduce the complexity of experimental setups significantly. We propose two different solutions to this problem suitable for different applications.

Arbitrary combination of phase and amplitude modulation can be achieved by introducing one additional degree of freedom into standard amplitude modulator setup which utilizes matched crystal pairs. Unlike in an amplitude modulator, crystals are driven with individual driving voltages, therefore allowing for individual amplitude selection and adjustment of phase between them. Due to practical limitations, the modulation frequencies we achieved with this approach were up to 100MHz, which is significantly higher than previously investigated in the literature [1], but still too low for many applications.

Another approach for achieving all three types of modulation in one device is to use a phase modulator followed by a birefringent crystal [2]. This configuration allows us to achieve modulation in the GHz domain. This device can create not only amplitude and phase modulation, but also a single-sideband spectrum or carrier suppression that can be used, for example, to drive Raman transitions. Different polarization outputs are achieved by tuning the temperature of the birefringent crystal. Combining the device with appropriate polarization elements allows for reaching any point on the Poincare sphere.

[1] Cusack, B. J., Sheard, B. S., Shaddock, D. A., Gray, M. B., Lam, P. K., & Whitcomb, S. E. (2004). Electro-optic modulator capable of generating simultaneous amplitude and phase modulations. Applied optics, 43(26), 5079-5091.

[2] Arias, N., Abediyeh, V., Hamzeloui, S., & Gomez, E. (2017). Low phase noise beams for Raman transitions with a phase modulator and a highly birefringent crystal. Optics express, 25(5), 5290-5301."

18:00-19:00
Virtual Drinks and Discussions on Gather Town

18:00-19:00
LIMQUET board meeting (all LIMQUET PIs)

19:30-22:30
Dinner

Wednesday, September 22nd

07:30-09:00
Breakfast

09:00-09:45
Entangling Quantum Repeater Nodes
Hugues de Riedmatten

09:45-10:30
Charles S. Adams

10:30-11:00
Coffee break

11:00-11:45
Morgan Mitchell

11:45-12:30
Stefanie Barz

12:30-13:45
Lunch

13:45-14:30
Super- and subradiant states of an ensemble of cold atoms coupled to an optical waveguide

Arno Rauschenbeutel, *Department of Physics, Humboldt-Universität zu Berlin*

We experimentally and theoretically investigate collective radiative effects in an ensemble of cold atoms coupled to a single-mode optical nanofiber. Our analysis unveils the microscopic (i.e., atom per atom) dynamics of the system, showing that collective interactions gradually build up along the atomic ensemble in the direction of propagation of the nanofiber-guided excitation light pulses. Our theoretical results are supported by time-resolved measurements of the light transmitted and reflected by the atomic ensemble. In particular, when the excitation pulse is switched off on a time scale much shorter than the atomic lifetime, a superradiant decay up to 17 times faster than the single-atom decay rate is observed in the forward direction, while no speed-up of the decay rate is measured in the backward direction. For longer time scales, our measurements reveal the evolution of the ensemble from the superradiant state to a set of states that are fully subradiant with respect to the nanofiber-guided mode. Notably, our theoretical model identifies this phenomenon as a key feature of the time evolution of one-dimensional systems prepared in a timed Dicke state. This complex dynamics can be accurately described with a simple analytical expression. Our results highlight the unique opportunities offered by nanophotonic cold-atom systems for the experimental investigation of collective light-matter interaction.

14:30-15:15
Local quantum field theories of light
Almut Beige, *University of Leeds*

An intuitive and straightforward modelling of many locally-interacting quantum system requires a local description of the quantised electromagnetic field. In a recent paper [1], we showed that such a description, which must overcome several no-go theorems, is indeed possible. Starting from the assumption that the basic building blocks of the electromagnetic field in one dimension are local bosonic particles with a clear direction of propagation—so-called bosons localised in position (BLiPs)—we identify a Schrödinger equation and construct Lorentz covariant electric and magnetic field observables. In addition we show that our approach simplifies to the standard description of quantum electrodynamics when restricted to a subspace of monochromatic photon Fock states [2]. Our local description of the quantised electromagnetic field can be used to design locally-acting mirror Hamiltonians which only affect incoming but do not change the dynamics of outgoing wave packets [1]. In this talk, we moreover have a closer look at the Casimir effect and show that our local description of provides new insight into the origin of this effect and into the general structure of the quantised electromagnetic field [3].

