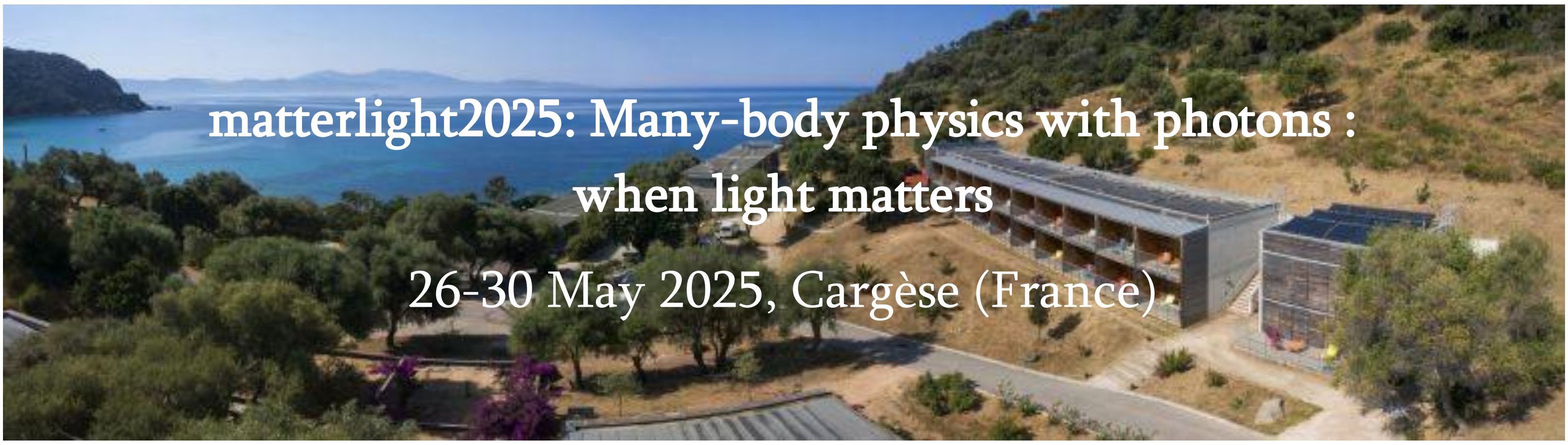
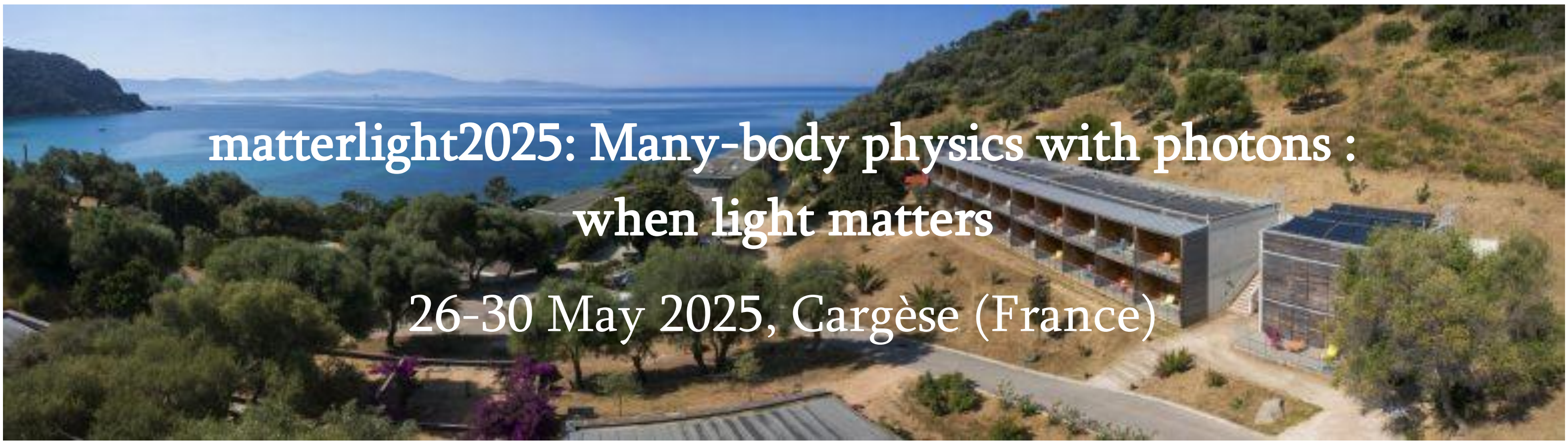


BOOK OF ABSTRACTS

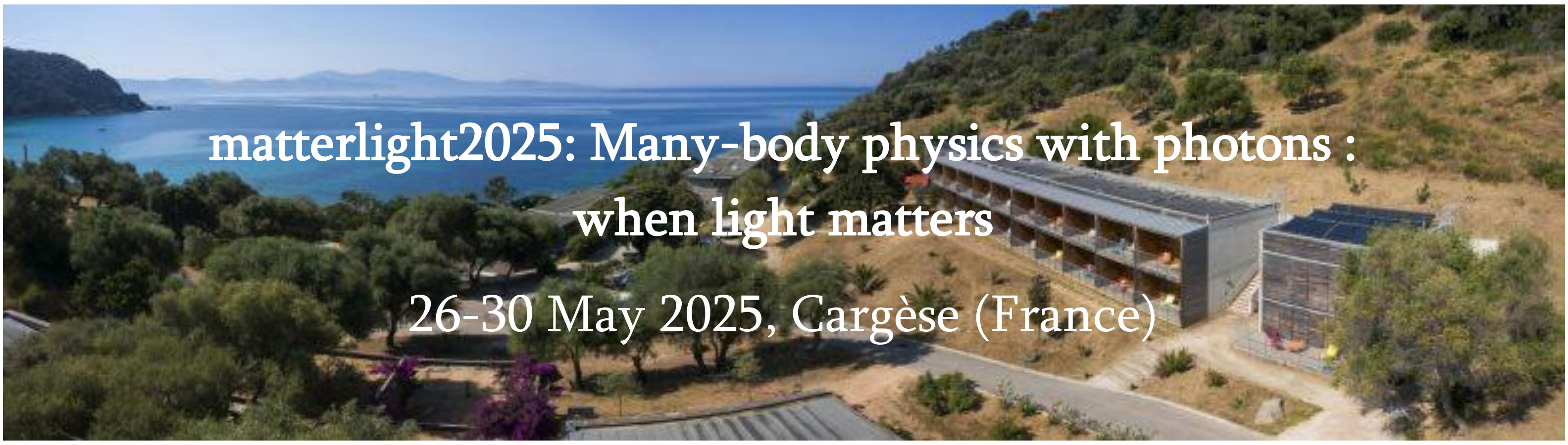


matterlight2025: Many-body physics with photons : when light matters

26-30 May 2025, Cargèse (France)

	Mon 26	Tue 27	Wed 28	Thu 29	Fri 30
08:30-08:45	Intro (Albert)				
08:45-09:00	Carusotto	Bouchoule	Felinto	Landini	
09:00-09:15					
09:15-09:30					Schamriß
09:30-09:45		Clément	von Zanthier	Sanchez-Palencia	
09:45-10:00					Garbe
10:00-10:15					
10:15-10:45	Coffee break				
10:45-11:00	Glorieux	Rauschenbeutel	Cherroret	Valentí-Rojas	Patera
11:00-11:15					
11:15-11:30	Ravets			Rassaert	Piotrowski
11:30-11:45					
11:45-12:00				Le Boité	Bachelard
12:00-12:15					
12:15-14:30	Lunch				
14:30-14:45	Dubail		Social Event		
14:45-15:00					
15:00-15:15		Lepleux		Ferioli	Larré
15:15-15:30					
15:30-15:45		Keyrouz		Tabarelli de Fatis	Ashfield
15:45-16:00					
16:00-16:30	Coffe break			Coffe break	
16:30-16:45	Poster	Slodicka		Guillet	Petkovic
16:45-17:00					
17:00-17:15		Trebbia		Ackemann	
17:15-17:30					
17:30-18:30					
18:30-19:00	Aperitif		Barbecue		
19:00-20:00					

Quantum Fluids of light	Correlations in atomic systems	Correlations in photonic systems	Phase transition and thermalisation


matterlight2025: Many-body physics with photons :
when light matters
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LECTURES

Lecture

QUANTUM FLUIDS OF LIGHT: BASIC CONCEPTS AND NEW TRENDS

Iacopo Carusotto

Pitaevskii BEC Center, INO-CNR and Dipartimento di Fisica, University of Trento, Italy

In this lecture I will start with an introduction to the basic concepts of quantum fluids of light. I will then review milestone experiments in the field and the different platforms they have exploited. I will conclude with my perspective on the most promising new directions and open questions of the field.

