# ICSCE-13

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Spontaneous Coherence in
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# BOOK OF ABSTRACTS

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# Towards Real-Time Quantum-Optical Spectroscopy on Polariton Condensates

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**Abstract**: We demonstrate ultrafast real-time photon statistics measurements on polariton condensates based on continuous-variable spectroscopy and demonstrate

Homodyne detection is a powerful technique heavily used in continuous variable quantum optics. So far, semiconductor spectroscopy has mostly relied on discrete variable measurements, such as traditional Hanbury Brown-Twiss measurements for obtaining the semiconductor emission photon statistics in terms of $g^{(2)}$, while homodyne detection has rarely been applied as a spectroscopy tool. However, already early pioneering work showed that photon counting is not required to obtain photon statistics, but already phase-averaged quadrature distributions obtained from homodyne detection are sufficient to measure $g^{(2)}(0)$ [1] and $g^{(2)}(\tau)$ [2].

Here, we demonstrate that combining multichannel homodyne detection with pulsed local oscillators at 76 MHz repetition rate and state of the art digitizers with sampling rates of 5 Gs/s opens the possibility to measure $g^{(2)}(0)$ in less than a millisecond [3]. Simultaneously, we achieve the sub-picosecond temporal resolution necessary to resolve ultrafast processes in semiconductors. We further show discuss how to tailor the mode structure of the local oscillator to turn it into a spectroscopic tool for continuous real-time measurements of $g^{(2)}(0)$ and the density matrix of a light field [4]. We utilize these approaches to develop a resource-theoretical treatment of the formation of coherence of a polariton condensate in an ultra-high quality microcavity [5] that relates the obtainable quantum coherence to the mixedness of the state and investigate spontaneously arising dynamics of a coupled polariton system.

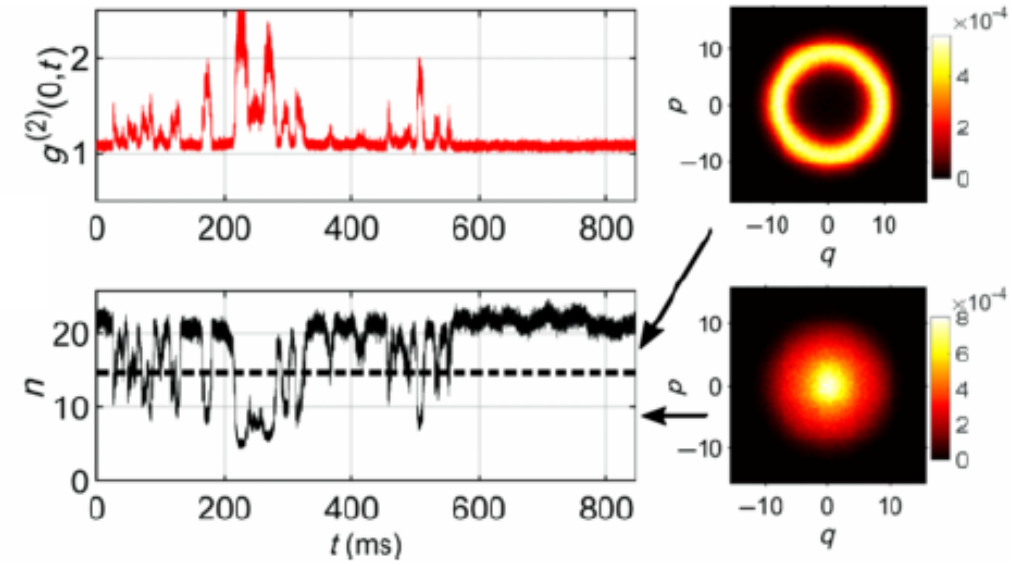


**Fig. 1** Real-time time trace of a fluctuating polariton condensate subject to mode competition. Changes in the occupation number (bottom) are directly correlated with the occupation number statistics (top), which are also directly reflected in the time-resolved Husimi Q function of the polariton mode.

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# Universal scaling laws in the coherence decay of 2D polariton condensates

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**Abstract**: We present measurement of the spatio-temporal coherence decay measured in two dimensional polariton condensates. Our result highlight a cross over from super-diffusive to diffusive regime when reducing the polariton exciton content.

Cavity polaritons, hybrid light-matter quasiparticles emerging from the strong coupling between photons confined in cavities and quantum well excitons provide a powerful platform to explore the physics of Bose Einstein condensates in a driven dissipative context [1,2]. In 2015, it was discovered that the phase dynamics of a polariton condensate is governed by the celebrated Kardar Parisi Zhang (KPZ) equation [3]. This means that the first order coherence of a polariton condensate could reveal universal spatio-temporal KPZ scalings [4,6]. Such features could be experimentally demonstrated in 1D [7] and more recently in in 2D [8] systems.

In the present talk I will describe recent interferometry experiments realized on 2D polariton condensates generated in a planar semiconductor cavity. Depending on the strength of the non-linearity in the system that can be varied changing the detuning between the exciton resonance and the cavity mode, we observe different scaling laws in the spatio-temporal decay of the coherence. Our results hints toward a cross over between a diffusive and a superdiffusive regime [9].

This work highlights the profound difference between driven-dissipative out of equilibrium condensates and their equilibrium counterparts.

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# Rotational superradiance in a polariton fluid of ligth

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**Abstract**: By optically imprinting a multiple charged vortex, we generate an ergoregion in a polariton quantum fluid. We excite negative and positive energy modes, respectively inside the vortex core and at large radii, confirming the rotational superradiance observation.

The amplification of field excitations in rotating systems is a universal phenomenon known as rotational superradiance. Initially predicted in shear layers of water flows, rotational superradiance was later recognized as a fundamental aspect of black hole physics [1]. It has also been recently proposed to govern the instability of multiply quantized vortices in quantum fluids [2] [3], though direct experimental evidence remains elusive.

In this work, we leverage the high optical tunability of our system to generate a multiply charged vortex in the fluid profile. In this geometry, the azimuthal velocity becomes supersonic towards the centre, creating an ergosurface where superradiance can occur. We send a probe towards the ergosurface and stimulate superradiance, observing negative energy modes at the vortex core, accompanied by the generation of positive energy modes at larger radii, which leads to the amplification of the probe field.

These findings confirm the origin of dynamical instabilities in superradiant amplification and open new perspectives on quantum rotational superradiance, particularly the entanglement between negative and positive energy waves, a phenomenon recently predicted in our system [4]. Such effects could be explored using quantum optics techniques.

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# Supersolids: basic concepts and new perspectives

**Iacopo Carusotto**[1]

1. *Pitaevskii BEC Center, CNR-INO and Department of Physics, University of Trento, 38123 Povo, Trento, Italy*

**Abstract**: I will start with an historical introduction to the general concept of supersolid state of matter. After a brief review of recent experimental realizations, I will then outline my personal view on the perspectives of this field and on a number of exciting interdisciplinary connections.

Supersolids are a most intriguing state of matter that combines spatial order with superfluid properties. After a long quest in a condensed matter context, this state has recently been observed in atomic clouds [1] and, then, polariton systems [2,3].

In this talk I will give an overview of the general concept of supersolid, highlighting the main conceptual steps that have led from its original formulation in the context of solid Helium to its recent experimental observations in dilute quantum gases. A special emphasis will be given to the fundamental features of a supersolid state and on the observable signatures of the underlying symmetry-breaking processes. I will then review the different mechanisms that may lead to the simultaneous stabilization of superfluid and spatial order, both in conservative and driven-dissipative systems, and I will then outline my personal account of the open questions that stand in front of the community.

I will finally explore how the concept of supersolid may be fruitfully used to describe the physics of a wide class of condensed matter and optical systems and I will outline the new perspectives offered by this novel point of view.

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# The hyperbolic quantum processor

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**Abstract**: Optical polariton waves in hyperbolic materials provide a promising platform for achieving strong light matter coupling. We will review the phenomenon of super-resonance in such systems and demonstrate that it can be used to achieve long range entanglement between qubits. As a concrete example, we will discuss optical polaritons in hexagonal boron nitride (h-BN) and show that they can provide the foundation of a hyperbolic quantum processor with gate fidelity exceeding 99%. We will also discuss applications of hyperbolic polaritons for quantum nonlinear optics and quantum simulations.

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arXiv:2412.14098

# Supersolid crystals of dipolar excitons in a lattice

**A. Dubin**[1]

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We report supersolid crystals in a GaAs bilayer, by confining dipolar excitons in a nanoscopic lattice where they genuinely realize the Bose-Hubbard model model extended by dipolar repulsions and long-range hopping. At fractional lattice fillings – 1/4, 1/3 and 1/2 – we report dipolar quantum solids, with mesoscopic dimensions i.e. extending across over a few hundreds lattice sites, spontaneously breaking translational symmetry. At the same time, we show that off-diagonal long-range order is induced by long-range hopping, such that exciton solids are superfluids. Numerically exact calculations quantitatively confirm that supersolidity builds up in the ground-state of the lattice Hamiltonian.

# Photon condensation from thermal sources and the limits ofheat engines

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**Abstract:** We investigate condensation of photons supplied by thermal sources such as sunlight. We show how the source temperature required for condensation is determined by entropy changes and the second law of thermodynamics.

In the weak-coupling regime cavity photons can equilibrate through inelastic scattering, allowing them to form Bose-Einstein condensates. This has been observed in dye-filled microcavities [1], where the scattering leads to equilibrium atthe solventtemperature $T_c$ and, more recently, for semiconductors [2, 3]. Although the steady-state ofthese photon gases is close to equilibrium their density – and hence whether condensation occurs or not – is dependent on the kinetics and the strength and form of pumping. Here we show that there are simple and universal conditions, related to the operation of quantum heat engines [4], that capture these effects in both equilibrium and non-equilibrium condensates.

We investigate photon condensation in a dye-filled cavity, described by a generalization of a previous kinetic model [5] to the case where the cavity modes are populated by coupling to an external thermal photon reservoir with temperature $T_h$. For a spectrally filtered reservoir, with a single frequency $\omega_s$, we find that condensation occurs at frequency $\omega_0$ when

$$0 = \frac{\hbar\omega_s}{kT_h} + \frac{\hbar(\omega_s - \omega_0)}{kT_c}. \quad (1)$$

This corresponds to the entropy balance in a reversible (Carnot) heat engine, and is therefore the lowest possible $T_h$ consistent with thermodynamic principles. We show that a similar result can be derived also for the case where the pump excites the electronic transition of the dye, and that these simple expressions for the threshold agree with the full kinetic simulations, as shown in Fig. 1. We discuss the extensions of these results to account for non-negligible loss rates, non-equilibrium steady-states, and pumping by unfiltered multimode sources. These effects lead to increases in the critical temperature $T_h$ due to entropy production and irreversibility. The increases are relatively small, however, and for the multimode pumping this disadvantage is offset by a larger condensate and output power. Our results show the feasibility of condensing sunlight and so implementing an efficient all-optical heat engine.

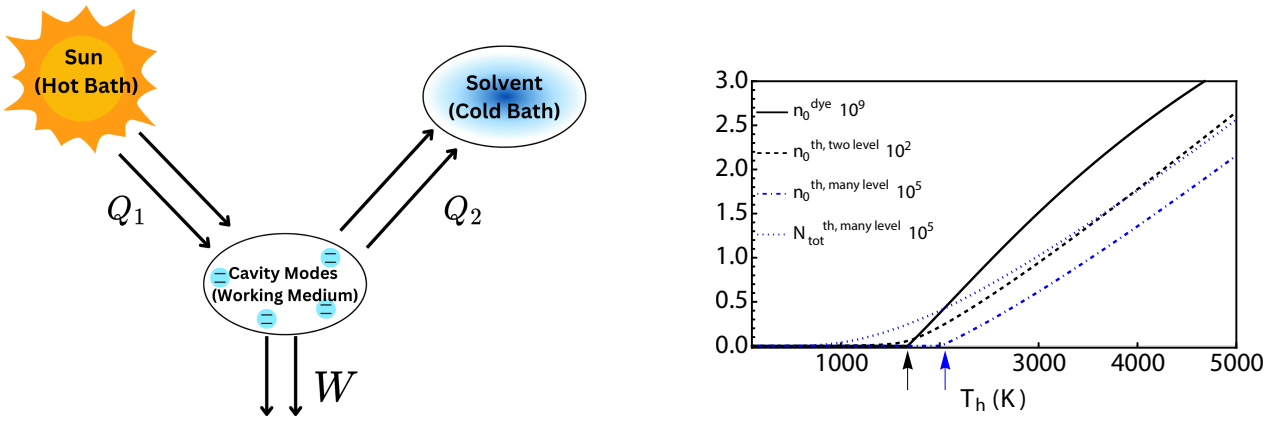


**Fig. 1.** Left: illustration of a dye-filled cavity as a heat engine. The hot bath is provided by a thermal source, such as sunlight, coupled through the cavity mirrors. The cold bath is the solvent, and the work outputis the coherent emission from the condensate. Right: Computed number of photons in the lowest-energy cavity mode, as a function of the temperature of the hot bath, for filtered (black dashed) and unfiltered (blue dot-dashed) thermal pumping of the cavity modes, and thermal pumping of the dye transition (black solid). The black arrow is the bound set by the reversible heat-engine result, Eq. 1, which is reached for the filtered cases. The blue arrow is the critical temperature for the multimode pump, which is increased over the filtered case due to entropy production.

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## Exciton-Polariton quantum circuits

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**Abstract**: I will review recent routes towards the exploitation of the quantized exciton-polariton field, with a focus on quantum information processing, exploiting the polariton nonlinearity beyond the mean-field level to optimize quantum gates and elementary quantum photonic operations.

Despite several efforts, so far exciton-polaritons in semiconductor nanostructures have mostly been explored (and exploited) in the classical regime, where the emergence of spontaneous coherence can be described at the mean field level through driven-dissipative versions of the Gross-Pitaevskii equation. Here the aim is to rather show prospective applications of quantized polaritons in integrated circuits, with the goal of realizing quantum nonlinear interferometers with characteristics that are unattainable in available quantum photonic circuits operated in the linear regime. The polariton nonlinearity is orders of magnitude larger than silicon, which allows for key functionalities such as the realization of two-qubit entangling gates with arbitrarily high fidelity in suitably engineered nonlinear interferometers [1,2]. In this talk I will present recent results showing that the previous conclusions [2] hold true also when correctly accounting for the finite temporal extent of the single-polariton wavepackets injected into the device, thus going beyond the single-mode (i.e., continuous wave) approximation that is commonly employed.

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# Observation of 2D Kardar-Parisi-Zhang universal scaling

Simon Widmann[1], **Siddhartha Dam**[1], Johannes Düreth[1], Christian G. Mayer[1], Romain Daviet[2], Carl Philipp Zelle[2], David Laibacher[1], Monika Emmerling[1], Martin Kamp[1], Sebastian Diehl[2], Simon Betzold[1], Sebastian Klembt[1], Sven Höfling[1]

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**Abstract**: Universality provides a powerful framework for grouping systems with different microscopic details into common macroscopic behaviors. Here, we present the experimental evidence of 2D Kardar-Parisi-Zhang (KPZ) universal scaling in exciton-polariton condensates.

One of the most well-known examples in nonequilibrium physics is the Kardar-Parisi-Zhang universality class [1], which describes growing interfaces in various dimensions. While one-dimensional KPZ phenomena - such as forest fire spread or bacterial colony fronts - have clear analogues in nature, true two-dimensional KPZ behavior can only arise far from equilibrium. Quantitative results of 1D KPZ have been shown in many platforms, including exciton-polariton condensates [2]. Although exciton-polaritons are nonequilibrium by nature, this condition is not tied to KPZ scaling in one dimension. The scenario is completely different in two dimensions, since KPZ physics cannot exist in equilibrium systems. Even though theoretical studies have predicted the existence of 2D KPZ in exciton-polaritons [3,4], no experimental studies have been reported so far.

Here, we present the experimental evidence of 2D KPZ scaling in driven-dissipative exciton-polariton condensates, quantum fluids of light confined in semiconductor microcavity lattices [5]. By engineering square and triangular lattice geometries, we condense at negative effective-mass states, suppressing vortices and obtaining large, coherent condensates. With space and momentum-resolved photoluminescence and space-time interferometry, we map out the first-order coherence $g_1(\Delta\mathbf{r}, \Delta t)$.

When rescaled, our data collapse onto the universal 2D KPZ scaling function obtained from numerical solutions of the KPZ equation (**Fig. 1**), yielding critical exponents and a universal curve in precise agreement with theory. This unambiguous collapse distinguishes the nonequilibrium KPZ dynamics from any equilibrium analogue and firmly establishes 2D exciton-polariton condensates as a versatile platform for probing universal scaling in two dimensions, extending nonequilibrium universality far beyond the realm of interface growth.