[1] J. Southall, D. Hodgson, R. Purdy and A. Beige, J. Mod. Opt. 68, 647 (2021).
[2] D. Hodgson, J. Southall, R. Purdy and A. Beige, Quantising the electromagnetic field in position space, submitted. arXiv:2104.04499 (2021).
[3] C. Burgess, D. Hodgson, J. Southall, B. Altaie, A. Beige and R. Purdy, Local relativistic quantisation and the Casimir effect, in preparation (2021).

15:15-15:45
Coffee break

15:45-16:30
Remote entanglement of cavity-coupled trapped ions over 400 m
Tracy Northup, *Universität Innsbruck*

Quantum interfaces between light and matter are the basis for remote entanglement of matter-based qubits, which has been demonstrated on a handful of leading experimental platforms for quantum technologies. We focus on the trapped-ion platform, in which high-fidelity entanglement has previously been achieved between ions in separate vacuum chambers over distance scales of a few meters [1,2,3]. Here, two calcium ions are entangled with one another over a distance of 400 m, via an optical fiber channel linking two buildings. The ion-ion entanglement is based on ion-photon entanglement via a cavity-mediated Raman transition. Entanglement metrics will be analyzed in the context of this Raman process, and extensions to more complex network protocols will be discussed.

[1] D. L. Moehring et al., Nature 449, 68 (2007)
[2] D. Hucul et al., Nat. Phys. 11, 37 (2015)
[3] L. J. Stephenson, D. P. Nadlinger et al., Phys. Rev. Lett. 124, 110501 (2020)

16:30-16:45

Application of coherent quantum control techniques in classical physics

Mouhamad Al-Mahmoud, *University of Sofia (LIMQUET ESR)*

Quantum mechanics is the field of physics describing the motion and the energy in the atomic and the sub-atomic scales. It explains the strange behaviours in these two scales, seeming in full contradiction with classical physics. This strangeness allowed Richard Feynman to say in his book “The character of physical law”: “I think I can safely say that nobody understands quantum physics. However, the clear contradiction between quantum mechanics and classical physics does not negate the possibility to apply analogies between these two fields.” Generally, analogy allows us to transfer concepts from one field to another by searching for the similar mathematical formalism and equations describing different phenomena.

On one hand, the composite pulse technique [1] is widely used in NMR, atomic physics, quantum optics and quantum information, in order to prepare broadband atomic transition especially in two-state quantum systems. This quantum coherent control technique consists of the application of a train of laser pulses with carefully-optimized phase and pulse area each.

Some important domains of classical optics, such as polarization manipulation and nonlinear optical frequency conversion (for instance optical parametric amplification, OPA), can profit from analogies with quantum phenomena and from the composite pulse technique. Polarization is mainly manipulated by polarization rotators composed by a sequence of wave retarders, while the OPA is used to amplify a weak signal at the expense of the presence of an intense pump.

We theoretically suggested and experimentally verified the application of the analogy between the composite pulses technique and two sensitive classical systems such as the polarization manipulation [2,3] and the OPA to make them robust and broadband against the experimental parameters [4]. Another analogy can be applied to other similar systems, such as the analogy between the non-Hermitian system via a dissipative intermediate state [5] and the nonlinear frequency generation in a dissipative system, which also will be discussed.

[1] Vitanov, N. V., Halfmann, T., Shore, B. W., & Bergmann, K. (2001). Laser-induced population transfer by adiabatic passage techniques. Annual review of physical chemistry, 52(1), 763-809.
[2] Al-Mahmoud, M., Coda, V., Rangelov, A., & Montemezzani, G. (2020). Broadband polarization rotator with tunable rotation angle composed of three wave plates. Physical Review Applied, 13(1), 014048.
[3] Stoyanova, E., Al-Mahmoud, M., Hristova, H., Rangelov, A., Dimova, E., & Vitanov, N. V. (2019). Achromatic polarization rotator with tunable rotation angle. Journal of Optics, 21(10), 105403.
[4] Al-Mahmoud, M., Rangelov, A. A., Coda, V., & Montemezzani, G. (2020). Segmented composite optical parametric amplification. Applied Sciences, 10(4), 1220.
[5] Vitanov, N. V., & Stenholm, S. (1997). Population transfer via a decaying state. Physical Review A, 56(2), 1463.

16:45-17:00
Ion-photon entanglement in a Fabry-Perot fibre cavity
Corentin Pignot, *University of Sussex (LIMQUET ESR)*

Ions and photons are some of the most promising qubits to create a quantum network. They give the possibility to create and transfer information at the quantum level. Quantum applications such as quantum key distribution or quantum computing rely on efficient entanglement processes between qubits. In this talk, I will present one scheme to entangle a single calcium 40 ion with a single photon within an optical fibre cavity operating in the strong coupling regime. I will also present a way to measure the fidelity of the process with the use of a second mapping photon. This scheme is being implemented in one of our ion traps and some preliminary results will be shown.