Further reading material can be found in recent review articles [1-5]

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Lecture

PARAXIAL FLUIDS OF LIGHT

Q. Glorieux, C. Piekarski, Q. Schibler, T. Aladjidi, M. Baker-Rasooli

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Over the past decade, the paraxial propagation of coherent laser beams in nonlinear optical media has emerged as a powerful platform for exploring analogies between nonlinear optics and many-body quantum physics. In this lecture, we will introduce the concept of a *paraxial fluid of light*, in which the transverse dynamics of a laser beam propagating in a nonlinear medium maps onto the evolution of a 2D quantum fluid governed by a nonlinear Schrödinger equation (NLSE), with the propagation axis playing the role of time.

We will discuss the mathematical basis of this analogy, pointing out the correspondence between optical parameters (refractive index, Kerr nonlinearity, diffraction) and atomic quantum gases quantities. From this, we will explore several important phenomena of quantum fluids, such as superfluidity, solitons, vortex dynamics, and dispersive shock waves.

The lecture will also discuss recent theoretical developments and experimental realizations, including the extension to 3D+1 dynamics with temporal dispersion.

Reference
[1] Paraxial fluids of light. Q. Glorieux, C. Piekarski, Q. Schibler, T. Aladjidi, M. Baker-Rasooli
https://arxiv.org/abs/2504.06262

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Lecture

SYNTHETIC POLARITON MATTER: ASSEMBLING MATTER WITH LIGHT

Sylvain Ravets[1],

[1] Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies (C2N), 91120 Palaiseau, France

In this lecture, I will explore how hybrid light-matter quasiparticles, exciton polaritons, can be used to engineer synthetic materials in solid-state platforms [1]. Polaritons arise from the strong coupling between cavity photons and excitons confined in semiconductor quantum wells. By structuring the microcavity into arrays of coupled resonators, we implement tight-binding Hamiltonians and engineer tailored photonic band structures [2].

I will focus on our recent progress in Hamiltonian engineering using polariton lattices, highlighting the development of an optical tomography technique that enables direct measurement of both eigenstates and eigenenergies across the Brillouin zone. This allows full reconstruction of the Bloch Hamiltonian, including the amplitudes and phases of its matrix elements (see Figure).

Our approach allows the design and characterization of Hamiltonians with light, and provides a versatile for studying the topology of synthetic materials.

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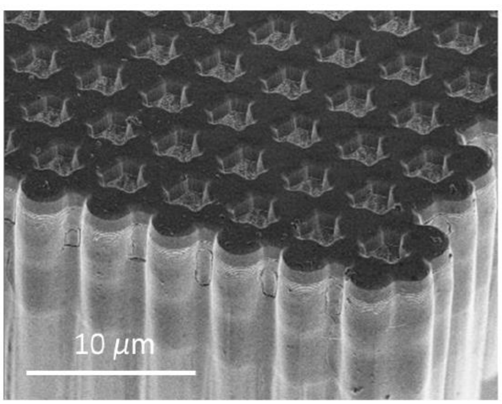

$$\hat{H}_{\boldsymbol{k}} = \begin{bmatrix} \epsilon_0/2 & -t\gamma(\boldsymbol{k}) \\ -t\gamma^*(\boldsymbol{k}) & -\epsilon_0/2 \end{bmatrix}$$

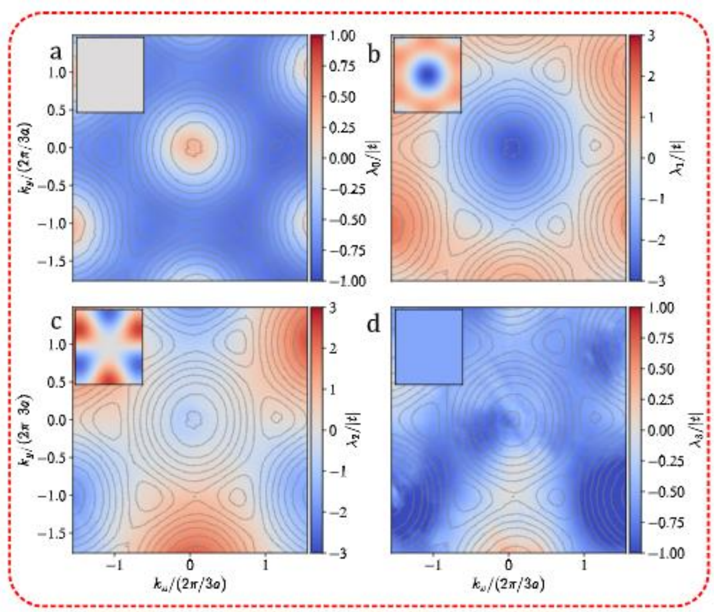

Figure : *SEM image of a polariton honeycomb lattice (top left). Experimental reconstruction of the tight-binding Hamiltonian associated to this lattice (right). Each panel represents a coefficient of the Hamiltonian decomposition along the basis of Pauli matrices, plotted as a function of k_x and k_y.*

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Lecture

INTRODUCTION TO CORRELATIONS IN ONE-DIMENSIONAL ATOMIC GASES

Jérôme Dubail

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I will give a short introduction to correlations of one-dimensional Bose gases in the strongly interacting regime. I will introduce the Lieb-Liniger model of interacting bosons, discuss the different regimes of the Lieb-Liniger gas (quasi-condensate, ideal Bose gas and Tonks-Girardeau regimes), its coherence properties, and universality in both the long-distance and short-distance asymptotics of correlations. On the technical side, I will assume some familiarity with basic notions of quantum many-body physics, such as second quantization and path integrals.

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Lecture

PROBING THE LOCAL RAPIDITY DISTRIBUTION OF A ONE-DIMENSIONAL BOSE GAS

I. Bouchoule[1], L. Dubois[1], G. Themèze[1], J. Dubail[2]

1 Laboratoire Charles Fabry, Institut d'Optique, CNRS and University Paris-Saclay

2 CESQ-ISIS, University of Strasbourg and CNRS

One dimensional Bose gases with contact repulsive interactions belong to the class of integrable systems, which renders their dynamics and the description of the stationary states very different from that of chaotic systems. The stationary states are parameterized by a function, dubbed the rapidity distribution. The latter can be seen as the velocity distribution of the quasiparticles of infinite lifetime in the system. The rapidity distribution is also homothetic to the density profile of the gas after expansion in 1D to very large distances. The latter property can be used to measure the rapidity distribution.

In system with long scale spatial variations, one can describe the system introducing a spatially-dependent local rapidity distribution. This key notion is at the heart of the Generalized Hydrodynamic theory, which gives a prediction for the time evolution of the spatially-dependent rapidity-distribution. In our cold atom experiment, we implemented a method to measure the local rapidity distribution, based on a method to select a slice of the cloud [1]. This permits us to reconstruct the spatially-dependent rapidity distribution of a gas. We used this techniques to probe different out-of-equilibrium dynamics, including the bi-partide quench protocol [2].

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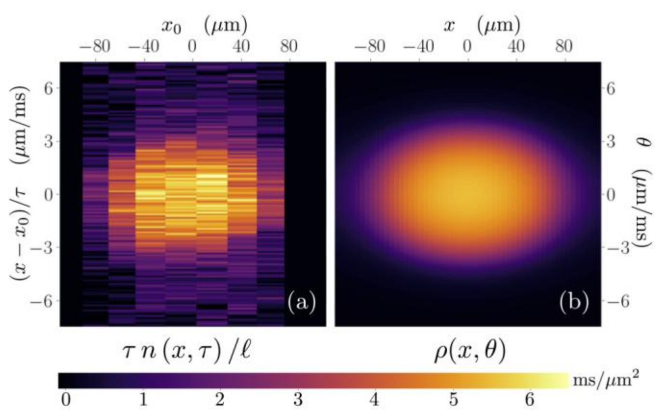

Figure 1: Taken from [1]. Position-resolved rapidity distribution of a cloud. The measurement (left) is compared to theory (right)

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Lecture

CORRELATIONS INDUCED BY CONTACT INTERACTIONS IN ULTRACOLD BOSE GASES

David Clément[1]

[1] Institut d'Optique Graduate School

In this lecture, I will explore how quantum fluctuations driven by contact interactions reveal themselves through atom correlations in a gas of interacting bosons. By interpreting contact interactions as a four-wave mixing process in momentum space, I will highlight the emergence of correlations predicted by Bogoliubov theory in the weakly interacting regime—specifically, the formation of pairs with opposite momenta—as well as those that appear beyond the scope of weak interactions.

Introducing the experimental detection of individual helium atoms in momentum space [1], I will present measurements of full counting statistics in momentum modes [2], the observation of Bogoliubov pairs [3] and the emergence of non-Gaussian correlations in strongly-interacting Bose gases [4]. If time allows, I will also discuss the non-Gaussian statistics of the condensate order parameter observed in a critical gas near the superfluid-to-Mott transition.