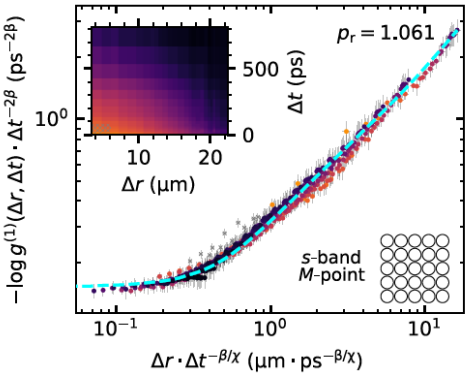


**Fig. 1** Scaling collapse of $g_1(\Delta\mathbf{r}, \Delta t)$ obtained for a square lattice onto the the theoretically obtained KPZ scaling function.

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# Exciton-polaritons in moiré heterostructures

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**Abstract**: Semiconductor van der Waals heterostructures with near-resonant band alignment and non-commensurate lattices such as MoSe2/WS2 [1] constitute effective Hubbard model systems for studies of correlated phenomena on triangular lattices [2]. Robust against mesoscopic lattice reconstruction [3] due to sizable lattice mismatch, they exhibit canonical periodic moiré potentials, while near-resonant band alignment induces hybridization of exciton states across the constituent layers and ensures sizable exciton oscillator strength for efficient light-matter coupling. We study this regime of strong light-matter coupling between moiré excitons and microcavity photons at cryogenic temperatures in the presence of out-of-plane electric and magnetic fields as well as electrostatically controlled electron doping. Striking optical and magnetic nonlinearities [4] reveal a rich interplay of cavity photons with excitons, electrons and spins ordered on moiré lattices, expanding the realm of polariton phenomena in semiconductor heterostructures.

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# Spatially coherent luminescence from degenerate interlayer excitons in reconstructed $MoSe_2/WSe_2$ heterostructures

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**Abstract**: We discuss various aspects of the spatially coherent luminescence of degenerate ensembles of interlayer excitons in van-der-Waal heterostructures as well as the excitonic center-of-mass wave function.

Heterostructures made from 2D transition-metal dichalcogenides are known as ideal platforms to explore excitonic phenomena ranging from correlated moiré excitons to degenerate interlayer exciton ensembles with a reported spatial coherence at cryogenic temperatures [1-3]. In this talk, we discuss different aspects of the spatially coherent luminescence of such ensembles.

Moreover, it is assumed that the atomic reconstruction appearing in some of the heterostructures gives rise to a dominating localization of the exciton states [4]. We demonstrate that excitonic states in reconstructed $MoSe_2/WSe_2$ heterostructures can extend well beyond the moiré periodicity of the investigated heterostructures. The results are based on real-space calculations yielding a lateral potential map for interlayer excitons within the strain-relaxed heterostructures and corresponding center-of-mass real-space excitonic wavefunctions. We combine the theoretical results with cryogenic photoluminescence experiments, which support the computed level structure and relaxation characteristics of the interlayer excitons [5].

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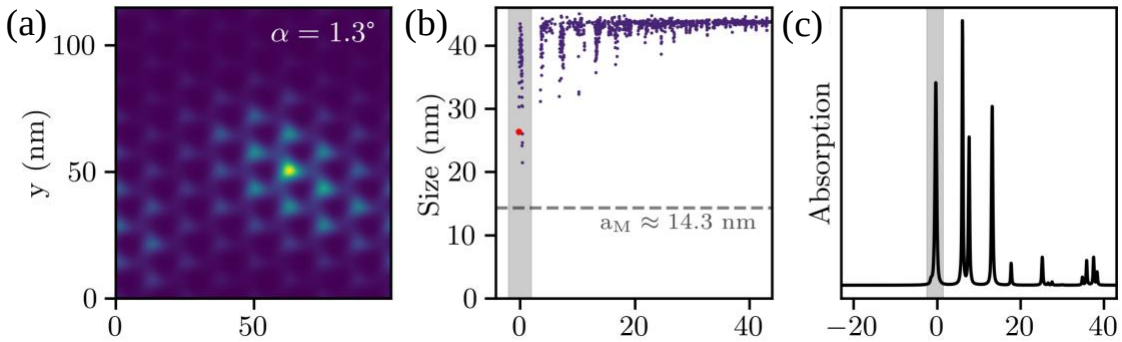


**Fig. 1.** (a) and (b): At a twist angle of 1.3° and above, the center of mass (COM) wavefunction of the interlayer exciton states with lowest energy within $MoSe_2/WSe_2$ heterostructures can extend well the moiré periodicity with $a_M \approx 14.3$ nm. (c) The lowest states can be attributed to a single, energetically sharp feature in the excitonic absorption and luminescence [5].

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# Long-range ferroelectric order in two dimensional excitonic insulators

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**Abstract**: We show that a ground state two dimensional interlayer exciton condensate can exhibit true long-range order at finite temperatures, provided that its low energy excitations couple to the electromagnetic near field.

The search for exciton condensation has been one of the key topics in condensed matter physics for the last six decades. The advances in materials technology has resulted in shifting this quest to two dimensional (2D) materials where it is generally assumed that off-diagonal long-range order is prohibited by Mermin-Wagner theorem. In contrast, we show here that generic bilayer semiconductors could demonstrate true Bose-Einstein condensation of interlayer excitons. We show that the key requirements include (i) reduction of the interlayer band gap using an applied electric field so that excitons spontaneously appear in the ground state, (ii) band structure that allows for long-range electron-hole exchange interaction, and (iii) a finite magnetic field. Our results indicate that superfluidity and ferroelectric order can co-exist in two dimensional excitonic insulators.

Even though vacuum electromagnetic field fluctuations lead to observable effects such as the Lamb shift or the Casimir effect, an interesting open question in condensed matter physics is whether the functionality of a quantum material can be modified through coupling to cavity enhanced vacuum fields. While we do not assume a cavity structure, we show here that the coupling of elementary excitations to the vacuum field leads to a qualitative change in the ground state of a 2D material by inducing a paraelectric-to-ferroelectric phase transition. Naturally, enhancement of vacuum fluctuations at vanishing energies would lead to a higher $T_c$ and a more robust ferroelectric state.

## Rotation of the polarisation of light induced by few-photon polariton nonlinearities. The role of biexciton.

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Quantum platforms that use photons as qubits hold great promise for quantum optical applications, including computing, communication and optical neural networks, paving the way towards sustainable quantum photonic artificial intelligence. A key challenge in these applications is the realization of scalable systems with strong effective photon-photon interactions, enabling high probability, or even a deterministic generation and control of complex multi-photon entangled states at much reduced resource overheads[1-4]. Polaritons offer a potential solution by providing the necessary giant photon-photon interactions and scalability [5,6].

In my work, I will present experimental findings on strong cross-phase modulation between signal and control beams at low photon intensities in tunable open-access microcavity systems [7]. In these systems, strong nonlinearity is achieved through polariton lateral confinement (~1 μm) and a high Q-factor (~30,000). We observe phase shifts of up to 240 mrad per polaritons [8], approaching the values found for single photon emitters, such as semiconductor quantum dots or atoms. The phase shift per polariton decreases rapidly from positive to negative photon-exciton detuning. This behaviour is attributed to biexciton resonance effects, which induce a strong energy dependence in interactions between cross-circularly polarized polaritons, as well as nonlinear dissipation. Our modelling, which takes into account birefringence, spin-dependent interactions and excitation of the biexciton shows that the polarisation rotation can be even observed for linearly polarised signal and control beans inside the cavity. Additionally, we measure the phase shift as a time delay between ~2 ns control and signal pulses, with a rise time of approximately 200 ps. The shift completely disappears when the pulses no longer overlap in time, confirming the ultrafast nature of polariton nonlinearity[8].

Overall, our work establishes strong foundation for utilising polaritons platforms in scalable, ultrafast and resource efficient nonlinear quantum information processing.

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# Non-epitaxial perovskite polariton laser diode operating under direct current

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Reaching lasing in electrically pumped microdevices based on solution-processed semiconductors poses a major scientific and technological challenge. Halide perovskites offer a promising platform for electrical injection, since their optically excited single-crystal cavities and predesigned or postprocessed microstructures have exhibited low lasing threshold. Indirect electrical pumping of a dual-cavity perovskite laser was recently obtained, utilizing a well-established technological concept of embedding a high-luminosity light-emitting diode (LED) with a high-gain medium into an integrated device. Direct charge-carrier injection into a perovskite LED excited by auxiliary short-, optical-pulses resulted into amplified spontaneous emission. Other efforts for rational engineering of architectures that allow for high charge-carrier density are still to demonstrate lasing. Here, we develop a novel strategy for achieving direct electrical pumping of a perovskite laser. We integrate a solution-grown CsPbBr3 microplate with chemically inert single-walled carbon nanotube electrodes and embed them into an optical microcavity. By cooling the microdevice down to 8 K at a constant current, a perovskite p-i-n diode is formed that facilitates a balanced carrier injection at high current densities. The perovskite microcavity diode operates in the strong coupling regime, exhibiting polariton lasing under a direct current of 65 uA.

# Geometrical features of polariton condensation

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Polariton condensation is one of the oldest as well as most fundamental problems in the field. In this talk, I will describe condensates from the point of view of the spatial correlations of particles as they undergo a change from a thermal (below threshold) to their coherent phase (above), reporting previously unsuspected effects such as extremization of bosons (getting farther from each other than fermions would do). I will describe the quantum Boltzmann Master Equation approach which we introduced at the time of the first ISCE, its recent upgrades by Shishkov et al. and how this may bring about new directions toward a better understanding of out-of-equilibrium, two-dimensional condensation. Finally, I will discuss within such a paradigm the hallmark of condensation as a phase transition—spontaneous symmetry breaking—and how this may impact other spontaneously-acquired coherent configurations.

# Supersolidity and Kibble Zurek mechanism in spin-orbit coupled exciton-polariton condensates.

Dmitry Solnyshkov[1, 2,*],Pavel Kokhanchik[1], Marcin Muszynski[3], Rafal Mirek[4],Darius Urbonas[4], Etsuki Kobiyama[4], Pietro Tassan[4], Ioannis Georgakilas[4] ,Rainer F. Mahrt[4] , Michael Forster[5] ,Ullrich Scherf[5] , Wiktor Piecek[6],Piotr Kapuscinski[3], Jacek Szczytko[3], Thilo Stoferle[4] and Guillaume Malpuech[1]

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In Bose-Einstein condensates (BEC), spin-orbit coupling (SOC) produces supersolidity. It is a peculiar state of matter, which, in addition to the superfluid behaviour shows periodic density modulation typical for crystals. Here, we report the fabrication of a new type of optical microcavity allowing to achieve room-temperature supersolidity for a quantum fluid of light [1]. The microcavity is filled with a nematic liquid crystal (LC) and two layers of the organic polymer MeLPPP hosting exciton resonances. We demonstrate exciton-polariton condensation in the two distinct degenerate minima of the dispersion created by the LC-induced Rashba-Dresselhaus (RD) SOC. By single-shot experiments we show that the condensate real-space distribution shows density stripes. At large condensate density, stripes are located randomly from one condensate realization to another despite the presence of a disorder potential. On the opposite, at lower condensate density (close to threshold) stripes are pinned by disorder. This density-dependent immunity of stripes against disorder is a direct proof of superfluidity and of the spontaneous breaking of translational invariance.

We also report the observation of vortices which can are detected in the supersolid as fork-like dislocations. The detected vortices are located randomly from one experiment to another. Their density depends on the pumping strength (quench parameter) and follows an original Kibble-Zurek scaling exponent $\eta = 1.0 \pm 0.2$. This is in agreement with a theoretical analysis we perform and which predicts two different scalings in the slow- and fast-quench regimes.

[1] arXiv:2407.02406

# Quantization of polaritons confined in dielectric structures

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**Abstract**: Using Bogoliubov transformation and third-quantization techniques, we derive structure-specific quantum master equations for polaritons, enabling engineered many-body nonlocal interactions and pronounced quantum correlations in semiconductor nanostructures.

Description of many-body light-matter interactions in the regime of strong-light matter coupling is usually presented within the framework of the seminal work of Hopfield [1]. However, this description has several drawbacks. The picture of well-defined modes of light and matter modes interacting with each other is correct as long as the shapes of eigenmodes are not substantially modified by the interaction. This may lead to incompatibility of theoretical descriptions and physical realizations.

We present a systematic method for obtaining the quantum master equation under the assumption of small size of emitters (such as excitons) compared to the wavelength of light. The method is based on Bogoliubov transformation [2], in the conservative case and on the concept of third quantization [3], in the dissipative case. The procedure involves finding eigenmodes of Maxwell equations coupled to macroscopic polarization field in the classical limit. We propose that this method can be used for engineering many-body nonlocal interactions between polariton modes. In one example, we design a semiconductor structure characterized by high nonlocality of interactions which leads to substantial quantum correlations between modes of emitted light (see Fig. 1).

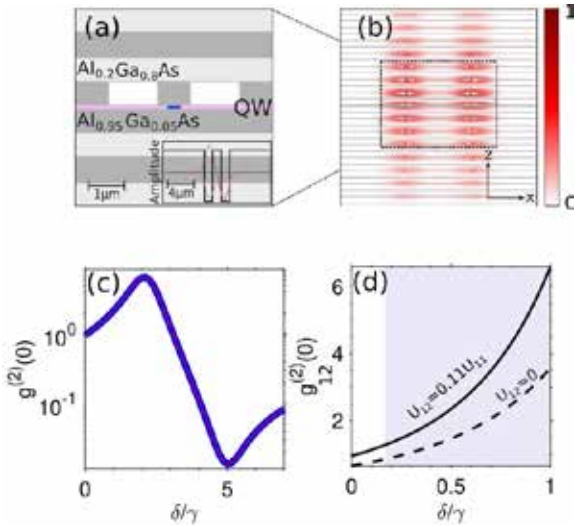


**Fig. 1** (a) An example of an engineered semiconductor structure hosting exciton-polariton modes with nonlocal interactions. (b) Electric field intensity in the symmetric eigenmode. (c) second-order correlation function of emitted light in function of detuning. (d) cross-correlation showing enhancement of cross-mode correlations due to nonlocal interactions.

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**Exciton - Photon- Magnon interaction in 2D magnets**

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Two-dimensional van der Waals (vdW) magnets that host excitons that show strong correlation to underlying magnetic order present a unique opportunity to realize strong interaction between magnons, excitons and photons. In this talk, I will first discuss our work on magnetic semiconductor, CrSBr where in the bulk limit, the excitons are inherently dressed by photons forming self-hybridized exciton-polaritons [1]. The signature of coherent magnon oscillations imprinted on the polaritons and the potential to modify magneto-optical response by tuning the photon fraction of the polariton states will be discussed. Following this, I will present our recent work on the role of magnons on nonlinear exciton-exciton interaction in CrSBr [2].Finally, time permitting, I will discuss confinement and propagation of magneto-exciton polaritons [3].

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## Exploring the supersolid phase of matter with dipolar quantum gases

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Supersolids are a fundamental quantum phase of matter combining properties of crystals and superfluids. A supersolid phase was recently discovered in Bose-Einstein condensates of strongly dipolar atoms. I will discuss the exceptional properties of dipolar supersolids, spanning from double symmetry breaking to mixed superfluid and classical dynamics. I will in particular show how a supersolid can behave as a self-induced Josephson junction array, and how it is possible to deduce from the Josephson dynamics the superfluid fraction, which is the universal property quantifying the deviation of supersolids from both crystals and superfluids.

# Engineering electronic matter with exciton polaritons

**Meera M. Parish**[1]

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**Abstract**: I will present a new proposal for achieving polariton-mediated superconductivity in an atomically thin semiconductor monolayer

Recently, there has been much interest in using light to manipulate the properties of materials, thus opening the prospect of realizing states of matter that go beyond those allowed by the constraints imposed by material science or chemistry [1]. In this talk, I will explore how the behavior of electronic and excitonic systems can be modified in the regime of strong light-matter coupling in semiconductor microcavities. I will particularly focus on exciton polaritons in atomically thin materials, where the coupling to light can enhance the interactions between charges [2] and lead to superconductivity at elevated temperatures using the proposed setup in Fig. 1 [3].