17:00-17:15
Developing a compact wide-field microscope based on NV-diamond magnetometry
Mateja Prslja, *Qutools GmbH (LIMQUET ESR)*

Imaging the magnetic field of magnetic or magnetically labelled samples has become a wanted technique in various scientific areas, e.g. biology, material science, electronics, and geology. Many applications require simultaneously high sensitivity and high spatial resolution over a large field of view at room temperature, which in combination is unattainable with existing methods such as Magnetic Force Microscope or SQUID. The recent and here adapted approach is to use a wide-field microscope with diffraction-limited spatial resolution to image the magnetically sensitive fluorescence of NV-centres in a diamond in proximity to the sample. The Optically Detected Magnetic Resonances in NV-diamonds will be briefly introduced, followed by possible techniques for sensing DC and AC vector magnetic fields. I will then present the idea of our device with an emphasis on specific parts. The compact wide-field microscope based on NV-diamond magnetometry that I develop at Qutools will be available in a scientific and in an education version.

18:00-19:00
Virtual Drinks and Discussions on Gather Town

19:00-19:30
Drinks reception

19:30-22:30
Dinner

Thursday, September 23rd

07:30-09:00
Breakfast

09:00-10:30
Oxford Session

Decreased fast time-scale spectral diffusion of a non-polar InGaN quantum dot
Robert A. Taylor, *University of Oxford*

Spectral diffusion leads to considerable broadening of the linewidth of nitride quantum dots. Here, InGaN quantum dots grown on a non-polar plane were shown to exhibit a decreased spectral diffusion rate compared to polar nitride dots. A robust intensity correlation method was used to measure the spectral diffusion on rate of 6 quantum dots. A maximum spectral diffusion time of 1170(50) ns was found. An increase of the rate with increasing power was observed. Because of the decreased internal field the lifetime of non-polar dots is shorter than those of polar ones, the important ratio of spectral diffusion time to lifetime is more favourable for non-polar quantum dots, thereby increasing the chances of generating indistinguishable photons.

Cavities and colour centres – materials processing for quantum technologies
Jason Smith, *University of Oxford*

The talk will be an overview of our recent work on fabrication of open cavities using focused ion beam milling and on laser writing of colour centres in diamond. Focus will be on the degree of 'engineerability' afforded by these techniques and the advance towards highly parallelised chip-scale devices.

Recent experiments on a two-node ion/photon quantum network
David Lucas, *University of Oxford*

Light-matter interactions in cavities: Single photons for optical quantum processing
Axel Kuhn, *University of Oxford*

10:30-11:00
Coffee break

11:00-11:15
How to administer an antidote to Schrödinger's cat
Juan-Rafael Álvarez, *University of Oxford (LIMQUET ESR)*

In his 1935 Gedankenexperiment, Erwin Schrödinger imagined a poisonous substance which has a 50% probability of being released, based on the decay of a radioactive atom. As such, the life of the cat and the state of the poison become entangled, and the fate of the cat is determined upon opening the box. We present an experimental technique that keeps the cat alive on any account. This method relies on the time-resolved Hong-Ou-Mandel effect: two long, identical photons impinging on a beam splitter always bunch in either of the outputs. Interpreting the first photon detection as the state of the poison, the second photon is identified as the state of the cat. Even after the collapse of the first photon's state, we show their fates are intertwined through quantum interference. We demonstrate this by a sudden phase change between the inputs, administered conditionally on the outcome of the first detection, which steers the second photon to a pre-defined output and ensures that the cat is always observed alive.

11:15-11:45
Physics and Wine
Cecilia Muldoon, CEO of VeriVin Ltd

11:45-12:30
Surviving in Science: what they don't tell you about careers in research!
John Dudley, *Université de Bourgogne Franche-Comté*

Obtaining a PhD is an important and significant achievement in your life, but it is really only the start! A successful career in research requires not only a PhD but also many other skills in multiple areas: from an appreciation of the broader aims of basic science, to writing and communication, to management and leadership. When starting out, the breadth of this required expertise can seem daunting, but the aim of this presentation will be to try to provide simple and practical advice to help early-career researchers to build and enjoy a long term career in photonics. Amongst topics to be covered will be: networking; career options; paper writing and conferences; ethics; transitioning from student to postdoc to team leader; funding opportunities etc.