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Lecture

CORRELATIONS IN PHOTONIC SYSTEMS
(WITH FOCUS ON THE SECOND-ORDER COHERENCE FUNCTION IN QUANTUM OPTICS)

Arno Rauschenbeutel[1]

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Photon correlations offer a powerful lens through which to understand and characterize quantum light. In this lecture, we explore the physical significance, formal definition, and practical evaluation of the second-order coherence function $g^{(2)}(\tau)$. We discuss its role as a tool to distinguish classical and quantum optical fields, examine criteria for nonclassicality, and present established theoretical methods to compute it. We then survey experimental platforms where nonclassical $g^{(2)}(\tau)$ behavior has been observed. In the second part of the lecture, I will then present an alternative way of understanding the origin of antibunching and, more generally, the appearance of photon correlations in light that has interacted with quantum emitters. According to this model, the modification of $g^{(2)}(\tau)$ stems from the quantum interference of multiphoton scattering amplitudes [1]. This approach provides fundamental insight and points toward novel ways of realizing sources of nonclassical light [2,3,4].

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Lecture

QUANTUM CORRELATIONS IN FUNDAMENTAL LIGHT SCATTERING PROCESSES IN FREE SPACE

Daniel Felinto

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Full quantum-mechanical treatments of light-matter interaction result in a rich phenomenology of quantum entanglement that only in the last few decades we are starting to fully appreciate. For light scattering, the formation of collective entangled states on atomic ensembles is heralded by detection of photons spontaneously emitted by the sample. Its origin is the coherent interaction of atoms with the quantum reservoir of vacuum modes. In the last two decades, many groups have explored this process to devise applications for quantum technologies. Here I present the recent works of my group on the problem, exploring quantum correlations generated from simple systems, like ensembles of two- and three-level atoms in free space [1-4]. I particularly discuss the peculiar position of this problem on the backdrop of the broad discussion about the role of quantum entanglement in our macroscopic world. Finally, I review how these correlations may be used to build a quantum internet and comment on the perspectives for the field in Recife.

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Lecture

SUPERRADIANT LIGHT EMISSION FROM ENTANGLED ATOMS IN FREE SPACE

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Superradiance is one of the enigmatic problems in quantum optics since Dicke introduced the concept of enhanced spontaneous emission by an ensemble of identical two-level atoms, situated in collective highly entangled Dicke states [1]. While single excited Dicke states have been investigated since a long time, the production of Dicke states with higher number of excitations remains a challenge. In our approach, we generate these states via successive measurement of photons at particular positions starting from the fully excited system [2–7]. In this case, if the detection is unable to identify the individual photon source, the collective system cascades down the ladder of symmetric Dicke states each time a photon is recorded. We apply this scheme to demonstrate directional super- and subradiance with two trapped ions [8]. The arrangement for preparing the Dicke states and subsequently recording directional super- and subradiance corresponds to a generalized Hanbury Brown and Twiss setup. This shows that the two fundamental phenomena of quantum optics, Dicke superradiance and the Hanbury Brown and Twiss effect, are two sides of the same coin.

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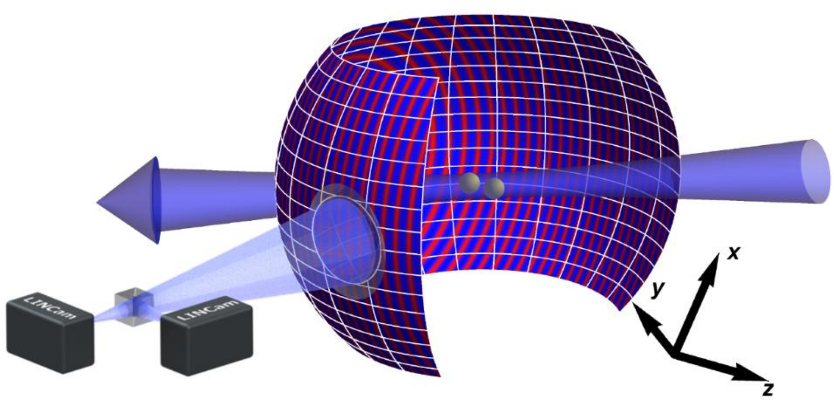

Figure 1: Setup of the experiment performed in [8]: Two $^{40}Ca^{+}$ ions are trapped and continuously excited by laser light on the $S_{1/2}$-$P_{1/2}$ transition while the scattered light is fed into a Hanbury-Brown and Twiss setup to measure $g^{(2)}(r_1,r_2,\tau)$ using two ultrafast microchannel plate cameras. The sphere around the two ions sketches the spatial pattern of $g^{(2)}(r_1,r_2,\tau=0)$ as a function of r_2 for r_1 fixed at = 0π.

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Lecture

NONTHERMAL FIXED POINTS IN OUT-OF-EQUILIBRIUM BOSE GASES

Nicolas Cherroret[1]

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The general context of this talk will be the non-equilibrium dynamics of closed many-body systems following a quantum quench. In the generic case of a non-integrable dynamics, the quench typically leads to a rapid production of entanglement, ultimately making the system thermalize. However, the question of how — and through which physical mechanisms — a given quantum system evolves toward a thermal state remains largely open. Over the past decade, it has been also observed that in some cases, thermalization proceeds in two distinct stages, the system first relaxing toward a transcient, nonthermal fixed point (NTFP), before possibly reaching thermal equilibrium at longer times. These NTFPs have attracted considerable interest, as they are characterized by spatio-temporal scaling laws in the system's correlations, involving universal dynamic exponents with no counterpart in equilibrium physics. Such scaling behavior has recently been observed in several experiments with quantum gases, through a comprehensive theoretical framework is still lacking.

After general considerations on the concept of thermalization and nonthermal fixed points, I will present three specific examples involving Bose gases, in which a NTFP emerges in the dynamics. The first and most thoroughly understood case concerns a dilute Bose superfluid quenched within its superfluid case [1,2]. In this scenario, a 'prethermal' fixed point arises due to the nearly-integrable nature of the dynamics. I will show how the quantum hydrodynamic of Bose gases captures the full evolution of the system in that scenario, from the initial approach to the NTFP to the eventual thermalization at long times The second example I will present involves the quench of 3D Bose gases across their condensation transition—an archetypal protocol where a nonthermal (or weakly turbulent) fixed point appears and can be described theoretically. In this case I will also adress the robustness of the NTFP against spatial and temporal perturbations induced by an external drive and a weak spatial disorder [3]. Finally, in the third part, I will discuss another example of NTFP—the coarsening fixed point— which appears during the dynamics of binary Bose mixtures near their miscibility quantum phase transition [4]. For this scenario, I will present a novel theoretical approach giving access to the dynamic exponents.

The presentation will be punctuated by several experimental examples involving quantum fluids of cold atoms and light in out-of-equilibrium configurations [5,6,7].

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Lecture

Ultracold atoms: a quantum playground for phase transitions and thermalization

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Ultracold atomic gases provide a uniquely clean and controllable platform for investigating quantum many-body physics. With precise control over dimensionality, interaction strength, and disorder, these systems have enabled landmark studies of both equilibrium and nonequilibrium phenomena. This lecture will explore how ultracold atoms have been used to probe quantum and thermal phase transitions—including the superfluid–Mott insulator transition [1] and Anderson localization in disordered Bose gases [2]. We will then turn to nonequilibrium dynamics: ultracold atoms allow experimental access to unitary quantum evolution following quenches, revealing mechanisms of thermalization, prethermalization, and many-body localization. These results offer fundamental insights into how closed quantum systems approach (or fail to approach) equilibrium. Importantly, we will also highlight emerging connections with the photonics and exciton-polariton communities, where engineered dissipation, driven-dissipative steady states, and synthetic gauge fields enable parallel studies of collective behavior [5–7]. Analogies between polariton condensation and atomic BECs, as well as recent progress in observing nonequilibrium phase transitions in photonic platforms, suggest a promising landscape for cross-disciplinary collaboration.

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Lecture

QUENCH DYNAMICS IN CORRELATED QUANTUM MATTER

Laurent Sanchez-Palencia

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We discuss out-of-equilibrium dynamics of strongly correlated quantum systems. This topic has attracted considerable attention in recent years due to time-dependent control techniques in artificial quantum matter. Here, we demonstrate that this issue leads to highly complex dynamics that remain largely unexplored. We first devise a general microscopic approach to infer the generic dynamical behaviour of lattice systems with both short- and long-range interactions. This reveals a dynamics characterised by a twofold cone-like structure of space-time correlations. In long-range systems, we show that the cone is sub-ballistic while its internal dynamics can be ballistic or super-ballistic, depending on whether or not the system is gapped. We then show that the structure of the space-time correlation pattern contains full information about the elementary excitations of a correlated quantum system. We propose a new spectroscopy method based on quench dynamics. We apply the latter to a wide variety of systems including short-range interactions, long-range interactions, and disorder. Quasi-exact numerical calculations based on tensor network approaches confirm our analytical predictions, revealing the remarkable robustness of quench spectroscopy in particular.