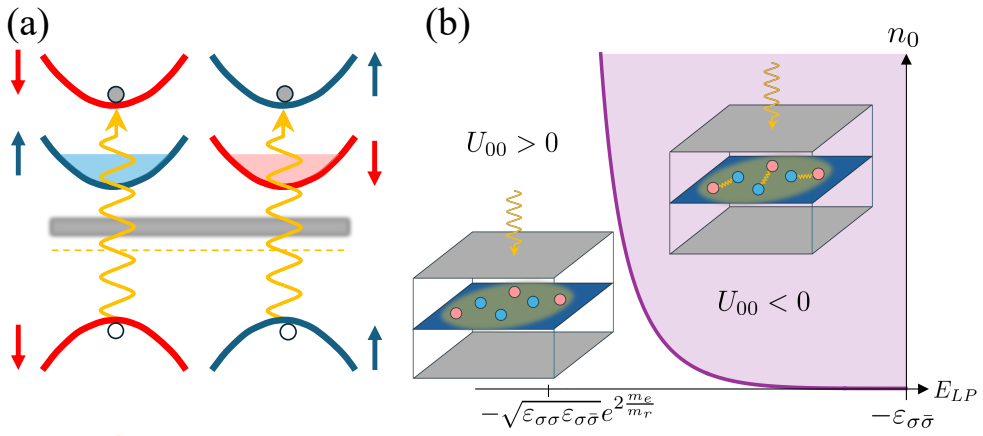


**Fig. 1** (a) The inverted bandstructure of a tungsten-based TMD monolayer allows exciton polaritons to be created in the upper conduction bands, without any Pauli blocking of the doped electrons in the lowest conduction bands. The lower-polariton energy (dashed yellow line) is controlled via the coupling to the cavity photon (wiggly lines) such that it can be tuned below dark states (gray region), including trions. (b) The polaritons induce an attraction between spin-up and down electrons which can overcome the repulsive Coulomb interactions and cause the effective electron-electron interaction $U_{00}$ to be net attractive (purple region) when the lower-polariton energy $E_{LP}$ approaches the lowest trion energy. Far below the trion resonance, there is no attraction for any polariton density $n_0$. The insets illustrate the microcavity setup where the Bose-Fermi mixture of spin-up and down electrons (blue and red circles) and resonantly excited polaritons is realized in a single TMD layer.

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# Exciton-polariton neural network with perovskite crystal

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**Abstract**: Using a template-assisted method, we fabricate geometry-tunable perovskite microwires supporting polariton optical neural networks at room temperature. The mirror-free architecture ensures high optical quality and nonlinear response, paving the way toward scalable all-optical neural computing.

The performance limits of conventional electronics have driven the search for new computing platforms capable of fast and energy-efficient information processing. Optical neural networks (ONNs), offer a promising route to overcome bottlenecks in data transfer and power consumption. A variety of ONN architectures have been proposed, most notably feed-forward, spiking, and reservoir networks. Among these, feed-forward ONNs currently stand out in terms of accuracy and scalability, whereas reservoir ONNs excel in tasks requiring temporal or dynamic data processing but remain more limited in terms of generality.

Here, we discuss a feed-forward architecture of polariton ONNs that perform nonlinear operations entirely in the optical domain [1]. Exciton-polaritons, quasiparticles formed through strong coupling between photons and excitons, combine low-loss optical propagation with strong matter interactions, making them particularly well suited for information processing. We present a significant advancement in the development of room-temperature exciton-polariton neural networks using large-scale perovskite microwires of arbitrary shape. We have developed a versatile, template-assisted method for fabricating $CsPbBr_3$ perovskite microstructures, enabling the formation of microwires that can be bent into any pre-defined geometry without compromising optical quality [2]. These microwires demonstrate waveguiding capabilities and facilitate the formation of spatially extended condensates of coherent exciton-polaritons at room temperature.

Our approach overcomes the limitations of traditional waveguiding setups by eliminating the need for extrinsic cavity mirrors, significantly simplifying the fabrication process and enhancing compatibility with existing photonic devices. We observe polariton lasing from the edges and corners of the microwires, with substantial blueshifts under high excitation power. Far-field photoluminescence and angle-resolved spectroscopy reveal high mutual coherence between different lasing signals, indicating the formation of a coherent polariton condensate capable of propagating over long distances and coupling between neighboring wires through air gaps.

These properties enable the microwires to function as separate or coupled nonlinear nodes in optical neural networks. We propose to verify the performance of our system in various machine learning tasks, including binary classification and object detection, demonstrating its potential as an optical computing accelerator. Our work represents a first step towards the practical application of polariton neural networks, providing a simple, cost-effective, and room-temperature platform for future large-scale devices.

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# Excitonic landscape in layered semiconductors

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The optical properties of low-dimensional semiconductor nanostructures are often governed by excitons – quasi-particles formed by a photo-generated electron and hole bound together by Coulomb attraction. Strong excitonic effect, particularly pronounced in two-dimensional (2D) van der Waals semiconductors, provides an unprecedented platform for studying exciton quasiparticles, which exhibit different charges, spins, or spatial configurations. First, I will discuss the excitonic properties in homo-bilayer transition metal dichalcogenides where the interaction between two dipolar excitons with opposite dipole moments can lead to the formation of a new type of interlayer exciton, namely a quadrupolar exciton. Secondly, I will demonstrate that excitonic effect are very pronounced in recently discovered 2D magnetic semiconductors. This brings new possibilities for investigating fundamental interactions between excitons and a correlated spin environment, particularly pronounced in CrSBr. I will demonstrate that CrSBr hosts both localized Frenkel-like and delocalised Wannier-Mott-like excitonsa duality rare among other magnetic or nonmagnetic 2D materials.

# Quantum optics of interacting exciton-polaritons

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**Abstract**: we report and explain the emergence of two-photon correlations in the photoemission of many-body states of polaritons in different experimental context

Engineered photonic resonators involving a sizeable nonlinearity, like polaritonic micro-resonators, have the potential to generate bright and rich many-body quantum states of light [1,2]. The full picture of this family of states and their quantum features is still largely unknown, and its exploration is an exciting prospect both to gain insights into the emergence of quantum phenomena in many-body quantum systems, and for the generation of potentially useful many-body states of photons for quantum applications. In this talk, I will present our recent results on the quantum properties of light that can be generated in spatially confined polaritonic systems, in different experimental conditions.

Under non-resonant excitation for instance, a low-density fully-incoherent steady-state of polaritons is sustained. Using frequency-resolved two-photon correlations measurement, we observe a photon-cascade correlation in the spontaneous emission of this many-body state, which is the result of two-body interaction between the polaritons. Indeed, these correlations emerge from the fact that the frequency of an emitted photon at a given time, carries partial information on the number of polaritons inside the system at this time [3].

If instead, we drive the system coherently in its lowest energy states with laser light, we achieve a completely different intracavity state: a mean field surrounded by a small incoherent fluctuating polaritonic field -- the Bogoliubov fluctuations – which constitutes a non-trivial many-body quantum state. Using two-photon two-colour correlations measurements on a single discrete Bogoliubov mode, we observe a large and uniquely time-ordered correlation, that grows for decreasing number of Bogoliubov excitations below unity, i.e. for increasing participation of the Bogoliubov fluctuations vacuum.

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# Condensation of Exciton-Polaritons in the van der Waals magnet CrSBr

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***Abstract**: This contribution features the formation of exciton-polaritons in the van der Waals magnet CrSBr. I will address the formation of a polariton condensate and discuss its magnetically tuneable non-linear features.*

Two dimensional materials have emerged as a new and interesting platform for studies of tightly bound exciton in ultimately thin materials. Meanwhile, various types of 2D- or quasi 2D materials have become available that feature giant light-matter interactions, charge tunability, and intriguing magnetic and topological properties. These features can be exploited for implementing novel photonic devices, and for fundamental, as well as quantum photonic investigations in the framework of cavity quantum electrodynamics [1].

I will present the implementation of a spectrally tunable open optical cavity in a liquid-helium-free magneto-optical cryostat [2]. It is ideally suited for the study of magneto-optical phenomena of exciton-polaritons based on van-der-Waals materials [3,4]. In my presentation, I will specifically highlight the case a CrSBr thin layer embedded in our cavity. The CrSBr slab forms a Fabry-Perot cavity of low quality factor, which coherently couples to a high Q-factor open cavity resonance. The resulting system undergoes a transition to a non-linear regime of polariton condensation, and features a magnetically tunable non-linearity arising from the interaction with incoherent magnons[5].

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# Optically trapped polariton condensates in a magnetic field

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**Abstract**: The long coherence times of optically trapped InGaAs exciton-polariton condensates permit delicate tuning between their fine structure and mean field energies, resulting in Zeeman inversion and suppression and possible evidence for dark-exciton mediated Feshbach resonance.

Optically trapped polariton condensates display extremely long coherence times (up to ns) and small linewidths compared to most other trapping and excitation techniques of polaritons. This gives a unique advantage to explore long-time dynamics and competitive behaviour triggered by small, and comparable, fine-structure and mean-field energy scales that would normally not be detectable. It is well known that polaritons and their condensates experience well known phenomena such as Zeeman splitting and Larmor precession through their excitonic component when subjected to external magnetic fields. By adjusting the excitation intensity the condensate mean field energies, determined by interparticle interactions, result in dramatic new many-body effects such as Zeeman inversion and Zeeman suppression [1] and possible condensate Feshbach resonance due to a biexciton-polariton coupling mediated by dark-excitons [2,3].

If time allows, I would like to present results how ballistically coupled optically-trapped polariton condensates can spontaneously arrange their spatial structure into extended states that remind of $\pi$- and $\sigma$-bonded artificial molecules [4]. The results underpin the potential of using nonequilibrium quantum fluids of light and matter to explore sudden ordering and pattern formation in flexible and reconfigurable optical setups

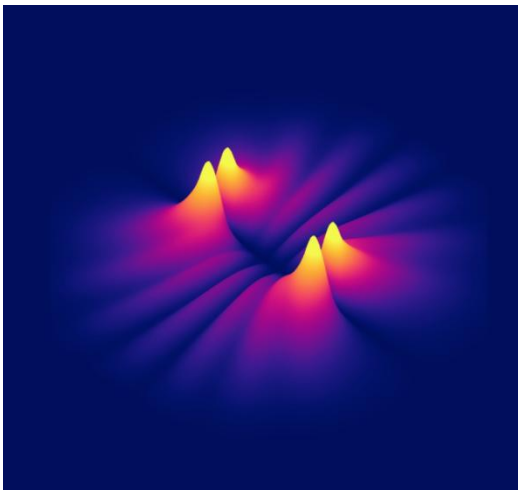

**Fig. 1** Two dipole-shaped polariton condensates in optical traps (not shown) can ballistically couple and spontaneously synchronize and align their mutual dipole axis, mimicking $\pi$- and $\sigma$-bonding between artificial atoms.

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# Strong Coupling and Upper Polariton Condensation of Polaritons in GaAs/AlGaAs Structures up to Room Temperature

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Having extremely high cavity Q allows many new possibilities for polariton condensates. Recent results using high-Q GaAs/AlGaAs structures grown by molecular-beam epitaxy include demonstration of a polariton condensate in thermal equilibrium,[1] with the predicted behavior for the coherence,[2] a clear demonstration of persistent current circulating in a ring,[3] and coupling of two condensates via an external photon path.[4] Recently, we have shown that the polaritons in this system remain in strong coupling all the way up to room temperature,[5,6] and that the coherent polariton condensate remains in strong coupling as well. As part of our studies, we have mapped out a phase diagram when the condensate is in the upper polariton state and when it is in the lower polariton state, for a full range of temperatures from cryogenic temperature up to room temperature, and for a full range from photonic to excitonic character of the polaritons. We also find that right on the phase boundary between upper and lower polariton condensation, we can see metastable switching behavior between the two states. Comparing several samples with different cavity Q also allows us to have greater understanding of the system.

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# Multiphoton emission from a single-photon source

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**Abstract**: We show how to control multiphoton emission in a coherently driven quantum system (quantum dot), revealing that quantum fluctuations, though small, dominate the dynamics. A new path toward crafting complex light via interference and classical-field engineering.

Detecting more than one photon at a time from a single-photon emitter is usually regarded as accidental, undesired and something to be suppressed. Such multiphoton emission can turn out, however, to be even more fundamental and interesting than the single-photon emission, which is a particular case of a pervading quantum phenomenon: interferences of probability amplitudes. In a coherently driven system, the multiphoton suppression indeed arises from quantum interferences between virtual multiphoton fluctuations and the mean field in a Poisson superposition of all number states [1]. With such a picture in mind, one can control the multiphoton dynamics of a two-level system by disrupting these quantum interferences through a precise and independent homodyne control of the mean field [2]. In this experimental work [2], we show that, counterintuitively, quantum fluctuations always play a major qualitative role, even and in fact especially, when their quantitative contribution is vanishing as compared to that of the mean field. Our findings provide new insights into the paradoxical character of quantum mechanics and open pathways for mean-field engineering as a tool for precision multiphoton control [3,4].

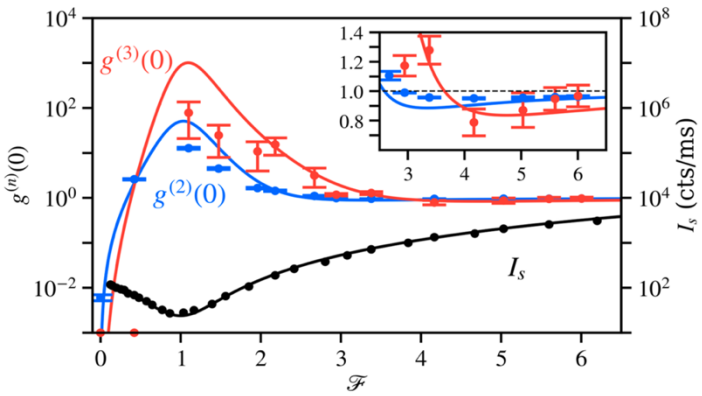


**Fig. 1** from [2]. Experimental points and theoretical curves for the homodyned resonance fluorescence signal vs the LO field amplitude *F*. At *F=1*, the external field cancels the mean field of the system laying bare its quantum multiphoton fluctuations (manifesting as strong superbunching). For a sizable coherent field, one can suppress *n*-photon emission independently. The cases *n=2* and *n=3* are shown and magnified, confirming the transition from two-photon suppression to three-photon suppression.

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# Dark lakes of cold indirect excitons in nitrides.

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**Abstract**: Observation of dark indirect excitons in GaN/AlGaN quantum wells at T< 15 K and excitation powers between two temperature-dependent critical values: do we observe the condensation into the spin-forbidden state?

Fluids of dipolar (or indirect) excitons offer an interesting test bed for studying emergent collective states of strongly interacting two-dimensional bosons in the presence of disorder. Exciton fluids hosted by GaAs-based coupled quantum wells (QWs) have been shown to exhibit a rich variety of many-body phenomena: gas-liquid transition, superfluidity, vortex formation, Mott insulator states, and Bose-Einstein condensation (BEC) [1]. The salient feature of the excitonic BEC state is its vanishingly weak optical emission, since the lowest-energy exciton state is spin-forbidden in GaAs heterostructrues. Thus, on the phase diagram of the exciton fluid, the density/temperature range in which darkening of the optical emission is observed, is expected to correspond to the condensation.

In this work, we explore the phase diagram of dipolar excitons confined in wide GaN/AlGaN QWs. In these materials, many-body states may form at temperatures higher than in GaAs, because excitons are more robust. The giant built-in electric field along the QW growth axis makes excitons spatially indirect (Fig. 1 (a)), so that no external electric bias is required to induce exciton dipolar moment. By depositing metallic patterns on the surface of the sample, it is possible to efficiently trap excitons in the bare surface areas of the QW plane, see Fig. 1 (b).

We have demonstrated that electrostatic trapping prevents exciton fluid from fast radial expansion and dilution [2]. This allows us to study emission of the excitonic fluids tens of microns away from the laser excitation spot, in the excitonic "lake" (Fig. 1 (b)), at macroscopic thermodynamical equilibrium with well-defined temperature close to the sample temperature. The density of the thermalised exciton fluid can be controlled by changing the laser excitation power.