12:30-13:45
Lunch

13:45-14:30
further ESR presentations

14:30
Departure

List of Attendees:

Name	Online/In person	Affiliation
Almut Beige	In person	University of Leeds
Axel Kuhn	In person	University of Oxford
Cecilia Muldoon	In person	Verivin Ltd
Chloe So	In person	University of Oxford
Corentin Pignot	In person	University of Sussex
Daniel Hodgson	In person	University of Leeds
David Lucas	In person	University of Oxford
Jack Clarke	In person	Imperial College London
Jan Ernst	In person	University of Oxford
Jason Smith	In person	University of Oxford
Jon Goldwin	In person	University of Birmingham
Juan Alvarez	In person	University of Oxford
Marwan Mohammed	In person	University of Oxford
Michael Vanner	In person	Imperial College London
Robert Nyman	In person	Imperial College London
Robert Taylor	In person	University of Oxford
Thomas Doherty	In person	University of Oxford
Alexander Bruns	Online	Technische Universität Darmstadt
Ana Mićević	Online	QUBIG
Andon Rangelov	Online	University of Sofia
Andrea Alberti	Online	IAP Bonn
Andreas Svela	Online	Imperial College London
Anna Fontcuberta i Morral	Online	EPFL
Arno Rauschenbeutel	Online	Humboldt-Universität zu Berlin
Astghik Saharyan	Online	Université de Bourgogne Franche-Comté
Akshay Balgarkashi	Online	EPFL
Brahim Lounis	Online	Université de Bordeaux
Cécil Pham	Online	Teem Photonics
Chandra Vardhan	Online	Technische Universität Darmstadt

Name	Online/In person	Affiliation
Charles S. Adams	Online	Durham University
Chia Yu Hsu	Online	Technische Universität Darmstadt
Christoph Becher	Online	Universität des Saarlandes
Christophe Couteau	Online	University of Technology of Troyes (UTT)
Enrico Vogt	Online	QUBIG
Evan Cryer-Jenkins	Online	Imperial College London
Felix Tebbenjohanns	Online	Humboldt-Universität zu Berlin
Francisco Garcia Vidal	Online	Universidad Autónoma de Madrid
Georg Enzian	Online	Imperial College London
Gerard Colas des Francs	Online	Université de Bourgogne Franche-Comté
Gerhard Rempe	Online	Max Planck Institute for Quantum Optics
Hans Jauslin	Online	Université de Bourgogne Franche-Comté
Hayk Gevorgyan	Online	University of Sofia
Jacopo de Santis	Online	ICFO
Jakob Reichel	Online	ENS, Laboratoire Kastler Brossel
Jean-Jacques Greffet	Online	Institut d'Optique
Jean-Marc Merolla	Online	FEMTO-ST
Jean-Pierre Hermier	Online	Université de Versailles
John Dudley	Online	FEMTO-ST
John Price	Online	Imperial College London
Kirthanaa Indumathi	Online	FEMTO-ST
Lars Freisem	Online	Imperial College London
Laura Zarraoa	Online	ICFO
Lorena Bianchet	Online	ICFO
Lydia Kanari-Naish	Online	Imperial College London
Mackrine Nahra	Online	University of Technology of Troyes (UTT)
Mark Ijspeert	Online	University of Oxford
Martin Blaha	Online	Humboldt-Universität zu Berlin
Mateja Pršlja	Online	Qutools
Matthias Keller	Online	University of Sussex

Name	Online/In person	Affiliation
Maxime Federico	Online	Université de Bourgogne Franche-Comté
Michael Woodley	Online	Imperial College London
Morgan Mitchell	Online	ICFO
Mouhamad Al-Mahmoud	Online	University of Sofia
Muhammad Ahmed	Online	Teem Photonics
Natalia Alves	Online	ICFO
Niall Moroney	Online	Imperial College London
Nikolay Vitanov	Online	University of Sofia
Sergiy Stryzhenko	Online	Technische Universität Darmstadt
Slava Tzanova	Online	Qutools
Sofia Pazzagli	Online	Humboldt-Universität zu Berlin
Sofia Qvarfort	Online	Imperial College London
Stefanie Barz	Online	University of Stuttgart
Stéphane Guérin	Online	Université de Bourgogne Franche-Comté
Thomas Ebbesen	Online	University of Strasbourg
Thomas Halfmann	Online	Technische Universität Darmstadt
Thorsten Peters	Online	Technische Universität Darmstadt
Tomas Lamich	Online	ICFO
Tracy Northup	Online	Universität Innsbruck
Vindhiya Prakash	Online	ICFO
Xiao Yu	Online	Université de Bourgogne Franche-Comté