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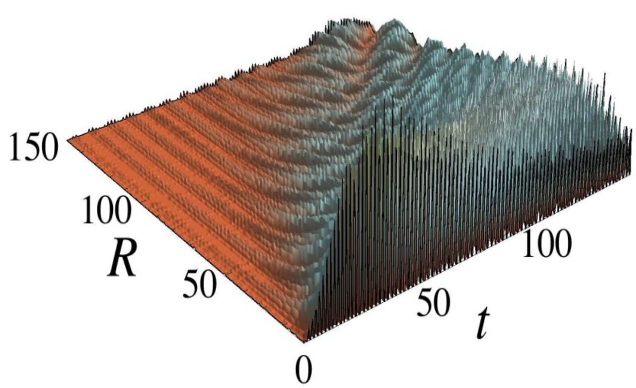

Spin correlation spreading in the long-range transverse Ising (LRTI chain as computed using time-dependent matrix product state techniques.

From L. Cevolani, G. Carleo, and L. Sanchez-Palencia, Phys. Rev. A **92**, 041603(R) (2015)

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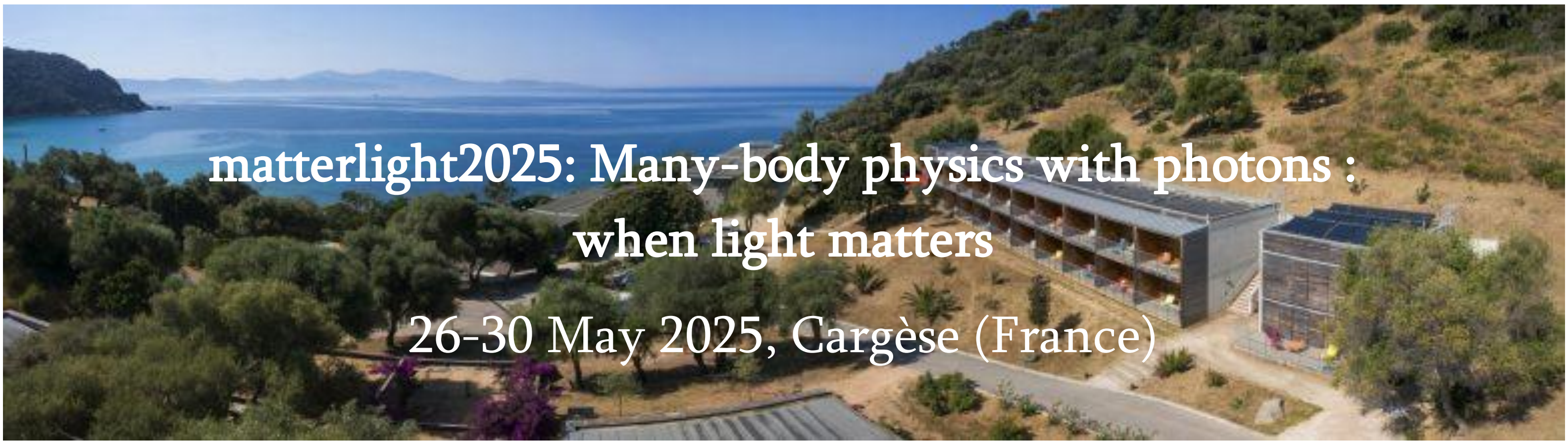

CONTRIBUTED TALKS

Oral

SWIRLING A QUANTUM FLUID OF LIGHT, FROM SINGLE VORTICES TO TURBULENT FLOW

S. Lepleux[1], M. Baker Rasooli[1], T. Aladjidi[1], Q. Glorieux[1]

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Quantum fluids Physics is the study of hydrodynamic systems which demonstrate a quantum behavior. We study here a fluid of photons that can acquire an effective mass due to the interaction with a hot vapor of Rubidium atoms. Fluid behavior then arises from an analogy between the nonlinear Schrödinger equation and Gross- Pitaevskii equation. Dimensionless temporal and spatial scales derived respectively from the nonlinear interaction strength and healing length are then used to characterize the evolution of the fluid.[1]

The group has shown experimental demonstrations of superfluidity and other quantum hydrodynamical effects such as quantized vortices and solitons.[2,3] We will cover the formation and dynamics of Jones-Roberts solitons generated by the merging of 2 vortices of opposite sign [4], and report the observation of isotropic turbulent flow following Kolmogorov theory.[5]

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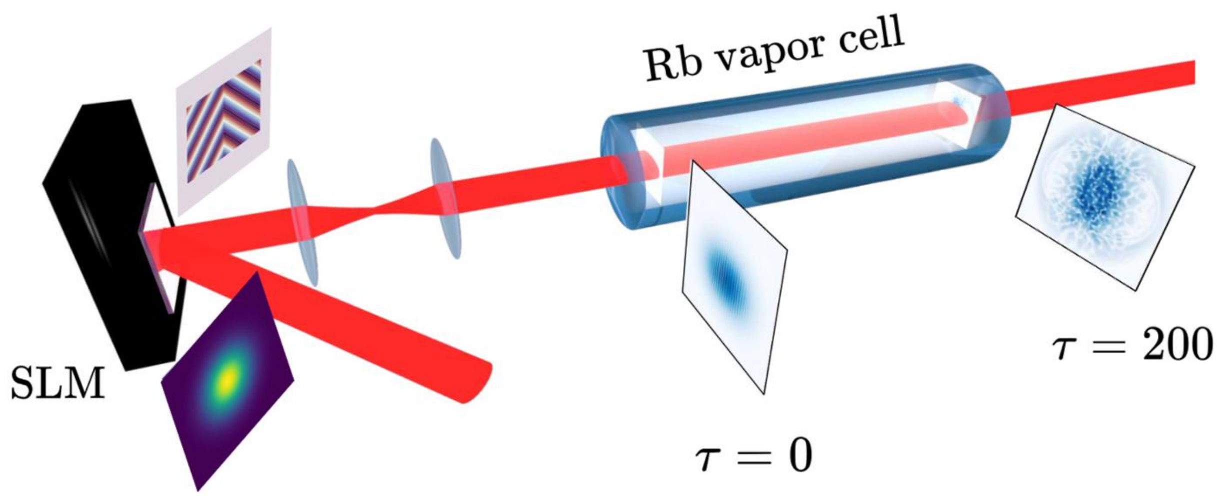

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Oral

FLUIDS OF LIGHT IN DISORDERED ENVIRONMENTS

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The fusion of nonlinear optics and quantum hydrodynamics has opened new doors for studying quantum fluids of light, providing insight into collective photonic behavior [1-2]. In carefully designed optical systems, photons can acquire an effective mass and interact repulsively, allowing them to behave like a quantum fluid. This leads to striking phenomena such as superfluidity and quantum turbulence, similar to those seen in superfluid helium [3-4] and atomic Bose-Einstein condensates [5].These quantum fluids offer a powerful platform for exploring hydrodynamic effects in optical systems [6-10].

At the Institut de Physique de Nice, we have developed a versatile experimental setup based on a photorefractive SBN crystal [11-13]. The key to the photorefractive effect lies in the movement of charge carriers under an external electric field, creating a refractive index change that can be finely controlled. This allows us to manipulate the optical properties of the medium in a flexible and reconfigurable way, enabling a broad range of experiments[14].

Recently, we achieved a major breakthrough by directly observing superfluidity in a fluid of light as it flowed around an obstacle [15] —something never done before. We also captured other remarkable behaviors, including a turbulent state where quantized vortices emerged [16]. By adjusting factors such as the size and strength of the obstacle, we could tune how the fluid interacted with it [17].

But what if we pushed the boundaries even further? Instead of limiting ourselves to simple configurations, we introduced disordered patterns within our photorefractive crystal. By carefully structuring the disorder, we were able to create a non-diffracting form of it, opening up an entirely new realm of possibilities. By going beyond single obstacles, we aimed to better replicate the complexity of natural systems. With this approach, we are now diving deeper into the interplay between spatial localization and superfluidity, particularly in the transition between different states, including the intermediate turbulent regime.

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COHERENT CONTROL OF LIGHT FROM MESOSCOPIC ENSEMBLES OF SINGLE-PHOTON EMITTERS

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Realizing an efficient coherent interface between light and ensembles of quantum emitters represents one of the most active research directions in experimental quantum optics. We present experimental realizations of several regimes of free-space optical emission of light from large trapped ion crystals, which result in different paradigmatic regimes of photon statistics, including pure single photons or large discrete nonclassical states.

We demonstrate the efficient implementation of single-modeness and phase coherence for light scattered from many ions, which are crucial for the efficient photonic generation of atomic entanglement, or for the directional control of optical emission from atoms. The achieved excitation and detection regimes provide the observation of the emergence of super-Poissonian quantum statistics from a finite number of indistinguishable single-photon emitters [1], significant enhancement of collection efficiency of nonclassical light scattered from linear ion strings [2], or feasible coherent control of their light statistics from mesoscopic ensembles of single-photon emitters [3].

These results suggest a broadly applicable enhancement of photon collection and control of its statistical properties from ions in a free space by using the scattering geometry that is intrinsic to the majority of modern linear ion traps. The considered small solid angle limit provides an inherent advantage for reducing wavefront aberrations of the collected light with simple paraxial collection optics, which promises perspectives in interferometric applications using collectively coupled ion crystals. A large focus depth of the small-NA fluorescence collection allows for simultaneous observation of light from many ions, which opens the possibility of mapping the internal state of a selected ion to the direction of the scattered light in trapped ion quantum registers.