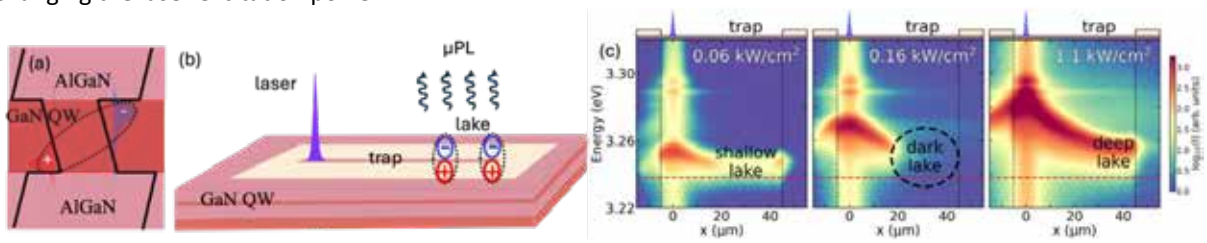


**Fig. 1** QW band diagram; (b) Artist view of the studied structure; (c) Color-encoded spectral map of the $\mu$PL intensity measured at T=8 K under three different excitation powers: below, above, and within power range required for the darkening. White dashed line indicates zero-density exciton energy.

Our recent, unpublished micro-photoluminescence ($\mu$PL) experiments under CW point-like excitation indicate that, at T< 15 K and excitation powers between two temperature-dependent critical values (see Fig. 1 (c)), emission of the excitonic fluid from the "lake" formed in the linear-shape trap fades out dramatically, as compared to either emission of the fluid excited below/above critical power range, or the emission of the non-thermalised fluid created outside of the trap under the same excitation power. Time-resolved experiments confirm the dramatic reduction of the exciton fluid radiative rate at low temperatures and under powers within a specific, temperature-dependent range. We will discuss possible interpretations of this "darkening" in terms of collective quantum effects: either as the onset of the condensation into the spin-forbidden state, or as the formation of a collective subradient state [3].

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# Dark Soliton Formation as a Dark State Phase Transition in a Dissipative Superfluid Chain

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**Abstract**: I will discuss a theoretical description of a dissipative ultracold atom system exhibiting bistability, highlighting the analogies and differences with bistability in driven Kerr resonators.

Ultracold atomic gases are tuneable platforms that are typically excellently isolated from any environment. Dissipation can be added however by shining an electron beam onto the cloud [1]. Such dissipative ultracold Bose-Einstein condensed gases resemble optical Kerr resonators that are driven by an external laser and therefore feature bistability.

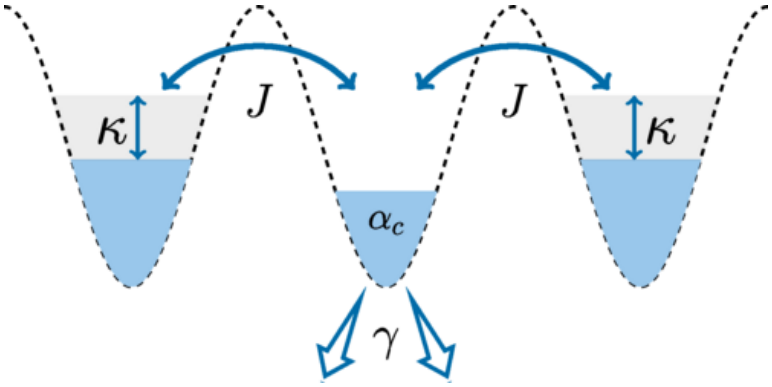


**Fig. 1** An atomic Bose-Hubbard model with local losses.The neigbouring sites drive the lossy site in analogy with a laser driving an optical cavity.

Our theoretical study has shown that the analogy is only partial. The role of the driving laser is now played by condensates at the left and at the right of the lossy site. In contrast to lasers, there is a significant backaction from the system on these condensates. I will discuss how this affects the steady state of the system, where a dark soliton is favoured rather than the usual lower branch of optical bistability, altering the nature of the dissipative phase transition. Our full numerical simulation of this system within the truncated Wigner approximation shows that the dark soliton is essential to explain the experimental observations [3].

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# Manipulating the ultrafast dynamics of exciton polariton condensates in halide perovskite microcavities

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**Abstract**: Recently, microcavity exciton polariton research has attracted considerable interests in a number of excellent optical gain materials that demonstrate unique properties compared with conventional III-V or II-VI semiconductor quantum wells and organic semiconductors. Those materials include transition metal dichalcogenides (TMDs), and certain halide perovskite semiconductors. Particularly, those materials exhibit large exciton binding energies (much larger than thermal fluctuation energy ~ 26 meV), large oscillator strength and peculiar electronic band structures such as valley polarization or encoded chiroptical responses. In this talk, we will discuss our recent effort in manipulating exciton polariton condensates in halide perovskite semiconductors microcavities, for instance demonstration of room-temperature optical spin Hall effect in planar microcavities and the characterization of ultrafast propagation of polariton in 1D waveguide structures. Next we will discuss the neuromorphic computing based nonequilibrium dynamics, the highly nonlinear nature enables 92% accuracy in benchmarking digit recognition with single-step training. Finally, we will conclude the talk with some perspective outlooks.

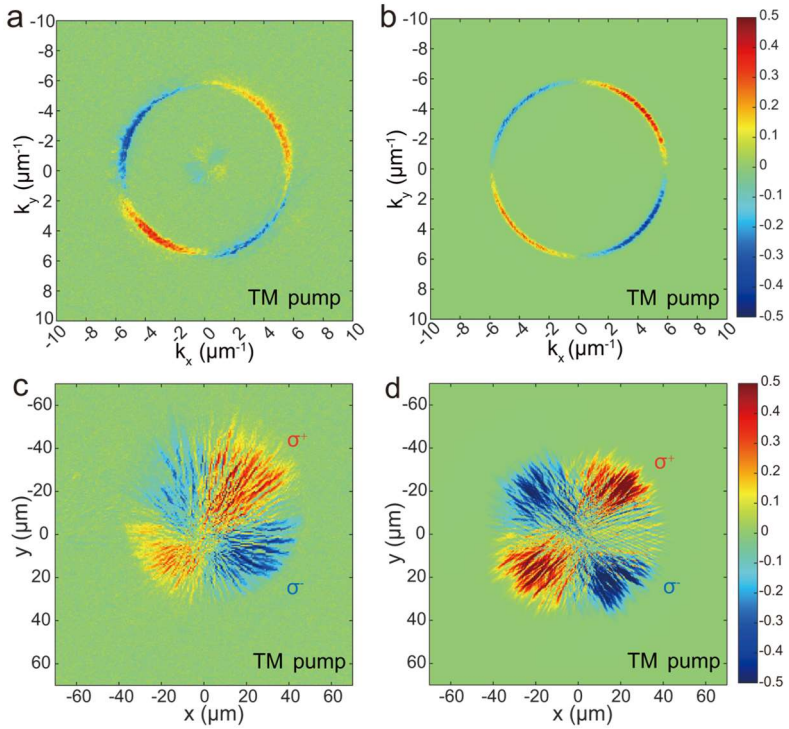


Figure 1: Room-temperature optical spin Hall effect in halide perovskite microcavities.

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# GaN-based microlasers: how far are we from an electrically-injected room-temperature polariton laser?

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**Abstract**: Electrically-injected GaN microlasers operating in the weak- and strong-coupling regimes based on in-plane cavities have been fabricated. The comparison between the two lasers will illustrate the challenges for achieving a useful room-temperature electrically-injected polariton laser.

Nowadays GaN-based laser diodes display wall-plug efficiencies larger than 50% at blue wavelengths and cover a wide spectral range from the near-UV to the green spectral region. They are based on waveguide structures that use InGaN/GaN quantum wells as active regions and whose typical lengths are in the order of milimeter/s, with the shortest electrically-injected GaN microlasers ever reported comprising hundreds of micrometers long cavities.

In parallel to this thirty-years long technological development, optically-pumped polariton lasers displaying gain as provided by the hybrid quasi-particles arising from the strong coupling between excitons and photons, have been developed. Their putative advantage over conventional lasers is that they do not require population inversion, but only that the net spontaneous scattering rate from an excitonic reservoir overcomes the decay rate of the polariton mode. While initial demonstrations of polariton lasing and polariton Bose-Einstein condensation were conducted in vertical cavities, in the last years the horizontal configuration, where photons are confined by total internal reflection, has gained increasing interest as it gives access to fast propagating polaritons, with group velocities in the order of tens of micrometres per picosecond, that still retain large excitonic fractions and, thus, large nonlinear interactions [1].

In this work we will demonstrate experimentally the achievement of polariton lasing in such a horizontal configuration (i.e. in a polariton waveguide) and will illustrate the difference between edge polariton lasers and conventional edge-emitting lasers operating under electron-hole population inversion [2,3]. We will then describe our approach to attain polariton lasing under electrical injection and will compare the actual operation performances of electrically-injected polariton and standard edge-emitting lasers fabricated with the same technology and with the same optical architectures.

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# Ultrafast exciton fluid flow in an atomically thin $MoS_2$ semiconductor

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**Abstract**: Experimental evidence for the formation of a collective exciton state in monolayer $MoS_2$ are provided. This exciton fluid flows over ultralong distances (at least 60 µm) at a speed of ~$1.8 \times 10^7$ m $s^{-1}$ (~6% the speed of light).

Excitons (coupled electron–hole pairs) in semiconductors can form collective states that sometimes exhibit spectacular nonlinear properties, such as superfluidity and/or superradiance, among some others[1,2]. Here, we show experimental evidence of a collective state of short-lived excitons in a direct-bandgap, atomically thin $MoS_2$ semiconductor whose propagation resembles that of a classical liquid[3]. This is suggested by the nearly uniform photoluminescence through the $MoS_2$ monolayer regardless of crystallographic defects and geometric constraints. The exciton fluid flows over ultralong distances (at least 60 µm) (see Fig. 1(A)-(C)) at a speed of ~$1.8 \times 10^7$ m $s^{-1}$ (~6% the speed of light). The collective phase emerges above a critical laser power, in the absence of free charges and below a critical temperature (usually Tc ≈ 150 K, see Fig. 1(D)) approaching room temperature in hexagonal-boron-nitride-encapsulated devices. Our theoretical simulations suggest that momentum is conserved and local equilibrium is achieved among excitons; both these features are compatible with a fluid dynamics description of the exciton transport. Our findings have implications for ultrafast exciton-mediated optical switches, exciton-valley Hall devices and on-chip exciton circuitry.

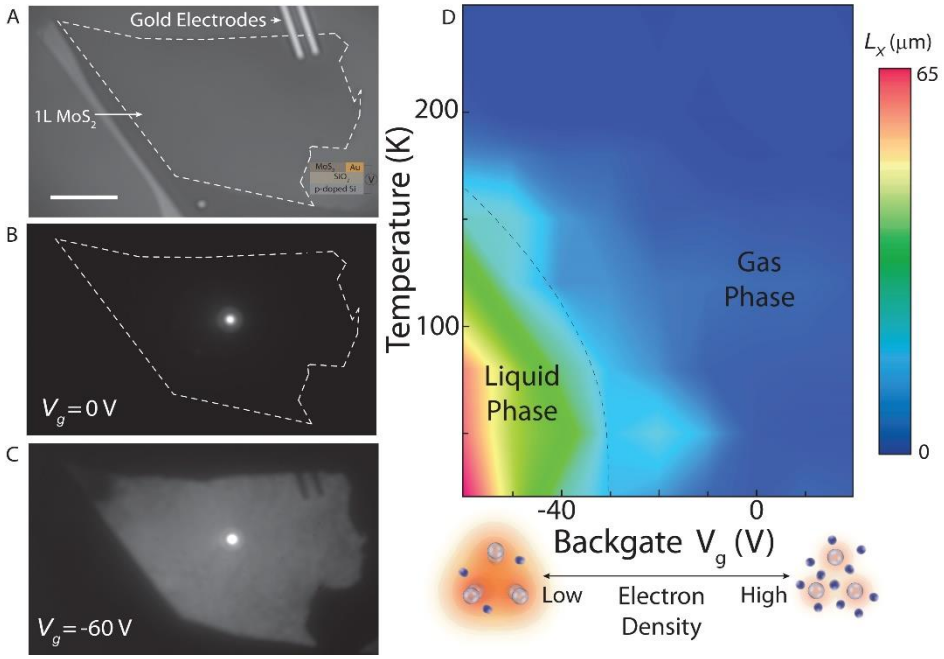


**Fig. 1** (A) Optical image of a gated monolayer, with highlighted contour. Inset: Device schematic. Photoluminescence images at (B) Vg = 0 V and (C) -60 V in a grey colour scale. Black denotes no light. The bright circle corresponds to PL emission under the laser. Grey corresponds to light emission by the sample at remote areas from the laser. The long-range exciton propagation over tens of micrometres seen in (C) is on clear contrast with the typically observed profile in (B). (D) Phase diagram of the exciton fluid transport length $L_x$. The collective (single-particle), phase domain occupies the left-side (right-side) of the dashed guideline. The scale bar is given. Illustration of the many-body interactions that controls the formation of the collective exciton state. For more details, see Ref. 3.

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# Interferometry with waveguide polaritons: towards few-particles phase-shifts in nonlinear integrated optical circuits

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**Abstract**: In this work we use waveguide polaritons as a platform to build nonlinear integrated optical circuits. We introduce ridge waveguides in strong light-matter coupling to perform optical cross-phase modulation experiments and show the potential of this platform to achieve few-particle phase-shift.

Recently, all-optical phase-shifts have been observed in polariton systems with confined geometries [1-2]. In this work we implement integrated photonic circuits using ridge waveguides [3]. We show that it is possible to design and fabricate several components such as Beziers curves and splitters/mergers, paving the way towards the realization of complex nonlinear optical circuits. We have performed cross-phase modulation experiments under different excitation conditions. Our results show that very different behaviours are observed depending on the excitation scheme. In particular we compare two kinds of resonant excitation: continuous wave excitation and ultrafast pulsed excitation. While a phase-shift is observed in both schemes, only the ultrafast pulsed excitation scheme allows us to access truly polariton-polariton interaction effects. Based on these results we can also speculate on the possibility to achieve few-particle phase shifts in polariton waveguides.

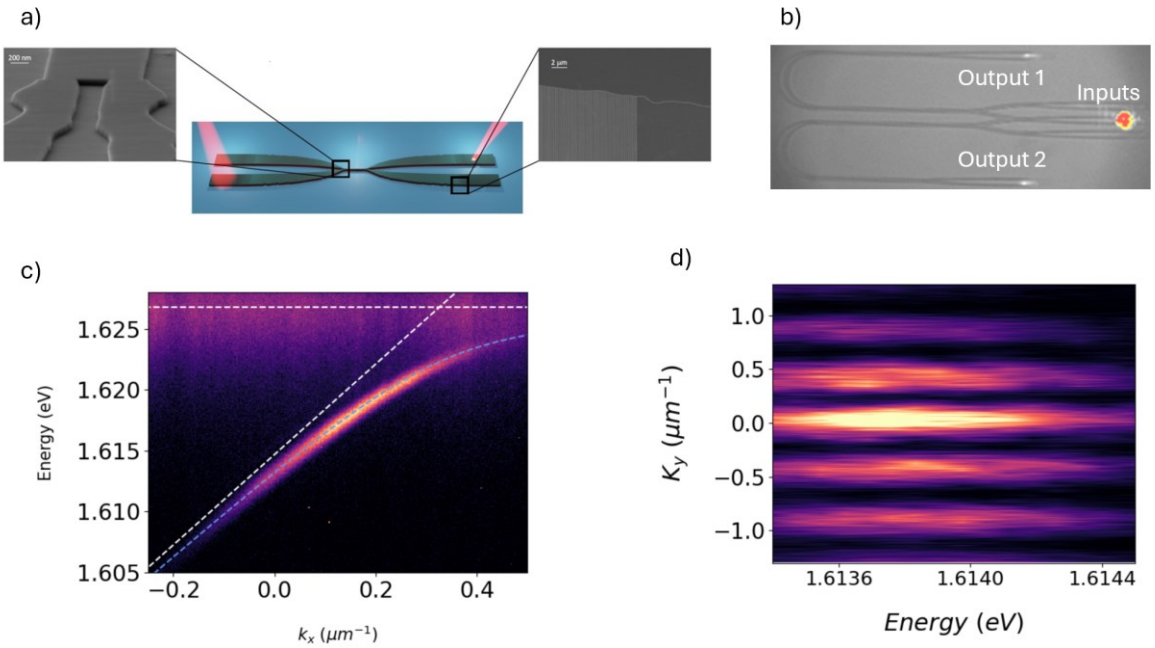


**Fig. 1** a) An example of different polariton circuit components designed and fabricated in polariton waveguides; b) An integrated polariton interferometer; c) Polariton dispersion (blue dashed line) and d) Interference pattern formed in the far-field by the outputs of a device similar to the one shown in b)

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# Topological edge states polaritons in hBN/$WSe_2$ double grating heterostructures

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A large emerging class of layered so-called van der Waals (vdW) crystals has recently attracted attention as a viable nanophotonics platform. Materials from this class such as hexagonal boron nitride (hBN) and transition metal dichalcogenides (TMDs), so far extensively studied in a few-atomic-layer form, exhibit a wide range of properties suitable for photonics in their quasi-bulk form including variety of transparency windows extending into the visible, high refractive indices and large birefringence. Importantly, vdW materials can be easily stacked or attached to any substrate thanks to the out-of-plane van der Waals forces, a further key enabler for nanofabrication of complex photonic structures requiring heterointegration.