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QUANTUM COHERENCE AND PHOTON CORRELATIONS IN ENTANGLED FLUORESCENT ORGANIC MOLECULE PAIRS

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The second quantum revolution relies on the ability to coherently manipulate quantum systems, a challenge that requires precise control over quantum states and their interactions. In the field of solid-state quantum optics, single emitters—such as molecules, quantum dots, and defect centers in diamonds (e.g., NV centers)—have emerged as promising candidates for quantum technologies, as they can be easily manipulated with light and seamlessly integrated into quantum photonics.
Among these emitters, single organic molecules embedded in solid-state matrices at cryogenic temperatures stand out due to their remarkable properties for quantum information processing. Their exceptional photostability, narrow optical transitions, and coherence times limited by the excited-state lifetime (around 10 ns) enable the preparation and manipulation of quantum states with high fidelity (above 97%), without any decoherence effects [1]. Recent experimental advances have led to the identification of coupled pairs, where nearly pure Bell states are achieved by tuning the molecular optical resonances using the Stark effect. The super-radiance and sub-radiance characteristics of these entangled states are demonstrated through lifetime measurements, revealing how the degree of entanglement influences the system's emission properties [2].
In this context, we explore the role of quantum coherence in the emission properties of fluorescent organic molecules though the measurement of the second order correlation function. Using a new theoretical framework that incorporates vibrational modes in addition to the conventional electronic states, we analyze the statistical properties of both zero-phonon line (ZPL) photons and Stokes-shifted photons. Our model reveals that quantum coherence plays a crucial role in shaping the photon correlations. In particular, we demonstrate that the correlation statistics of ZPL and Stokes-shifted photons can exhibit significant differences due to coherence effects, which classical statistical approaches based on the computation of conditional probabilities fail to capture ([3,4]).
These findings have broad implications for the field of solid-state quantum optics, extending beyond organic molecules to atomic, ionic, and semiconductor quantum systems. By demonstrating the interplay between quantum coherence, photon correlations, and molecular entanglement, our work paves the way for the development of hybrid quantum platforms where solid-state emitters interact coherently to perform complex quantum operations.

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DUAL APPROACH TO SOFT-CORE ANYONIC LIEB-LINIGER FLUIDS

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The identity of quantum matter can be effectively altered by means of gauge fields. In two spatial dimensions this is illustrated by the Chern-Simons flux-attachment mechanism yielding a transmutation of statistics. Here, we study a one-dimensional interacting Bose gas in the presence of a dynamical gauge field. This model can be explicitly mapped into an interacting anyonic system by a large gauge transformation, indicating a statistical transmutation analogous to that of Chern-Simons. The Bogoliubov spectrum in the weakly-interacting limit reveals the presence of a roton minimum arising from the statistical interaction. At a mean-field level chiral solitons are recovered. Should these be understood as quantum bound states, it is natural to interpret them as corresponding to localised anyonic quasiparticles. Hydrodynamic arguments highlight the presence of dispersive chiral shock waves in the propagation of a wavepacket due to a Riemann-Hopf nonlinearity. Numerical calculations confirm the presence of both chiral soliton trains and shock waves [1].

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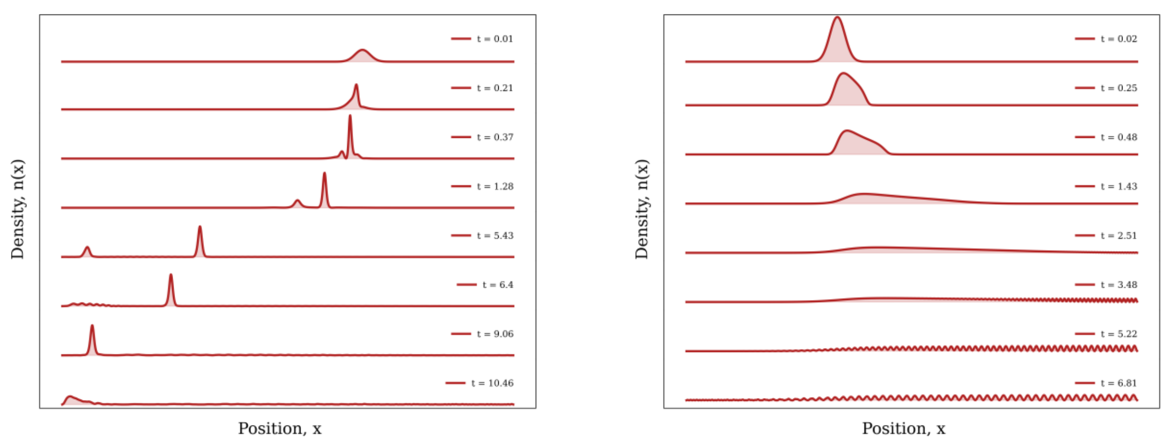
Figure

Anomalous reflection dynamics for a density-current nonlinear wavepacket boosted with an initial momentum kick.



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ABSTRACT:
ROBUSTNESS OF SUPERRADIANCE TO DECOHERENCE

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When an ensemble of N identical emitters is confined in a volume smaller than λ^3, where λ is the wavelength of the emitted light, the light cannot distinguish the emitters, and therefore leads to a collective coupling of the emitters with the light mode. The emitters synchronize their dipoles, developing large correlations, and begin to coherently emit their excitation in the light mode. This leads to N times faster emission and an equivalent increase in emission intensity, known as superradiancee, i.e. coherent spontaneous emission [1].

Solid-state emitters collectively coupled to light — such as nano-spheres or nano platelets — are inevitably immersed in a finite-temperature environment introducing dephasing. This destroys correlations between the dipoles of the emitters, and therefore it is detrimental for collective emission phenomena such as superradiance. This raises the question whether superradiance can survive the presence of individual dephasing; and whether it can be observed at all in the solid state without engineering the environment of the emitters.

By exploiting the existence of an efficient numerical solution for systems with permutational invariance [2], in this work we study the collective emission property of large ensembles of emitters, both in the case of an excitation pulse, as well as under continuous incoherent pumping. In both situations, we observe that superradiance survives up to a sizeable critical dephasing rate, comparable with the collective emission rate. The critical dephasing marks a sharp dynamical transition in the pulsed case; and a steady-state dissipative phase transition under continuous pumping. In both cases the critical point is characterized by a well defined scaling of the emission intensity, respectively $I \sim N^{4/3}$ and $I \sim N^{3/2}$, intermediate between the normal one $I \sim N$ and the superradiant one $I \sim N^2$.

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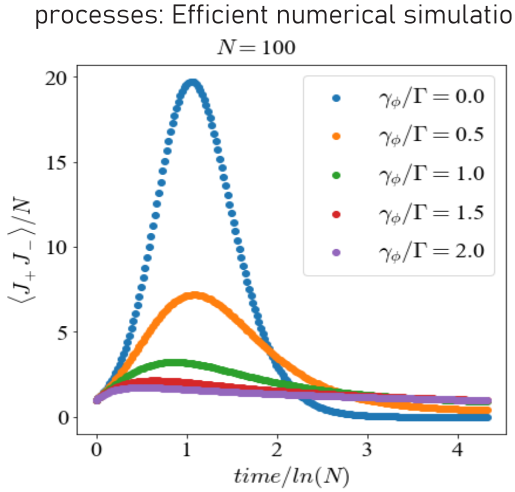

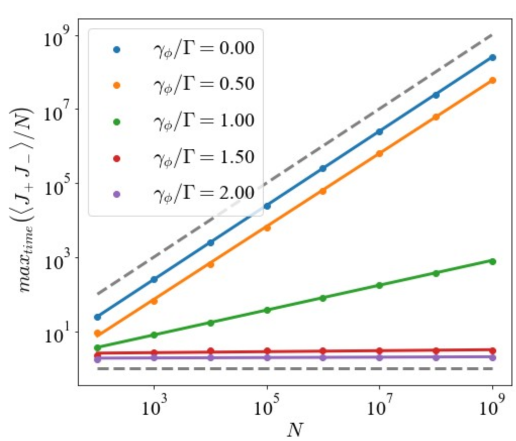

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NON-LINEARITY DRIVEN TOPOLOGY VIA SPONTANEOUS SYMMETRY BREAKING

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Understanding the emergence of topological properties is a fundamental challenge across various scientific fields. In condensed matter and photonic systems, topological band theory provides a unifying framework for characterizing topological phases in quantum materials in the absence of non-linearities [1].

Going beyond quadratic Hamiltonians, nonlinear interactions can profoundly influence topological systems [2]. For example, interactions can modify or destroy existing topological effects, perturb boundary modes or give rise to topologically ordered phases. These phenomena demonstrate the deep connection between topology and nonlinearity. However, whether topological effects can arise solely from the structure of nonlinear interaction terms, and the nature of the resulting topological phases, remain to large extent open questions.