Here, we realise a topological photonic edge state at the boundary of two subwavelength gratings etched in an exfoliated hBN flake (30-110 nm thickness). The observed edge state is a photonic analogy of the celebrated Jackiw-Rebbi model describing a state that lies between two 1D media containing fermions with masses of opposite signs [1]. The studied hBN gratings are designed to have photonic band-structures with different topology, achieved by varying the filling factor (the relative thickness of the grating bars and grooves) leading to the band inversion (i.e. changing the sign of the "mass"), which can be probed in angle-resolved reflectance measurements. The experimental realisation of band inversion requires very accurate control of the refractive index contrast in the grating that we achieve by using "inverted" structures where an hBN grating is made first and then covered by an unetched hBN slab. Both the hBN flakes have precisely selected thicknesses creating an "inverted" grating with parameters unachievable by controlled depth etching of a single hBN flake. This approach also allows us to insert additional layers between the hBN grating and the top layer thus creating a photonic vdW heterostructure (Fig.1a), in our case comprising a monolayer of semiconducting WSe2 exhibiting excitons with a high oscillator strength. This allows us to observe the strong light matter interaction regime with formation of the edge state exciton-polaritons up to room temperature (Fig.1b). We study nonlinear properties of such topological polaritons as a function of temperature both in photoluminescence and reflectance contrast under resonant excitation with a pulsed laser.

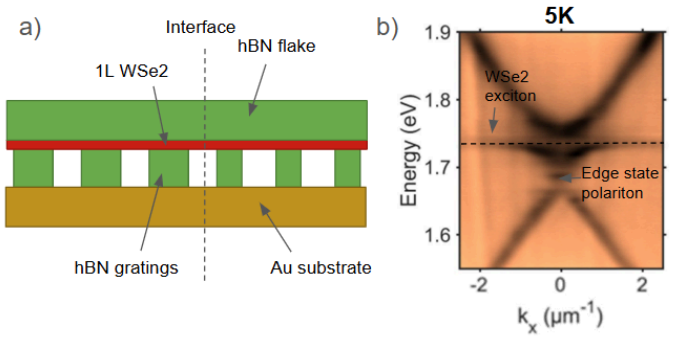


**Figure 1: a)** Inverted double grating structure diagram showing the interface between the two different grating regions. **b)** Polariton and Photonic mode dispersion at the boundary between the two gratings with different topology measured in angle-resolved spectra at 5K

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# Fine structure and optical properties of interface excitons at lateral heterojunctions

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**Abstract**: We show that the low symmetry of lateral heterointerfaces between monolayers of transition metal dichalcogenides results in the in-plane valley Zeeman effect and linear polarization of the interface-exciton photoluminescence.

Vertical stacks of transition metal dichalcogenides (TMDCs) and other two-dimensional (2D) crystals have attracted enormous attention in recent years [1]. Due to the type-II band alignment between different TMDCs, it is possible to form interlayer dipolar excitons, where electron and hole are separated vertically but remain bound in lateral directions due to Coulomb interaction. Another emerging and promising class of 2D materials comprises lateral heterostructures, where, in contrast to vertical stacks, different TMDC monolayers are stitched together in the monolayer plane and form one-dimensional interfaces [2]. Similarly to vertical heterostructures, electron and hole at lateral heterojunctions are spatially separated due to the type-II band alignment and can form an indirect interface exciton with a large built-in electric dipole moment [3,4], Fig. 1.

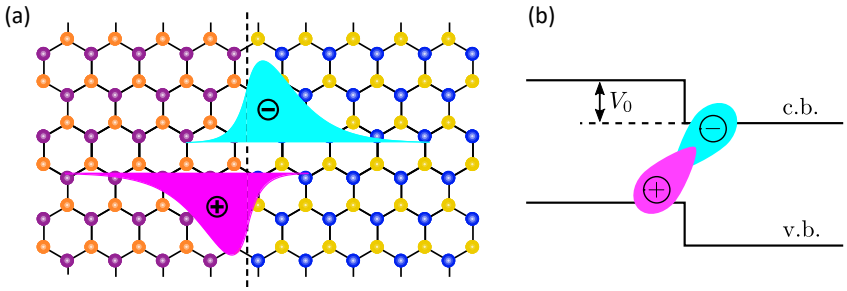


**Fig. 1** (a) Sketch of an interface exciton localized at a lateral heterojunction. The circles of different colors correspond to metal and chalcogen atoms, which differ on the two sides of the junction. The electron and hole wave functions are schematically shown. (b) Electron and hole are spatially separated due to the type-II band alignment of the lateral heterojunction and are bound together due to the Coulomb interaction.

The fine structure of energy spectrum as well as dynamics and optical properties of interface excitons are to a large extent determined by the microscopic structure of the heterointerface. In particular, the “armchair” interface shown in Fig. 1 leads to the mixing of electronic states at K and K’ valleys located at the opposite corners of the Brillouin zone. We develop a microscopic theory of this valley mixing and investigate new physical effects induced by the mixing of valleys [5]. In particular, we show that the valley mixing leads to the Zeeman splitting of electron and exciton states by the in-plane magnetic field. We also show, that the low symmetry of the lateral heterointerface results in the linear polarization of exciton photoluminescence, as high as tens of percent. Microscopically, this polarization is caused by the trigonal warping of the conduction and valence bands, whereas the polarization axes depend on the crystallographic orientation of the interface. The Stokes parameters of interface-exciton PL are calculated as functions of interface orientation as well as external electric and magnetic fields.

The work was supported by the Russian Science Foundation (Project No. 25-72-10031).

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# Time-Periodic Driving of a Bath-Coupled Open Quantum Gas of Light

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**Abstract**: I will present experiments demonstrating the time-periodic driving of a photon Bose-Einstein condensate inside a dye-filled microcavity. Our measurements of the response spectrum reveal the emergence of a collective density mode in the driven-dissipative system.

Temporally controlling many-body systems on the timescale of their microscopic dynamics is of significant importance in a variety of physical settings. In coherent systems, time-periodic Floquet driving has enabled the realisation of phenomena as topological insulators in photonic waveguides. In dissipative systems, however, the implications of periodic driving are much less explored. A new approach along those lines involves quantum gases of light, which are coupled to periodically driven reservoirs. Recent work on exciton-polaritons has demonstrated, for example, the injection of vortices by stirring a laser that pumps the nonequilibrium system. In contrast, photon Bose–Einstein condensates within material-filled microcavities provide a suitable platform for the study of reservoir-induced driving phenomena much closer to thermal equilibrium.

In my talk, I will discuss recent experimental work on the temporal control of an open quantum gas of light coupled to a bath by time-dependent driving [1,2]. Specifically, I will discuss measurements of the frequency-resolved density response of a photon Bose–Einstein condensate subject to an oscillating, time-periodic drive [1]. By monitoring the photon number dynamics for different drive frequencies, we obtain the spectral response of the condensate in a phase-sensitive way. We find that as the photon number increases, the response of the coupled condensate-bath system transitions from overdamped to resonant behaviour, indicating a transition from closed to open system dynamics. Our spectroscopy method paves the way for studies of collective excitations in complex driven-dissipative systems.

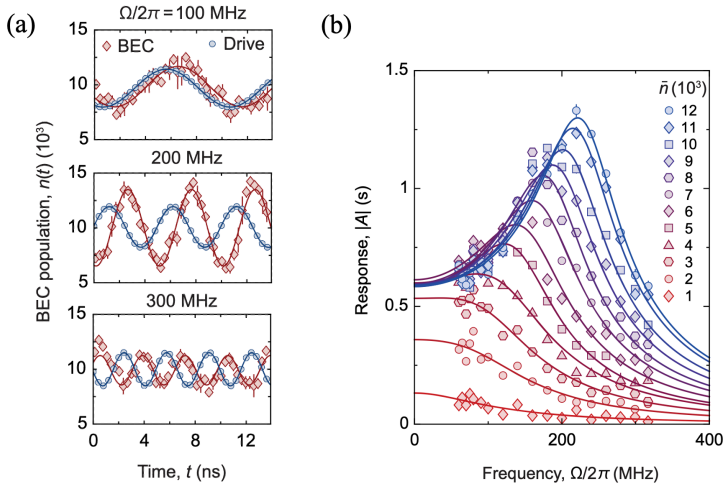


**Fig. 1.** (a) Time traces of the oscillating driving laser power (blue) and the response of the BEC population (red) for three modulation frequencies. (b) Frequency-resolved response spectra of a periodically-driven Bose-Einstein condensate of photons for increasing ground state population *n*. As the condensate grows, the spectral profiles exhibit a transition from overdamped to underdamped behaviour, highlighting the emergence of a driven-dissipative resonance.

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# Fully Integrated Perovskite Polaritonic Circuits

**Antonio Fieramosca[1],** Vincenzo Ardizzone[1], Rosanna Mastria[1], Andrea Notargiacomo[2], Fabio Bruni[3], Dario Ballarini[1], Ilenia Viola[1] and Daniele Sanvitto[1]

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**Abstract**: We demonstrate a fully integrated perovskite polaritonic circuit enabling room-temperature in-plane lasing, optical amplification, and active phase control via an integrated phase shifter, providing a scalable platform for low-power nonlinear photonic integrated circuits.

Photonic integrated circuits are a key technology for compact and energy-efficient optical information processing, but their practical implementation is limited by the weak optical nonlinearities of conventional materials, which require high power and large device footprints [1,2]. Exciton–polaritons offer a promising alternative by combining strong optical nonlinearities with high speed and scalability [3]. However, room-temperature on-chip polaritonic elements enabling coherent lasing, nonlinear propagation, or amplification remain challenging, particularly in planar waveguide architectures [4].

Here, we demonstrate a fully integrated perovskite polaritonic circuit realized through a single-step bottom-up fabrication approach combining surface-tension-driven lithography and microfluidic growth [5]. The resulting structures support robust in-plane polariton lasing, optical amplification of guided polaritons, and an integrated polaritonic phase shifter enabling active control of the propagating phase at room temperature. Our results establish perovskite polaritonic circuits as a promising platform for low-power nonlinear integrated photonics and neuromorphic architectures.

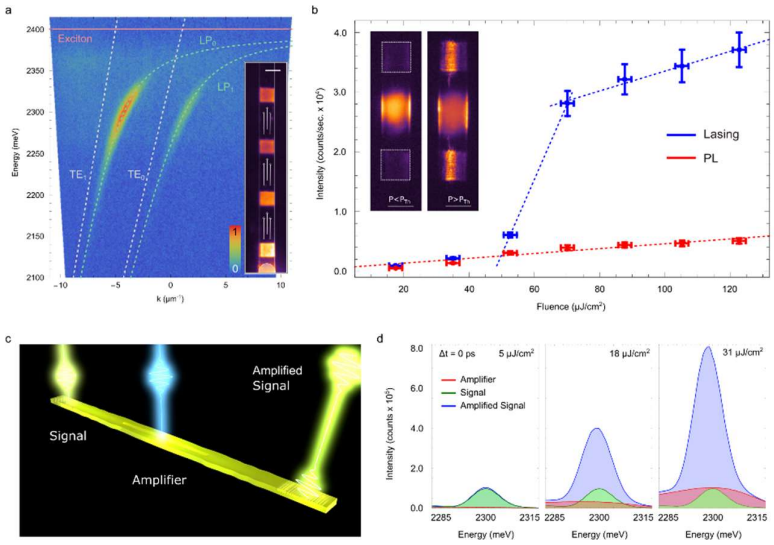


**Fig. 1** a) Polarization-resolved (TE) momentum-space PL map from a waveguide grating. Inset: real-space PL image of the waveguide. b) Fluence dependence of the emitted intensity, showing the lasing signal and background PL. Inset: real-space images below and above threshold. c) Schematic of the amplification experiment: an off-resonant beam (Amplifier) creates an exciton reservoir, enabling amplification of a resonantly injected polariton Signal. d) Power-dependent measurements at time delay 0 ps for different amplifier fluences showing a clear amplification of the Signal.

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# Dielectric control of exciton-polaritons in a two-dimensional semiconductor

**Lukas Husel**[1], Farsane Tabataba-Vakili[1,2,3], Johannes Scherzer[1], Lukas Krelle[1,4], Ismail Bilgin[1], Kenji Watanabe[5], Takashi Taniguchi[6], Iacopo Carusotto[7], and Alexander Högele[1,2]

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**Abstract**: We locally control transition metal dichalcogenide fiber-cavity exciton-polaritons by nanostructuring the dielectric semiconductor environment and demonstrate the dispersive cavity-coupling regime, where an effective hopping of highly exciton-like polaritons is mediated between different device domains.

Coherently hybridized states of semiconductor excitons and microcavity photons, frequently referred to as polaritons, are at the heart of experiments and devices in solid-state nonlinear optics, non-equilibrium many-body physics and quantum simulation. To enable engineered polariton energy landscapes and interactions, local control over the particle-like states can be achieved by tuning the properties of the exciton constituent. Monolayer transition metal dichalcogenides stand out in this respect, by allowing for a deterministic, flexible and scalable approach to local control of excitons and thus of hybrid exciton-polariton states via the exciton energy in tailored dielectric environment. In our work, we establish a fabrication technique that defines mesoscopic domains of excitons with distinct energies, subject to strong coupling to photonic modes of an open microcavity as illustrated in Fig. 1. We demonstrate that cavity-coupling of engineered exciton domains results in a local modulation of the polariton energy, a prerequisite for polariton potential well engineering. Moreover, we demonstrate that the cavity mediates an effective hopping between excitons localized in different domains addressed simultaneously in the dispersive regime of cavity-coupling. Our results represent a crucial step toward polariton-based bosonic lattices and quantum simulators in layered semiconductor devices.

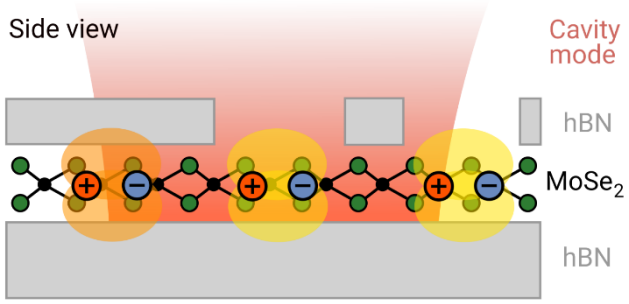


**Fig. 1** Schematics of a MoSe2 monolayer encapsulated by planar bottom and patterned top hBN layers with spatially distinct regions of exciton-polaritons formed by strong coupling to the mode of an open cavity.

# Role of the *Direct-to-Indirect* Bandgap Crossover in the *'Reverse'* Energy Transfer Process

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**Contribution:** Adaptation (lead), funding (lead), writing (lead), data analysis and experiment.

Energy transfer (ET) is a dipole-dipole interaction, mediated by the virtual photon. Traditionally, ET happens from the higher (donor) to lower bandgap (acceptor) material. However, in some rare instances, a 'reverse' ET can happen from the lower-to-higher bandgap material, depending on the strong overlap between the acceptor photoluminescence (PL) and the donor absorption spectra. In this work [1], we report a reverse ET process from the lower bandgap $MoS_2$ to the higher bandgap $WS_2$, due to the near 'resonant' overlap between the $MoS_2$ B and $WS_2$ A excitonic levels. Changing the $MoS_2$ bandgap from direct-to-indirect by increasing the layer number results in a reduced ET rate, evidenced by the quenching of the $WS_2$ PL emission. We also find that, at 300 K, the ET timescale of ~45 fs is faster than the reported thermalization of the $MoS_2$ excitonic intervalley scattering ($K^+ \leftrightarrow K^-$) time.

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# Electrically tunable quantum correlations of dipolar polaritons with micrometer-scale blockade radii

**Yoad Ordan[1], Dror Liran[1], Ephraim Keren[1i] Kirk W. Baldwin[2], Loren Pfeiffer[2], Hui Deng[3], Ronen Rapaport[1]**

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An extreme yet reconfigurable nonlinear response to a few photons by a photonic system is crucial for realizing a universal two-photon gate, an elementary building block for photonic quantum computing. Yet such a response, characterized by the photon blockade effect, has only been achieved in atomic systems or solid-state ones that are difficult to scale up.

Here we demonstrate electrically tunable partial photon blockade in dipolar waveguide polaritons on a semiconductor chip, measured via photon-correlations. Remarkably, these "dipolar photons" display a two-orders-of-magnitude stronger nonlinearity compared to unpolarized polaritons [1], with an extracted dipolar blockade radius up to more than 4 $\boldsymbol{\mu}$m [2], significantly larger than the optical wavelength, and comparable to that of atomic Rydberg polaritons [3,4].

Furthermore, we show that the dipolar interaction can be electrically switched and locally configured by simply tuning the gate voltage. Finally, we show that with a simple modification of the design, a full photon blockade is expected, setting a new route towards scalable, reconfigurable, chip-integrated quantum photonic circuits with strong two-photon nonlinearities.

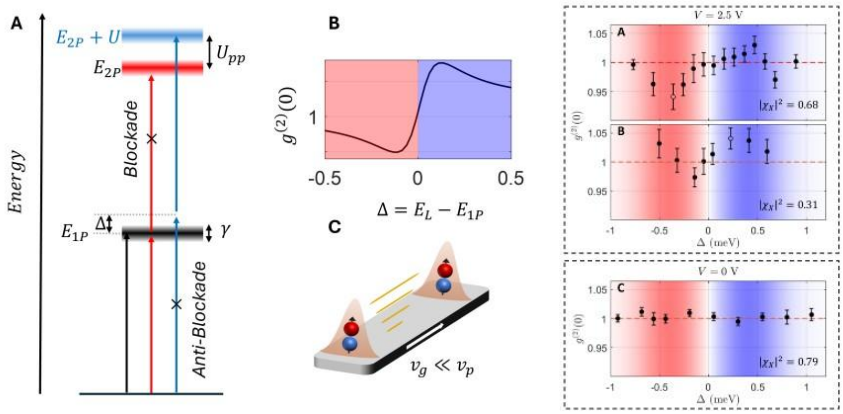


**Figure. 1** Left panel: (A) Energy levels diagram for one and two polaritons state, demonstrate how polariton-polariton interaction enables blockade (anti-blockade) using red detuned (blue detuned) laser. (B) Schematic plot of the behavior of $g^{(2)}(0)$ as function of the laser detuning. (C) Schematics of the repulsive interaction of two propagating "dipolar photons" in an optical waveguide.

Right panel: Three plots of measured $g^{(2)}(0)$ vs. laser detuning for different excitonic fractions. (A) $V > 0$ and large excitonic fraction displayiong a clear anti-bunching and bunching, suggesting partial blockade and anti-blockade of "dipolar photons". (B) same as (A) but in different excitonic fraction which means smaller blockade radius and so smaller bunching or anti-bunching. (C) $V = 0$ so the polaritons are not polarized and therefore the interaction reduces so no correlation even at large excitonic fraction. Both figures are from [1].

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[i] I continued to study the effect mentioned in [1] and succeeded in measuring this correlations with different optical setup and system configuration.

# Artificial Gauge Fields and Dimensions in a Polariton Hofstadter Ladder

S. Widmann[1], J. Bellmann[1], J. Düreth[1], S. Dam[1], C. G. Mayer[1], P. Gagel[1], S. Betzold[1], M. Emmerling[1], S. Mandal[2,3], R. Banerjee[2], T. C. H. Liew[2], R. Thomale[4], S. Höfling[1] and **S. Klembt[1]**

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**Abstract**: We demonstrate the topological Hall effect in micropillar chains using artificial gauge fields and polarization control, enabling non-reciprocal polariton transport without strong magnetic fields, advancing topological photonics.

Artificial gauge fields enable charge neutral particles to emulate the behavior of charged particles in magnetic fields, offering a versatile platform for investigating topological physics [2]. While real magnetic fields do not influence neutral particles like photons, artificial gauge fields can be engineered to govern their effective dynamics. Topological exciton-polariton lasers have garnered significant interest due to their wide tunability, though they often rely on strong magnetic fields to support topological edge state propagation. In this work, we experimentally realize the topological Hall effect in a micron-scale micropillar chain using an artificial gauge field. By exploiting the circular polarization of polaritons as an artificial dimension and carefully aligning elliptical micropillars with rotational precision, we introduce an effective plaquette phase. This phase induces edge-state propagation that depends strictly on polarization, thereby achieving non-reciprocal transport of polariton pseudospins [2]. Our findings show that the constraints posed by dimensionality and the need for strong external magnetic fields in topological laser arrays can be overcome through polarization control and precise engineering of the potential landscape. This paves the way for the development of topological polariton lattices and optically active devices enhanced by artificial dimensions.

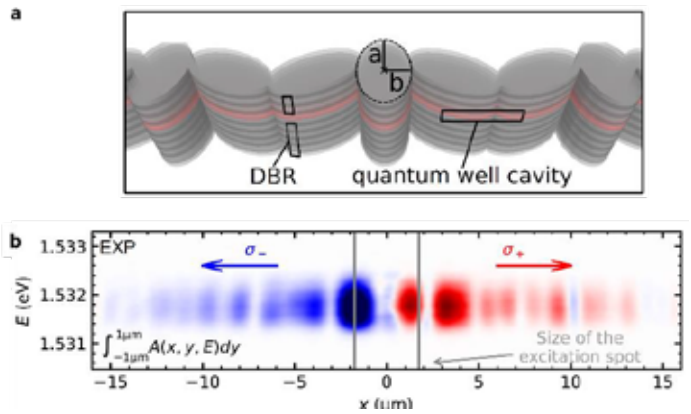


**Fig. 1 a**, Schematic of the structured microcavity, displaying the Bragg mirrors (grey) and the optically active cavity layer (red). Circularly polarised polaritons propagate in opposite directions within this chain of elliptical cavities. **b**, Polarisation of energy-dependent photoluminescence, integrated around y = 0, showing a strong relation between circular polarisation and propagation direction.

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# Doping Effect on the Brightening of Dark Excitons and Trions in a $WSe_2$ Monolayers

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**Abstract**: We observe magnetic-field-induced brightening of dark excitons and trions in monolayer $WSe_2$ under controlled doping. Photoluminescence reveals distinct excitonic features, highlighting spin–valley interactions and doping-dependent behavior of dark excitonic states at low temperature.

Semiconducting transition metal dichalcogenides (S-TMDs) are a remarkable class of layered van der Waals materials that have attracted significant attention over the past decade due to their unique electronic and optical properties making them promising candidates for next-generation optoelectronic applications. [1]

A key classification of S-TMDs monolayers (MLs) is based on their excitonic band structure. They can be classified as bright or darkish materials. WSe2 ML is one of the most studied darkish S-TMD, with well-characterized optical responses and excitonic behaviour both at low and room temperature [2]. The visibility of the dark excitons and dark trions can be significantly changed by tuning the doping level of the ML, which influences the balance of neutral and charged excitonic species [3]. However, a fundamental aspect, such as a magnetic-field-induced brightening of dark neutral and charged excitons, has remained elusive.

To explore this phenomenon, we fabricated a device with high-quality WSe2 ML encapsulated in hexagonal boron nitride (hBN) and embedded with a graphene contact attached to the ML and below the bottom hBN flake. This configuration allows us to investigate the photoluminescence (PL) of the WSe2 ML at low temperature (T=5 K) as a function of the gate voltage, which is equivalent to changes in free carrier concentration.

The Figure presents the false-color map of the PL intensity as a function of gate voltage. This configuration allows precise electrostatic doping through gate voltage, as seen in Figure 1. Three distinct regions of doping can be identified (neutral, n- and p-doped), which are correspondingly accompanied by the appearance of the bright neutral bright and dark excitons ($X^B$ and $X^D$), bright and dark negative trions ($T^S$, $T^T$ and $T^D$) and positive trions ($T^+$). The emissions of the dark excitons and trions are brighten due to external in-plane magnetic field.

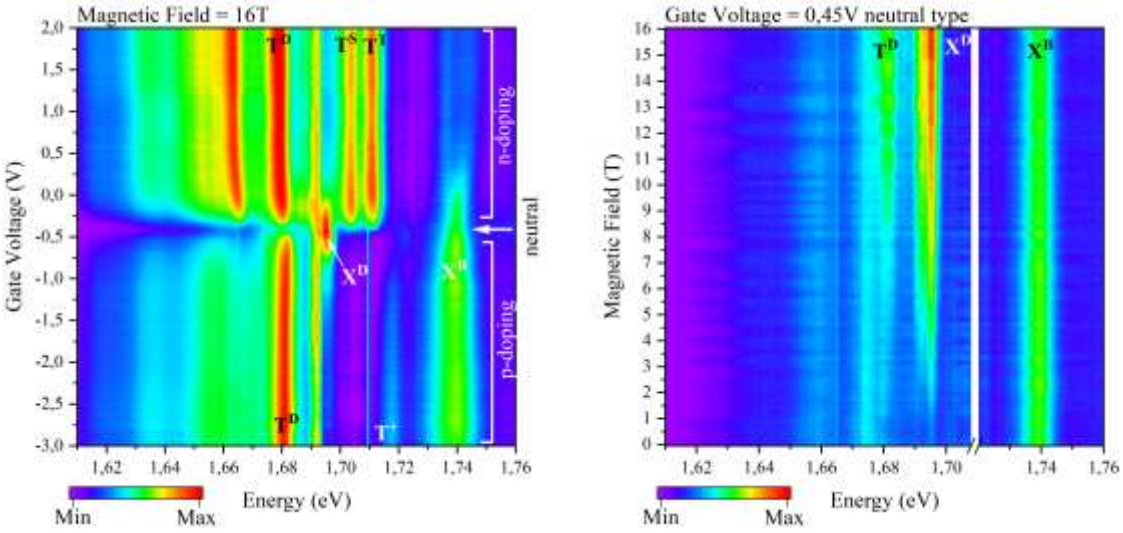


**Fig. 1** On the left: false-color map of the voltage-dependent PL spectra of the $WSe_2$ ML doping, in external magnetic field of 16T. On the right: false-colour map of magnetic field-dependant PL spectra of $WSe_2$ ML with fixed doping level on neutral type.

To extract brightening factor, we measured PL spectra under in-plane magnetic fields up to 16 T (Voigt geometry), while systematically varying the doping level. When the desired doping levels are achieved, as seen in figure 1 right side, the applied magnetic field mainly enhances the emission from dark excitonic states, accompanied with the given free carrier concentration (both sign and magnitude).

Our results reveal previously unobserved optical signatures of spin–valley interactions in dark neutral excitons and dark trions, addressing a key question in the dynamics of S-TMD excitons and offering insights for future valleytronic device design.

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# Electrically-tunable interlayer exciton-photon coupling in $WSe_2/WS_2$ microcavity

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**Abstract**: We demonstrate electrically-tunable interlayer exciton emission in a $WSe_2/WS_2$ heterostructure integrated into an optical microcavity, enabling enhanced photoluminescence, spectral tuning, and a platform for future interlayer exciton polariton devices.

Interlayer excitons (ILXs) in transition metal dichalcogenide (TMD) heterostructures have recently emerged as promising quasiparticles for quantum optoelectronics, owing to their long lifetimes, out-of-plane dipole moments, and strong light-matter interactions [1]. In this work, we demonstrate electric-field control [1,2] of the emission properties of interlayer excitons in a $WSe_2/WS_2$ heterobilayer embedded within an optical microcavity, operating at cryogenic temperatures (5 K). The heterostructure is encapsulated by hBN layers (each ~30 nm thick) and contacted with top and bottom graphene electrodes, forming a dual-gated device architecture.

Our measurements reveal a strong and tunable interlayer exciton photoluminescence (PL), with an emission energy shift exceeding 45 meV (in a half cavity) under applied electric field (Fig. 1a,b). Additional electrostatic doping contributes to a clear enhancement of the interlayer exciton emission intensity (Fig. 1b). By integrating the heterostructure into a planar optical microcavity, we observe an additional increase in emission intensity, as well as a spectral tunability that enables matching the ILX energy to the cavity resonance (Fig. 1c).

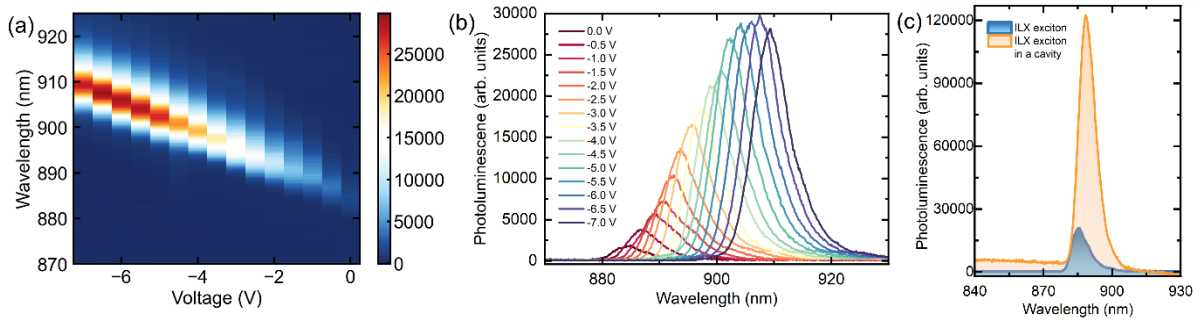


**Fig. 1** (a) Voltage-tuned emission from an interlayer exciton. (b) Graphical representation of the enhanced emission from (a) for the interlayer exciton in a half cavity. (c) ILX emission enhancement induced by coupling in an optical microcavity.

These results mark a key step toward realizing exciton–photon strong coupling in electrically tunable van der Waals heterostructures. The demonstrated platform lays the foundation for future studies of interlayer exciton polaritons [3] and their application in nonlinear optics and excitonic logic circuits.

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# Novel droplet phase of exciton-polariton mixtures in atomically thin semiconductors

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**Abstract**: We show that the competition between attractive spin-singlet and repulsive spin-triplet interactions in exciton-polariton systems can lead to the formation of novel self-bound quantum droplets, demonstrating that exciton-polaritons can display both liquid- and droplet-like phenomena.

Quantum droplets are self-bound low-density configurations which can appear in ultracold gases with competing interactions. Dilute bosonic mixtures, where the attractive mean-field energy is balanced by the repulsive Lee-Huang-Yang correction stemming from quantum fluctuations, are the prototypical platform where this novel state has been first predicted [1], and shortly after experimentally observed [2,3]. Since then, quantum droplets have gained significant interest, and their study has been extended to various cold-atom settings.

In this talk, I will show how a similar scenario can arise in a solid-state system. Specifically, we consider an atomically thin semiconductor layer embedded in an optical microcavity, where exciton-polariton quasiparticles (polaritons) result from the strong coupling between semiconductor excitons and cavity photon modes. Polaritons carry a spin degree of freedom inherited from both their matter and light components, thus resulting in the possibility of interactions between these quasiparticles [4]. We show that the competition between the attractive spin-singlet and repulsive spin-triplet channels of the interaction can lead to the formation of a novel self-bound quantum droplet phase, thus demonstrating that exciton-polaritons can display both liquid- and droplet-like phenomena [5].

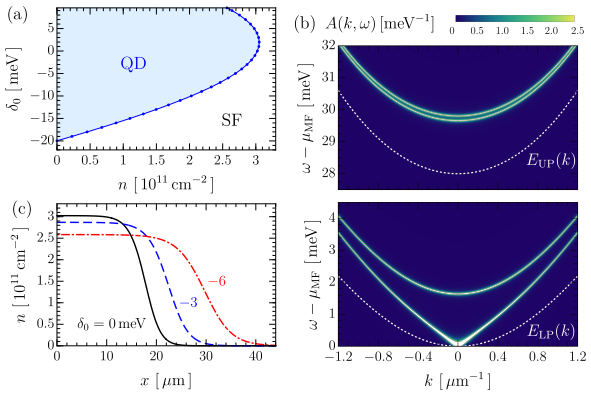


**Fig. 1** (a) Phase diagram of detuning vs. exciton density for typical parameters of a $MoSe_2$ monolayer in a microcavity. The blue solid line represents the quantum droplet saturation density and thus sets the boundary for the quantum droplet phase. Outside this phase the system is in a superfluid miscible phase. (b) Absorption spectrum, featuring the four Bogoliubov branches. The LP and UP dispersions are plotted as white dashed lines. (c) Droplet density profiles, obtained from a Gross-Pitaevskii-like approach.