In this work [3] inspired by the recent observation of a dissipative phase transition in a two-photon driven Kerr resonator [4], we consider a chain of such parametrically-driven resonators coupled only via weak nearest-neighbour cross-Kerr interaction, without any quadratic tunneling term. We show that, when the drive overcomes a critical threshold value, the system undergoes a transition from the atomic limit of decoupled oscillators to a symmetry-broken topological phase. The topology is dictated by the structure of the Kerr nonlinearity, yielding a non-trivial bulk-boundary correspondence. In the topological phase, we find different effective models for periodic and open boundary conditions and derive analytical approximations for the low-energy spectrum, identifying the conditions to observe topological edge modes.

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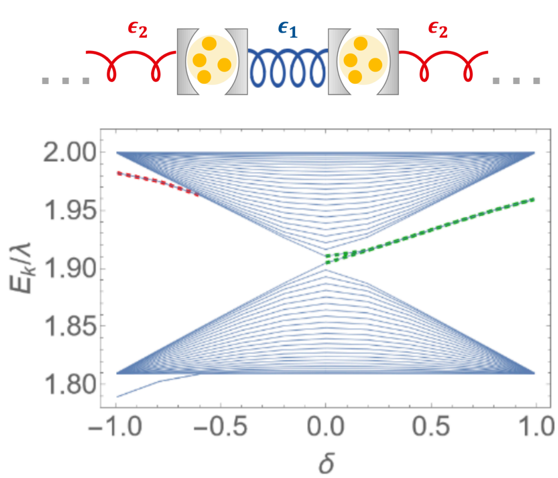

Figure. Top: Sketch of the chain with staggered cross-Kerr interactions. Bottom: Spectrum for open boundary conditions with topological edge modes (green dashed line) and non-topological disorder-induced localized modes (red dashed line) appearing.

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PHOTON STATISTICS AT THE EDGE OF DICKE`S LIMIT

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We experimentally measure the second-order coherence function of light emitted by a laser-driven dense ensemble of atoms with strong superradiant properties[1]. We observe a clear deviation from the Siegert relation (see Figure below) valid for Gaussian chaotic light. By measuring intensity and first-order coherence, we conclude that the violation is not due to the emergence of a coherent field. This suggests that the light obeys non-Gaussian statistics due to non-Gaussian correlations in the atomic medium [2]. In addition to these results obtained in the steady-state of this driven-dissipative system, we investigate the photon statistics during a superradiant burst [3,4] that follows the complete population inversion of the cloud. We observe the establishment of second-order coherence, in contrast to the situation where the cloud is initially prepared in a steady state.

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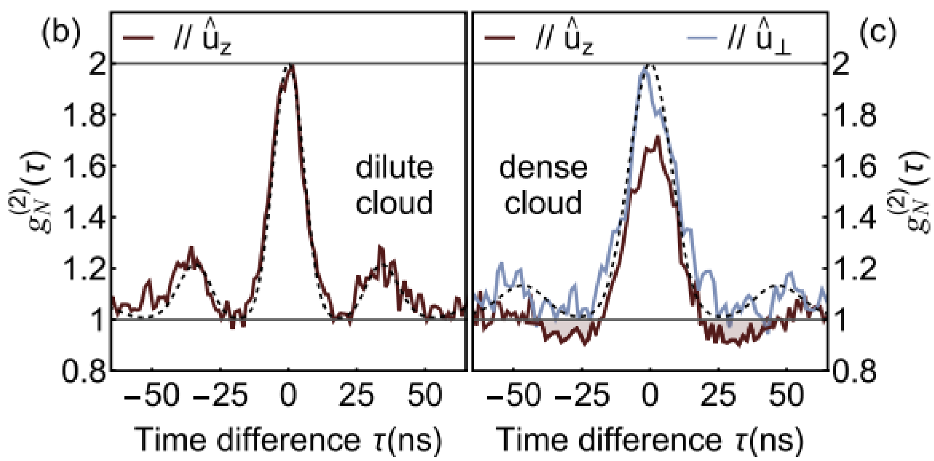

Figure: second order intensity correlation function measured for a dilute (left) and dense (right) cloud of Rb atoms, in comparison with the prediction of the Siegert relation (black, dashed line)

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ADIABATIC GENERATION OF A TONKS-GIRARDEAU GAS OF PHOTONS IN SUPERCONDUTING WAVEGUIDES

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Photons propagating in a one-dimensional superconducting waveguide behave like a quantum system of bosonic particles with contact interactions, where the role of the propagation axis and time are exchanged with respect to standard atomic Bose gases (t-z mapping [1]). Interactions in these kind of systems can be made strong enough to enter the Tonks-Girardeau regime, in which the photons acquire fermionic properties due to the strong repulsions and the limited dimensionality of the system. This behavior is particularly manifest in the pair correlation function of the photons, which exhibits complete antibunching and Friedel oscillations, analogously to a free Fermi gas. In my presentation I will show how to model the superconducting circuit to derive a Bose gas Hamiltonian outside of the mean-field regime, and I will discuss how to generate a Tonks-Girardeau gas of photons by injecting coherent radiation in a superconducting waveguide and adiabatically changing the nonlinearity during propagation. The pair correlation function after the propagation, computed using a Tensor Network Ansatz, shows that an adiabatic generation is indeed possible, as shown in the figure.

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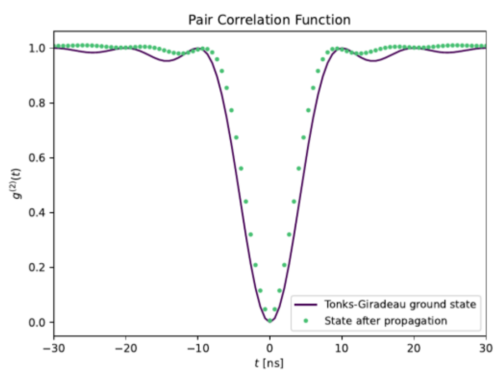

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FLUIDS OF LIGHT IN WAVEGUIDE POLARITON LASERS: SOLITON GENERATION AND INSTABILITIES

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The large nonlinearities of exciton-polaritons have been widely exploited in order to control the formation of temporal solitons, initially in microcavities and more recently in waveguides [1]. Within a GaN ridge waveguide forming a Fabry-Perot cavity, with a length of a few tens of microns, we have recently demonstrated a mode-locked polariton laser based on cavity solitons [2], with a very low energy per pulse (5 fJ). This device operates in the strong coupling regime, so that theses polariton solitons are typically 25% excitonic, 75% photonic. They therefore exhibit strong nonlinearities even at low polariton numbers per pulse, and form an interesting platform for fluids of light compatible with integrated photonics.

A few solitons can be simultaneously generated in the waveguide by controlling the optical pump, on a length-scale much shorter than the cavity length. Indeed, waveguide polariton lasers differ from conventional semiconductor lasers since the polariton absorption in unpumped sections is much smaller than the polaritonic gain arising from the stimulated relaxation of excitons towards the polariton branch in the pumped section. Lasing occurs through a dynamical polariton condensation process, the solitons then form spontaneously as the third order polariton nonlinearity compensates the group velocity dispersion. Figure 1.c presents the emission spectrum of the pulsed polariton laser in a 40 µm-long cavity pumped over 6.5 µm with a line-shaped spot (see Fig. 1.a; 4 ns pulses at 355 nm): the envelope of the Fabry-Perot modes follows a characteristic secant-hyperbolic lineshape. The pump is resonant with the GaN excitons, which large binding energy and Rabi splitting allow for an operation in the strong coupling regime up to 300 K [2]. Interestingly, the cavity soliton becomes instable when the excitation spot is moved away from the cavity center (Fig. 1.b), leading to the simultaneous propagation of two cavity solitons (Fig. 1.d). Longer cavity even lead to the observation of more than 2 solitons, revealing strong interactions. This soliton dynamics is modeled and understood when solving the Gross-Pitaevskii equations for the coupled exciton-photon system within the waveguide cavity (Fig. 1.e,f).

This work paves the way towards more complex polariton waveguide architectures intended to control the interactions between multiple solitons, with a small number of polaritons per pulse and a small device footprint.

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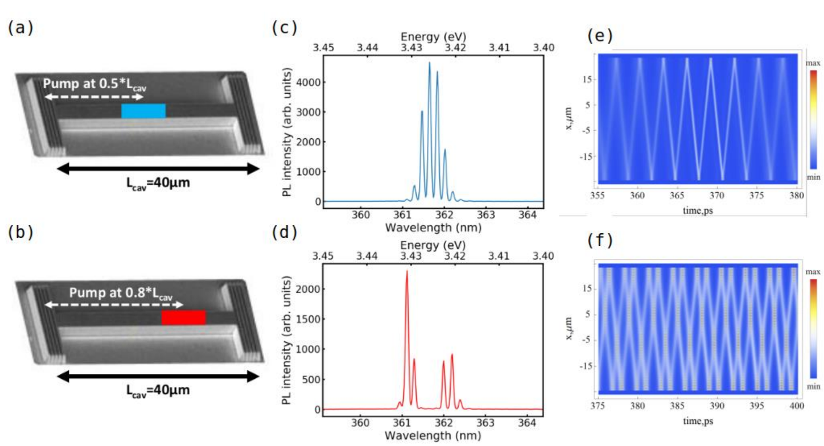

Figure 1: (a,b) Sketch of the optical pumping scheme overlayed on the scanning electron microscopy image of a GaN waveguide polariton laser. The GaN core waveguide stands over an (Al,Ga)N cladding; it is etched into a 1 µm-wide ridge ending with distributed Bragg reflectors. (c,d) Laser emission spectrum at T = 150 K when the 6.5 µm pump is positioned at the center (c) or at 0.8 L_{cav} (d); (e,f) corresponding GPE simulations.

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SUPERSOLID LIGHT

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Superfluids are macroscopic quantum states of atoms in which atoms can flow without friction. In contrast, crystals consist of a periodic arrangement of atoms that do no move within the structure. Supersolids intriguingly combine these properties, as they possess both periodic order and superfluidity. Supersolid behaviour was initially proposed in the context of low-temperature phases of helium but direct experimental evidence of supersolid structures was only recently obtained in experiments using ultracold atoms in dipolar gases [1] and cavity QED systems [2]. In the former, interactions are directly between atoms whereas they are light-mediated in the latter.

We are also interest in coupled light-matter structures, but propose to "trace" over the matter part in order to investigate light structures, similar to how a Nonlinear Schroedinger or Gross-Pitaevskii Equation for light emerges from the nonlinear light-matter interaction, e.g. [3], which is part of the rapidly developing field of "quantum fluids of light".

The first system is a single-mirror feedback system as described in [4]. In the experiment a large cloud of 10^{11} ^{87}Rb atoms is released from a magneto-optical trap and illuminated by a blue-detuned laser beam. The transmitted beam is retro-reflected by a plane mirror. Above a pump threshold, hexagonal structures form in the transmitted light. These show spontaneous symmetry breaking (Fig. 1). Coherent coupling between adjacent spots is provided by the diffraction in the feedback loop. We calculated the excitation spectrum below threshold and it shows the "roton softening" typical for supersolids (Fig. 1). Whereas without or for weak pumping periodic structures need a finite energy to be excited, a minimum at finite wavenumber (a "roton") develops in the dispersion curve for increasing pump due to the nonlocal interaction via the diffraction in the feedback loop. Threshold is reached if this minimum touches zero, i.e. becomes the new ground state.

The other potentially very interesting system are broad-area lasers which exhibiting spontaneous formation of structured light [5]. These states break also spontaneously the translational symmetry of space although in real devices pinning at boundaries might be relevant. In addition, they break spontaneously the U(1) phase symmetry as an atomic supersolid forming from a thermal cloud does. However, as the laser cavity has dissipation, a laser light supersolid is a flow equilibrium similar to polariton condensates or photon condensates in semiconductor microcavities.

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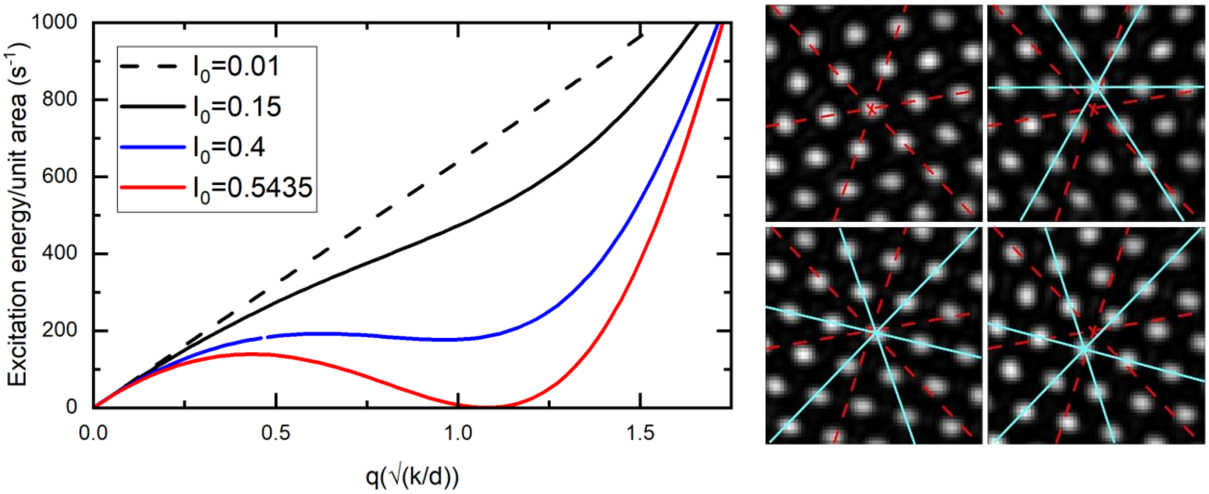

Figure 1: Left panel: Roton softening at various pump intensities for light interacting with laser-cooled thermal atoms via optomechanical nonlinearities. Right panel: Examples for hexagonal structures in transmitted light with iIllustration of spontaneous symmetry breaking.

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GENERATING A PHOTONIC BOSE EINSTEIN CONDENSATE IN A WAVEGUIDE

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While the creation of photonic Bose-Einstein condensates in the optical regime is well established, an analogous mechanism for microwave photons remains unexplored. We propose a superconducting platform to bridge this gap, harnessing the advantages of superconducting hardware for analog quantum simulation. The core-component is a coupler that enables a pure three-wave mixing interaction, linking a waveguide which contains the condensate to an LC mode that facilitates energy dissipation. This interaction drives an incoherent, photon-number-conserving thermalization process in the waveguide, similar to the so called asymmetric simple inclusion process [1], allowing independent control over both a reduced effective temperature and the total photon number.

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EVERY BOSON IS A WATERFALL: COLLECTIVE TRANSPORT IN BOSONIC SYSTEMS

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Bose statistics predicts that bosons can not only occupy the same quantum state, but tend to accumulate in it. This effect, at the core of stimulated emission and Bose-Einstein condensation, implies that bosonic particles form an inherently many-body system, even in the absence of direct interactions between them. I will discuss the consequences of this effect in a model describing transport of bosonic particles through a lattice, through the so-called asymmetruc inclusion process, and show how these effects can be leveraged to generate microwave photon condensates, or detect microwave photons through an avalanche process.

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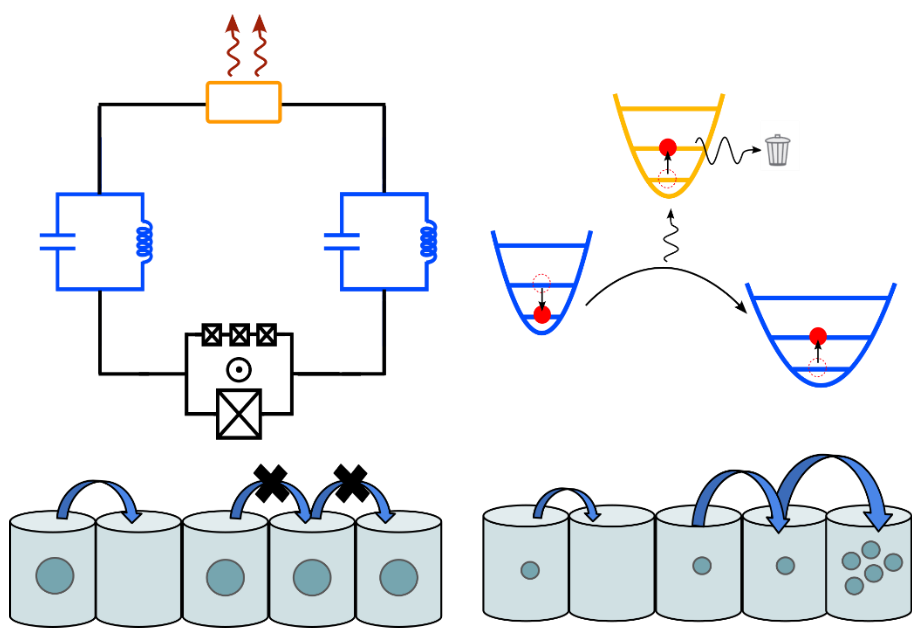

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SMOOTH DECOMPOSITIONS FOR DRIVEN-DISSIPATIVE MULTIMODE BOSON INTERACTIONS

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The most general form of Hamiltonians that are quadratic in the (boson) field operators plays a crucial role in both condensed matter physics and quantum photonics. These Hamiltonians essentially contain two distinct types of processes: those that destroy an excitation in one mode while creating it in another (mode hopping) and those that simultaneously generate pairs of excitations in two modes (pair creation terms).

In photonics, quadratic Hamiltonians arise in the description of multimode nonlinear processes, and their understanding is fundamental for predicting and engineering the nature of the quantum states generated by such light sources. In particular, pair production terms are responsible for establishing quantum correlations among optical modes. The Bloch-Messiah decomposition shows that these correlations can be irreducibly characterized in terms of squeezed normal modes (generally called supermodes).

Interestingly, in condensed matter physics, these pair-production terms are responsible for superconductivity and superfluidity and rely on the Bogoliubov-Valatin transformation.