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# Theory of Bose-Einstein condensation of moat-band excitons [1]

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**Abstract**: We theoretically study exciton Bose-Einstein condensation in 2D systems with camelback electron-hole bands resulting in moat exciton dispersions, which enable supersolid phases even in weakly interacting regimes, and propose candidate experimental systems.

We theoretically investigate Bose-Einstein condensation of excitons in two-dimensional systems where the electron and hole bands exhibit a camelback shape near the Γ point. This band structure arises in certain topological insulators with band inversion [2], as well as in specific monolayer materials [3,4]. In these systems, excitons can inherit the camelback feature, leading to a moat-shaped dispersion with a highly degenerate minimum at a nonzero momentum magnitude. These momentum-indirect excitons have inherently long radiative lifetimes, which can be further increased via the use of spatially separated electron-hole bilayers.

Under such conditions, a dilute quasiequilibrium gas of interacting excitons can undergo Bose-Einstein condensation into one or more degenerate momentum states. When multiple momentum states are macroscopically occupied, the system transitions into a supersolid—a unique phase of matter that combines superfluidity with broken translational symmetry along one or several directions.

To explore this, we model the excitons as interacting bosons with a Mexican-hat dispersion simulating the moat band, and analytically derive conditions under which the effective interaction potential supports supersolid phases. We show that these conditions are met by the *T*-matrix associated with general potentials approximating realistic interactions between excitons. Solving the Gross-Pitaevskii equation under these conditions, we map out the resulting phase diagram in one and two dimensions, finding in particular stripe and triangular phases.

Our findings reveal that moat dispersions can fully eliminate the energy barrier typically required for supersolid formation, allowing such phases to emerge even in weakly interacting regimes. In this talk I will present these results, propose potential candidate systems, and provide experimental parameter estimates highlighting the accessible regions of the phase diagram.

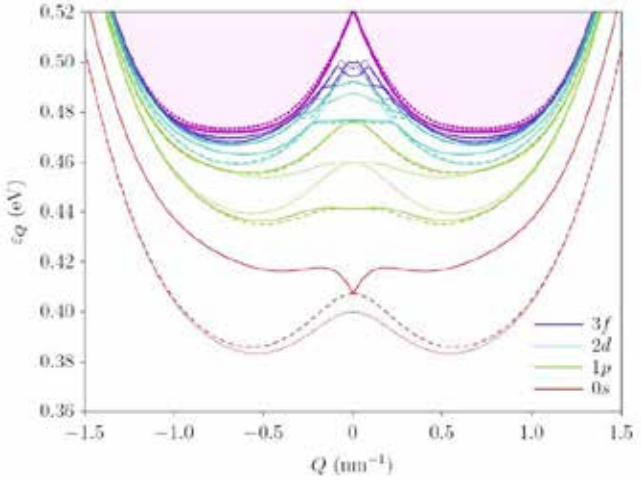


**Fig. 1.** Exciton dispersions in a Bernevig-Hughes-Zhang model for a band-inverted topological insulator, showing a Mexican-hat shape for the ground state exciton families [2].

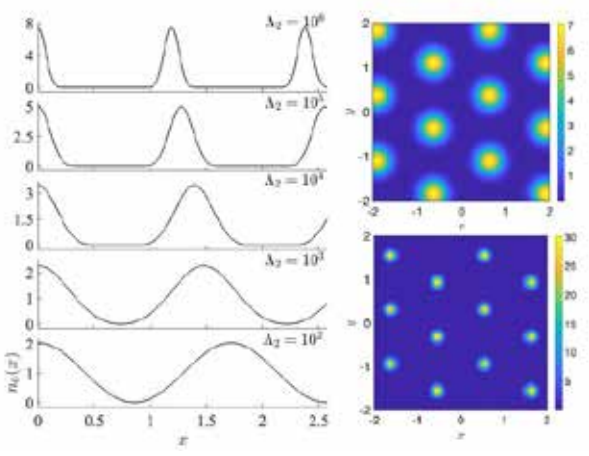


**Fig. 2.** Examples of supersolid density profiles in 1D (left) and 2D (right) arising from the Gross-Pitaevskii equation for different values of the microscopic parameters [1].

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# Topological Photonics in Perovskite Microcavities with Anisotropic 3D orientation

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**Abstract**: We investigate a perovskite microcavity with three-dimensional anisotropic orientation, showing how optical and geometric asymmetries generate synthetic gauge fields. This enables non-trivial topological states, advancing polaritonics and spinoptronics.

Photonic Rashba-Dresselhaus (RD) coupling in anisotropic microcavities offers a compelling platform for realizing unconventional topological states with nonzero Berry curvature [1,2]. In this study, we explore a self-assembled two-dimensional (2D) hybrid structure composed of anisotropically oriented organic/inorganic halide perovskite layers [3] confined within a microcavity. The strong optical anisotropies of these perovskite systems, driven by significant refractive index contrasts and robust excitonic resonances at room temperature [4], enable the emergence of synthetic magnetic fields that mediate photonic and polaritonic interactions. The interplay between polarization-dependent modes and spatial inversion symmetry breaking gives rise to strong photonic RD spin-orbit coupling (SOC) [5], leading to distinct modifications in band topology and energy dispersions. These effects result in the formation of unconventional topological features, including nonzero Berry curvature and off-axis diabolical points, within the photonic and polaritonic bands. Our findings reveal the critical role of optical anisotropies in engineering synthetic gauge fields for light, providing a versatile approach for designing photonic systems with novel topological properties. By leveraging the unique properties of halide perovskites and their ability to support room-temperature excitons, this work advances the development of polaritonic platforms for applications in topological photonics and spinoptronics.

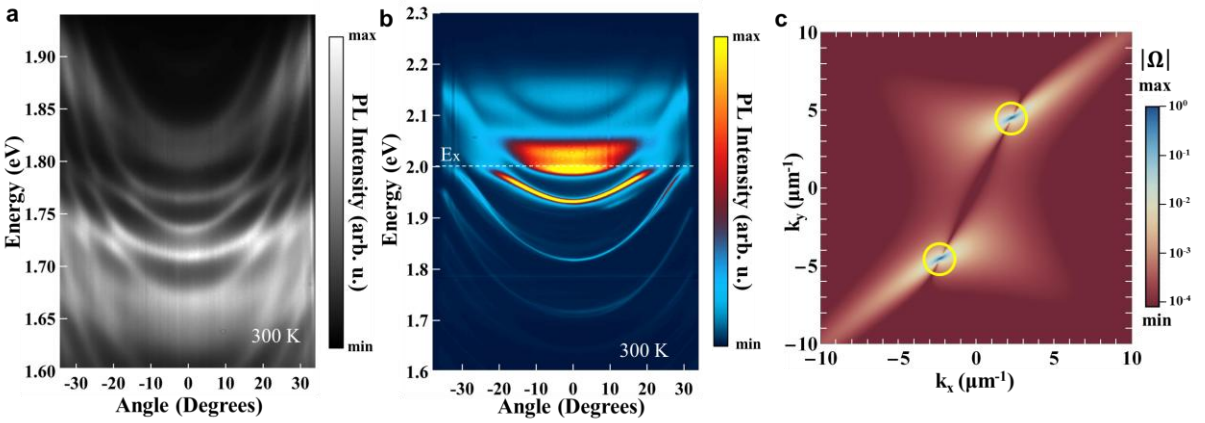


**Fig. 1**: (**a**) Photonic interaction and (**b**) strong coupling of perovskite microcavities. (**c**) Calculated Berry curvature and diabolical points.

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# KPZ phase in an optically-confined quasi-1D polariton condensate

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**Abstract**: We provide a theoretical study of a KPZ scaling behaviour in a phase of polariton condensate in a 2D planar microcavity without additional structure, where optical confinement in transversal direction creates an effectively 1D condensate.

It has been shown in [1,2] that the asymptotic behaviour of the phase fluctuations of polariton condensate at large times and system sizes abides the notorious KPZ equation, governing the stochastic dynamics of an interface between two system phases outside of thermal equilibrium. The corresponding critical exponents, manifesting the KPZ universality class for 1D system, have been extracted. Moreover, KPZ scaling was observed experimentally for the 1d polariton condensate chain formed in the 1d lattice of coupled micropillars in the groundbreaking work of Fontaine et.al. [3]. The necessity for positive phase diffusion coefficient however was a major obstacle. Since the exciton-polariton interaction strength is stronger than the polariton-polariton interaction, it can be shown that this condition is usually violated. In [3] a very clever band structure engineering in an explicitly discretized system was used to achieve negative effective mass. Together with the quadratic dependence of polariton losses on the in-plane momentum, the desired positive diffusion of the phase was demonstrated.

In this work, we propose an alternative solution that would allow for observation of 1D KPZ phase dynamics and ensure the positive diffusion without the necessity to explicitly discretize the system. Instead, we generate the polariton condensate in-between the two elongated exciton reservoirs, separating the exciton reservoir and the polariton field, as demonstrated in Fig.1a. We perform full 2D Gross-Pitaevskii equation simulations with best-fit parameters from previous experiments with the sample, and plot the behaviour of phase roughness along the unconfined axis of the condensate for different spatial sampling windows on Fig.1b. The KPZ region with a distinct growth exponent of 1/3 is observable. We further confirm the validity of our approach with study of correlation functions and fluctuations of the quasi-1D optically confined condensate.

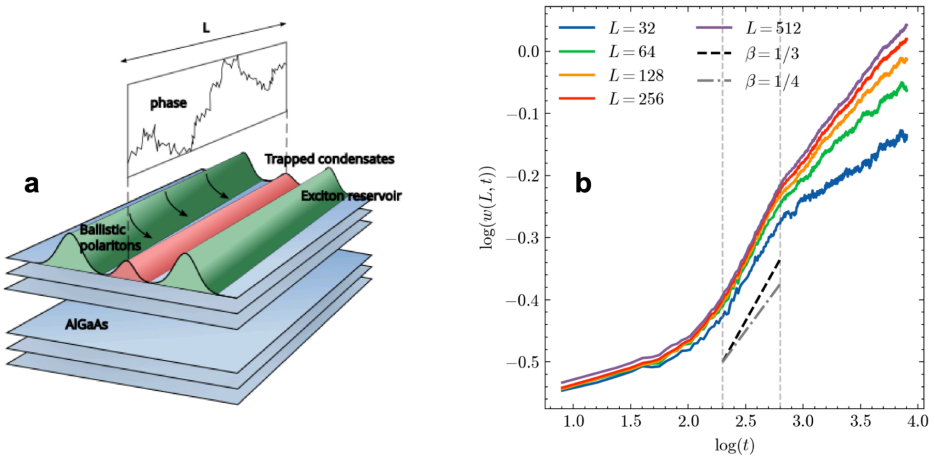


**Fig. 1** a) The proposed configuration. The two elongated exciton reservoirs (green) create a confined polariton condensate (red). The phase of the condensate along the unconfined axis exhibits the KPZ behaviour. b) Phase roughness vs time in double logarithmic scale. A linear part, unaffected by non-trivial finite size effects is demonstrated with two vertical lines.

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# Angular Resolved Raman Scattering in a Layered VOCl Antiferromagnet

**Chinmay Kumar Mohanty[1] , Igor Antoniazzi[1], Amit Pawbake[2],Adam Babiński[1], Clement Faugeras[2] , and Maciej R. Molas[1]**

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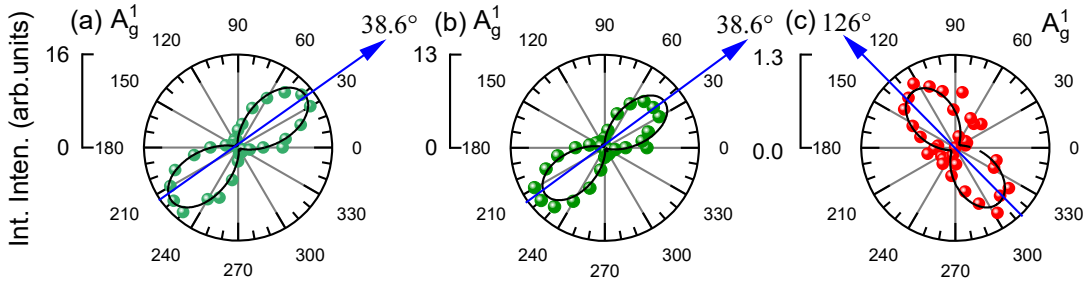
Two-dimensional (2D) layered magnetic materials (LMMs) form a newly emerging class of atomically thin van der Waals (vdW) materials with extraordinary physical features, highly suitable for modern opto-, spin-, and valleytronic devices, together with magnetic properties that persist in the monolayer limit. VOCl is an LMM from the oxychloride group that presents an easy magnetic ordering of the a-axis anisotropy for temperatures lower than 79 K [1]. Due to the magneto-optical coupling, magnetic transitions can be observed by optical measurements.

In this work, we explore the interplay between vibrational, electronic, and magnetic characteristics of multilayer VOCl through systematic angle-resolved polarised RS (ARPRS) under different excitation energies.

VOCl exhibits three main Raman active modes in the low-temperature phase, which are labeled $A^1_g$ , $A^2_g$ and $A^3_g$. The maximum intensity of the $A^2_g$ mode maximum measured in the co-linear configuration of the ARPRS, consistently aligns with the crystallographic axis across three different thicknesses. This alignment remains constant under various excitation conditions. Considering the bulk VOCl, the ARPRS dependence of the $A^1_g$ mode for the 2.41 eV, 2.21 eV and 1.96 eV are displayed in Fig. (a)-(c), respectively. We observe that the maximum of the $A^1_g$ Raman mode rotates almost 90° when excited by 1.96 eV. Furthermore, the same behavior is observed for the $A^3_g$ mode under different lasers.




Our measurements show that the $A^1_g$, $A^3_g$ modes are coupled differently to the electronic states compared to the $A^2_g$ mode [2]. Confirming the importance of the excitation energy on ARPRS. These observations reveal a close relationship between the polarized Raman scattering spectra and the crystalline orientation of VOCl. These findings contribute to our understanding of the fundamental characteristics of LMM and their potential applications, giving additional insight into their unique properties.

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# A Fourth-Order Kuramoto Model for Dense Associative Memory in Spontaneously Coherent Photonic Networks

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**Abstract:** We present a dense memory oscillator model with quartic interactions, inspired by photonic platforms. Mean-field theory and simulations show enhanced polynomial capacity and robust retrieval over classical networks, directly enabling scalable analog associative memory.

Traditional oscillatory associative memory models, such as Hopfield networks or coupled phase oscillators, face severe capacity and stability limitations, operating reliably only when the number of stored patterns P is much smaller than the number of oscillators N [1-6]. Beyond this sparse regime, interference leads to crosstalk, spurious attractors, and rapid memory degradation [7,8], requiring new architectures that break linear scaling and enhance robustness.

Meanwhile, new light-based oscillator platforms offer programmable nonlinear interactions and spontaneous phase synchronization. Examples include networks of exciton-polariton condensates, OPO arrays, and Josephson junction circuits, which exhibit spontaneous coherence and tunable coupling through optical interference or nonlinear media [9-11]. These systems evolve toward phase configurations that extremize cost functions, making them attractive for large-scale analog associative memories.

We introduce a fourth-order Kuramoto model as a theoretical framework for high-capacity associative memory in networks of N phase oscillators. Extending standard Kuramoto dynamics to include mixed pairwise and quartic couplings, the model realizes a higher-order Hopfield-like energy landscape that encodes both quadratic and quartic interactions.

$$\dot{\theta}_i = \omega_i + \frac{1}{N}\sum_j J_{ij}\sin(\theta_j - \theta_i) + \frac{1}{N^3}\sum_{j,k,l} K_{ijkl}\sin(\theta_k + \theta_l - \theta_j - \theta_i)$$

The first term implements conventional pairwise Kuramoto interactions [1,3], while the second captures fourth-order multi-phase coupling found in driven-dissipative condensates or laser networks [9]. This 4-body coupling encodes higher-order correlations, stabilizing P target patterns as robust phase-locked equilibria. By shaping the energy landscape to have deep minima only at these learned patterns, quartic terms overcome pairwise capacity limits and suppress spurious attractors. Consequently, the fourth-order Kuramoto dynamics naturally steer the system into memory states from arbitrary initial conditions.

Starting from Hebbian learning, we show via Landau expansion and saddle-point analysis that the free energy develops a tricritical point separating continuous onset from a discontinuous latching regime with coexisting incoherent and memory minima. Mean-field theory predicts cubic storage scaling, and Kramers theory gives long metastable lifetimes in the latching phase. Dynamically, an Ott–Antonsen reduction captures the tricritical bifurcation and confirms sub-nanosecond retrieval. Large-scale simulations map the phase diagram and identify critical loads where recall fails. Numerics demonstrate an order-of-magnitude capacity boost over standard models, alongside hysteresis and bistability under Langevin noise.