In this talk:

- I will briefly review the models typically considered in condensed matter physics and draw a parallel with those in quantum photonics;

- I will discuss the connections between the Bloch-Messiah decomposition and the Bogoliubov-Valatin transformation, aiming to highlight differences that could foster cross-fertilization between these approaches and potentially lead to collaborations with experts in condensed matter physics;

- I will introduce the “Analytic Bloch-Messiah Decomposition” [1], which we recently proposed as a general method for identifying the irreducible squeezing resource in the presence of driving and dissipation. I will explain why this approach is indispensable for a complete characterization of the generated quantum correlations and their corresponding time/frequency structure [2].

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CORRELATIONS OF SUPERRADIANT BURSTS IN CASCADED QUANTUM SYSTEMS OF TWO-LEVEL ATOMS

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Laser-cooled atoms interacting with the guided mode of an optical nanofiber can exhibit a direction-dependent coupling. We use this to generate large cascaded quantum systems consisting of hundreds of atoms. In such cascaded quantum systems, information can only flow in one direction along the ensemble. I will present recent experimental developments, where we understand the first- and second-order correlations of superradiant bursts emitted from such cascaded systems. For this we coherently excite the ensemble to highly excited initial states [1], before measuring the optical power [2] and the second-order correlation [3,4] of the superfluorescent light.

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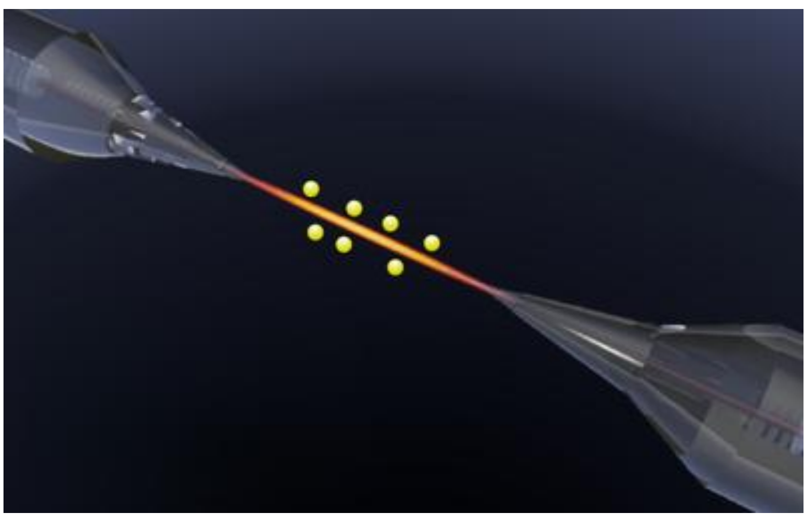

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ABNORMAL LIGHT STATISTICS FROM LARGE ENSEMBLE OF QUANTUM EMITTERS

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Large systems of emitters radiate light with thermal statistics, provided there is a phase randomization mechanism such as temperature, collisions, or spontaneous emission [1]. Differently, elastic scattering produces an interference pattern, characterized by a strong directionality. In this presentation, we discuss how cold samples of quantum emitters can emit light with extraordinary statistics, characterized by strong anti- or superbunching [2]. This phenomenon relies on the interference between spontaneous emission and elastic scattering, and it leads to an anticorrelation between the radiated intensity and the associated two-photon correlations. We also report on the observation of this anticorrelation on a trapped ion setup, for emitter numbers up to N=18 [3]. These results pave the way toward the generation of strongly correlated photons by interference from quantum emitters.

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COLLECTIVE TRANSPORT IN BINARY SUPERFLUIDS OF LIGHT AND MATTER: FROM DISSIPATIONLESS FLOW TO DISPERSIVE SHOCKS

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Superfluids provide an ideal platform for exploring macroscopic quantum phenomena, notably dissipationless flow and collective excitations. Within this domain, binary superfluids have garnered significant research attention. These systems are characterized by two internal degrees of freedom, giving rise to a spin mode in addition to the conventional density mode. This presentation will outline two ongoing theoretical investigations into these two-component systems. The first study examines the conditions for dissipationless flow of a two-dimensional repulsive miscible binary superfluid of light past a polarized obstacle. Two critical velocities, associated with the excitation of the density and spin modes, are identified as the onset of energy dissipation from the superfluid phase. These are analyzed through Landau's criterion, drag-force calculations, and beyond linear response using the hydraulic and incompressible approximations. Numerical simulations reveal the nucleation of density and spin vortex dipoles, Jones-Roberts solitons, and rarefaction pulses as mechanisms for dissipation. The second study concerns a coherently driven two-component Bose-Einstein condensate of potassium atoms. In its extremal-energy state, this system exhibits an effective three-body interaction governed by the microscopic inter-component interactions and the transition frequencies. The system's dynamics is effectively described by a single coherent field satisfying the cubic-quintic nonlinear Schrödinger equation. In one spatial dimension, we investigate its nonlinear periodic solutions arising from a steplike initial-value problem. Among these, dispersive shock waves are analyzed within the framework of Whitham modulation theory.

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GAP SOLITONS HOSTED BY A HARPER-HOFSTADTER MODEL WITH A SATURABLE NONLINEARITY

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Nonlinearities in lattice models with non-trivial topological band structures permit soliton-like (breather) solutions that are localised in the bulk of the lattice and with energies inside of the band gap. Such solutions have been found theoretically to be "hosted" by 2D quantum Hall models [1] and, in a low power limit, behave according to the local geometry of the band structure [2]. The goal of this work is to analyse gap solitons found in a Harper-Hofstadter model with saturable nonlinearities to find a connection between the nonlinear solutions and the global properties of the topological band, specifically, the topological invariants. Current work involves studying the wavepacket dynamics of the solitons under external forces through numerical simulations to extract Chern numbers. This work has potential implications for both cold-atom and nonlinear photonic systems.

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DISSIPATIVE IMPURITY DYNAMICS IN ONE-DIMENSIONAL QUANTUM LIQUIDS

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I will discuss the motion of a distinguishable particle (an impurity) in one-dimensional quantum liquids within a microscopic description. The impurity experiences the friction force due to scattering off thermally excited quasiparticles. I will present detailed analysis of an arbitrarily strong impurity coupling constant in a wide range of temperatures and uncover new regimes of the impurity dynamics. Then, I focus on the far-from-equilibrium zero temperature impurity dynamics after the interaction with a bath is quenched on, as well as in the presence of an external force.

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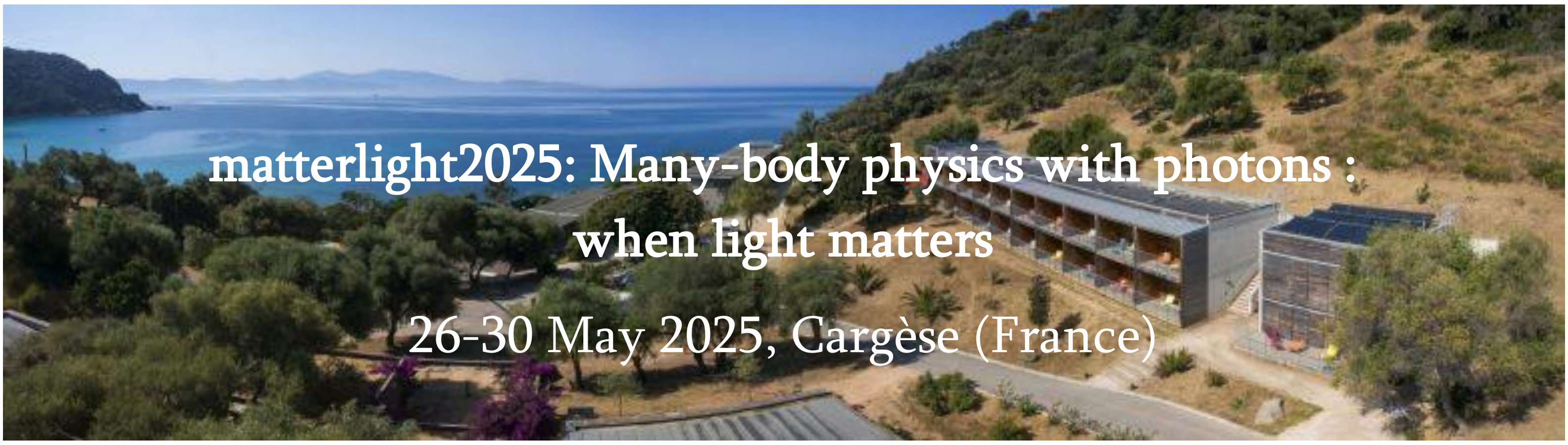
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"Topological signatures of a p-wave superconducting wire through light"

Gabteni Adam
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"Index of refraction in hot vapor"

Majumdar Saptarshi
CNRS, Université Paul Sabatier, Toulouse, France
"Out of equilibrium dynamics of Bose-polaron"

Scopa Stefano
LPENS, Paris, France
"Hydrodynamics and Correlations of 1D Low-Temperature Bose Gases"

Guillet Thierry
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