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# Extremely high excitonic g-factors in $MoWSe_2$ alloy monolayers

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**Abstract**: We investigate excitons in $Mo_xW_{1-x}Se_2$ monolayers using magneto-optical spectroscopy and first-principles calculations. Our results reveal exceptionally large, composition-dependent g-factors up to –10, driven by orbital mixing, making S-TMD alloys promising for spin-valley optoelectronics and tunable device applications.

Monolayers (MLs) of semiconducting transition metal dichalcogenides (S-TMDs), e.g. $MoSe_2$ and $WSe_2$, are direct bandgap semiconductors characterized by very interesting optical and electronic properties. S-TMD alloys have emerged as materials with tunable electronic structures and valley polarizations [1].

In this work, we investigate magneto-optical properties of excitonic complexes in $Mo_xW_{1-x}Se_2$ ML encapsulated in hexagonal BN (hBN) with different ratios of Mo and W atoms. Under applied magnetic fields, the neutral exciton resonances in S-TMD MLs split into two circularly polarized components as a result of the Zeeman effect [2]. Using low-temperature photoluminescence (PL) experiments carried out in external out-of-plane magnetic fields up to 30 T, we extract the g-factors of the neutral (X) and charged (T) excitons presented in Fig. 1(a). The g-factors for the X transitions change gradually from about -4 up to about -10. This striking tunability is verified by first-principles calculations of the band structures. The calculated values of the g-factors (Fig.1 (b)) show a trend similar to the experimental ones, and also reveal an additional sensitivity to lattice constant in the alloy.

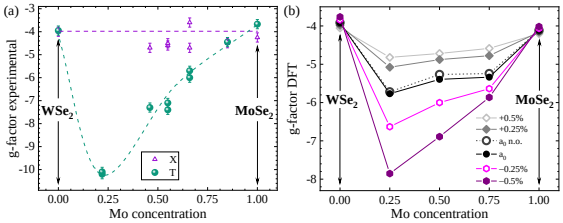


**Fig. 1** (a) Experimental values of g-factors extracted for the neutral and charged excitons measured on the $MoSe_2$, $WSe_2$, and $MoWSe_2$ MLs with different Mo/W ratios. (b) Exciton g-factors calculated from first principles.

Our studies indicate that the alloying of S-TMD MLs is an efficient mechanism to enhance the g-factors of neutral excitons, up to values that have only been observed for interlayer excitons in TMDs heterostructures (HSs) with nearly 0◦ or 60◦ twist angles so far [3]. Due to the much simpler fabrication process of MLs compared to TMD HSs with specific twist angles, alloy MLs open new avenues as potential candidates for valleytronic and quantum devices [4].

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# Self-organized optical bistability

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**Abstract** We propose to experimentally realise self-organized bistability of light in a nonlinear optical cavity.

In this contribution we will present our proposal to experimentally realise self-organized bistability (SOB), the self-organization to a first order phase transition [1], in a nonlinear optical cavity.
SOB describes how slowly-driven dissipative systems self-organize to a limit cycle around the bistability characterising a first order phase transition. This facilitates spatiotemporal scale-invariant responses to small perturbations, also known as avalanches, and anomalously large responses known as 'kings'.
While SOB has recently drawn major theoretical interest, no controlled experiments demonstrating it have been reported to date. We demonstrate that light in a nonlinear optical cavity has all necessary ingredients to experimentally realise SOB, with some differences. Light in an optical cavity is described by a complex Ginzburg-Landau type equation [2]. This contrasts with conventional systems to which SOB is conjectured to apply, which are described by real-valued scalar fields [3]. We will discuss how the complex-valued nature of the field in our system opens the door to novel feedback mechanisms that can influence the dynamics in intriguing ways, resulting in qualitatively different behavior from conventional SOB. Our results open new perspectives for probing self-organized phase transitions in well-controlled optical systems, where there are numerous opportunities for technological applications in information processing.

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# Engineering and probing *very-strong* light-matter coupling in patterned multi-quantum well heterostructures with a magnetic field

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**Abstract**:

Magneto-optical spectroscopy has long been a powerful and well-established tool for manipulating and probing exciton and polariton properties in inorganic semiconductor quantum well, as well as in transition metal dichalcogenide monolayer heterostructures. Crucially, the diamagnetic shift of polariton modes has been proposed and employed [1-3] as a method to confirm the realisation of the very-strong light-matter coupling regime. In this regime, the Rabi coupling is comparable to the exciton binding energy, leading to the hybridisation of multiple excitonic Rydberg states within a single polariton state.

In this work, we employ a patterned multi-quantum well GaAs/AlGaAs heterostructure [4] to access a regime where the waveguide light induces hybridization in the matter component, coupling multiple Rydberg heavy- and light-hole exciton states, as well as continuum states (Fig. 1). In contrast to microcavities, the steep waveguide dispersion uniquely enables simultaneous interaction of multiple excited states with the same photonic mode.

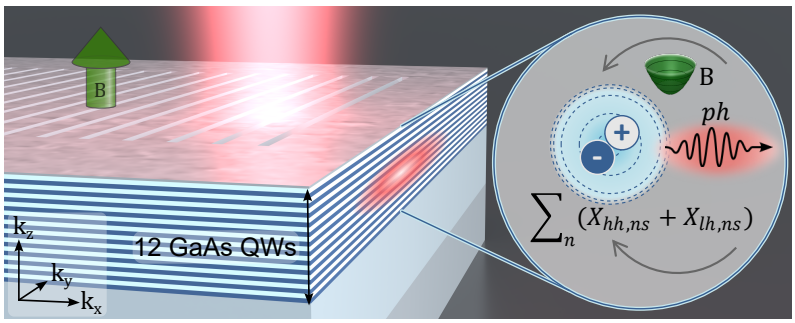


**Fig. 1.** Left: Sketch of the patterned multi-quantum well heterostructure in GaAs/AlGaAs waveguide. A magnetic field applied in the perpendicular geometry is used to tune and probe the polariton properties (right panel) and to verify the very-strong light-matter coupling regime. Here, the coupling to light leads to the hybridization multiple Rydberg heavy- and light-hole exciton states within the same polariton state.

We develop a microscopic theory describing heavy- and light-hole excitons that can couple very strongly with waveguide photonic modes and investigate the effects of a perpendicular static magnetic field. Our theory reproduces the experimental results as opposed to perturbative approaches and shows a very good agreement for the exciton diamagnetic shifts, the exciton oscillator strengths, and the polariton diamagnetic shifts within the non-perturbative very strong coupling regime.

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# Quantum fluids of bosons with power-law hopping in reduced dimensions

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Localization transitions in one-dimensional quantum fluids are generally expected to follow the Berezinskii–Kosterlitz–Thouless (BKT) paradigm. In this talk, we present exact results for ground-state phases and quantum phase transitions in strongly correlated one-dimensional bosons with power-law hopping $\sim 1/r^{\alpha}$. Studying both interaction- and disorder-driven localization, we show that the generic superfluid–insulator transition is continuous and scale-invariant for all for $\alpha \leq 3$ -- corresponding to a new universal behavior of bosons in one dimension, which is distinct from BKT criticality. We present a new phase diagram for quantum fluids of bosons in one dimension and discuss its relevance for experiments with dipolar gases, Rydberg arrays, trapped-ion systems, and indirect excitons. If time allows, we present recent results for indirect excitons in two dimensions, demonstrating the stabilization of both defect-induced and commensurate supersolids in mesoscopic dipolar fluids, enabled by power-law hopping.

# Measuring non-Abelian quantum geometry in multi-band photonic lattices

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**Abstract**:. We report on the direct measurement of non-Abelian band topology in a six-band synthetic lattice, revealing topological obstruction against band-node annihilation by evaluating the Euler class topological invariant.

Recent developments in modern condensed matter physics have highlighted the role of crystal electronic orbitals and their symmetries in describing the electronic properties of solids [1,2]. While two-band systems are well-understood in the context of Chern topology, many physical systems possess multiple bands and exhibit phenomenology reaching beyond previously known classifications. This gives rise to new topological invariants associated to groups of bands and band singularities, non-Abelian Berry curvatures, and novel physical responses. Notably, semi-metallic multi-gap systems featuring band singularities have generated enormous interest in particular due to the emergence of non-Abelian braiding properties of band nodes [3-5]. This set of topological phases necessitates novel approaches to probe them in laboratories.

In this work, we perform a direct measurement of non-Abelian topology. We achieve this by implementing a novel orbital-resolved polarimetry technique to probe the complex amplitudes of all Bloch wavefunctions in a six-band two-dimensional (2D) synthetic lattice. For every pair of bands, we experimentally reconstruct the non-Abelian Berry curvature and non-Abelian quantum metric and directly retrieve the Euler class topological invariants, that characterizes the ability of pairs of band nodes to annihilate. In particular, we exhibit pairs of nodes with non-trivial Euler class, revealing their topological obstruction against annihilation, a striking signature of their braiding properties. Our work unlocks the experimental probing of multiband topology in synthetic lattices, thus opening the way to manipulating non-abelian charges and implementing non-abelian braiding protocols.

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# Optimizing Quantum Photonic Integrated Circuits using Differentiable Tensor Networks

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**Abstract**: We present a differentiable tensor-network framework for gradient-based optimization of nonlinear quantum photonic integrated circuits, enabling efficient circuit design for low-photon-occupation tasks, demonstrated for quantum state preparation and phase-sensing readout, with GaAs as a baseline.

Strong excitonic light–matter coupling in semiconductor photonic platforms has recently enabled large optical nonlinearities, offering new opportunities for quantum photonic integrated circuits (qPICs). Incorporating such nonlinearities for efficient quantum processing requires design methods based on quantum statistics beyond linear optics.

We present a gradient-based optimization framework for qPICs, combining realistic device parametrization with differentiable quantum simulation [1]. Circuit gates are modeled as Kerr-type nonlinear unitaries, which we characterize by GaAs-based field simulations of the polaritonic field. The quantum state is represented within a truncated Fock space using the matrix product state (MPS) formalism, which efficiently captures modest entanglement. Crucially, this framework supports gradient backpropagation through differentiable tensor contractions, while accounting for waveguide losses via Monte Carlo sampling.

Two applications are demonstrated: (i) design of qPICs for nonclassical state preparation, including cat-state generation and single-photon sampling under noise, and (ii) optimal circuit readout for quantum phase sensing. In both cases, nonlinear interactions provide measurable performance advantages over linear architectures.

This approach establishes a practical route for device-specific qPIC optimization, bridging semiconductor simulations with differentiable quantum methods. The resulting open-source framework provides a foundation for advancing quantum state generation, communication, and sensing in integrated photonic platforms.

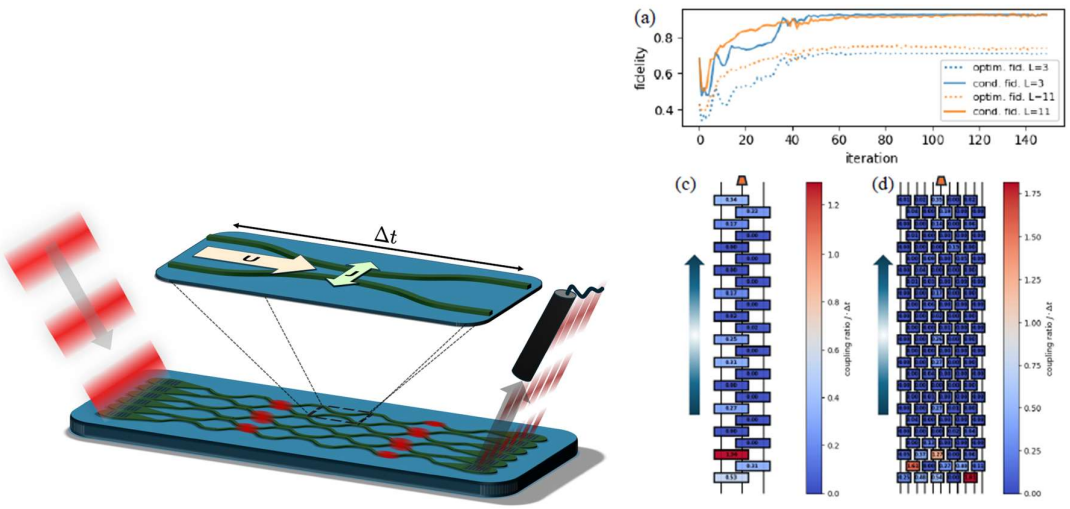


**Fig. 1** Left: the platform of integrated nonlinear waveguides for optimization of couplers J. Right: (a) The fidelity during optimization for odd cat-state preparation and the resulting circuits for 3 (c) or 11 bosonic modes (d).

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# Phase-Space Framework for Quantum Optical Neural Networks

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Abstract: This work introduces a scalable simulation method for quantum optical neural networks, enabling high-accuracy classification and feature prediction of quantum states, and revealing key performance dependencies on network size and nonlinearity.

Quantum optical neural networks (QONNs) take advantage of the combined principles of classical and quantum optics to achieve information processing capabilities that surpass classical approaches [1]. Nevertheless, simulating large-scale bosonic networks remains a substantial challenge due to the exponential expansion of the Hilbert space required for an accurate description of quantum dynamics. Consequently, previous theoretical studies have been limited to small-scale systems, leaving the behaviour of multimode QONNs unexplored.

This work presents an efficient computational framework based on the phase-space positive-P method for simulating bosonic neuromorphic systems [2]. This approach provides a view to previously inaccessible regimes, allowing the validation of large-scale bosonic networks in various quantum machine learning tasks such. In our work we employed the QONN to discriminate between three distinct classes of quantum-optical states: Schrödinger cat states, squeezed vacuum states, and coherent states. Due to the highly nontrivial response of the reservoir network to excitation by different states presented schematically on figure 1, we were able to achieve classification accuracy of 93% [3].

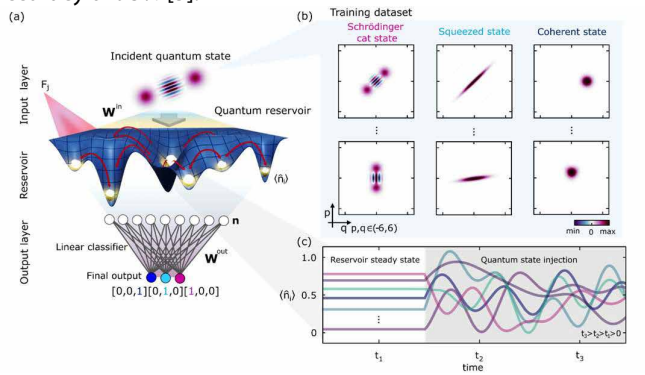


Fig. 1 Schematic illustration of a quantum reservoir applied for quantum state recognition. (a), Structure of the QRNN, depicting input, reservoir, and output layers. (b), samples from the training dataset consisting of various quantum states, represented as Wigner functions. (c), Schematic dynamics of reservoir states, when the incident quantum state perturbs the reservoir's steady state, maintained by continuous coherent driving fields.

Moreover, we studied the dependence of this accuracy on the network size and inherent Kerr-like nonlinearity. Our results show that the performance of a large quantum reservoir does not improve monotonously with the number of bosonic modes, instead following a complex dependence driven by the interplay of nonlinearity, reservoir size, and the average occupation of the input mode. A similar behaviour has been found for the task of quantum state feature prediction, a regression task where the complex squeezing parameter of a squeezed vacuum state has been predicted. These findings are essential for designing and optimising optical bosonic reservoirs for future quantum neuromorphic computing devices.

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# Integrated Coupled Arrays of Exciton–Polariton Condensates

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**Abstract**: On-chip arrays of contiguously coupled high-contrast grating microcavities support exciton–polariton modes that condense showing extended spatial-temporal coherence and altered emission spectra and threshold compared to single cavities.

We present an integrated photonic platform enabling direct coupling of exciton–polariton condensates within one-dimensional arrays of high-contrast grating (HCG) microcavities [1]. The structures were fabricated via electron-beam lithography on a silicon-on-insulator (SOI) substrate with spin-coated methyl-substituted ladder-type poly(para-phenylene) (MeLPPP) as the organic excitonic medium [2]. Multiple HCG mirrors, where each two resonators share a common mirror between them, form arrays of contiguously coupled microcavities that give rise to polariton coupling through direct population exchange between adjacent cavities. Consequently, resonance splitting is observed in coupled resonators compared to isolated single-cavity structures, confirming coupling-induced mode hybridization. Moreover, scanning near-field optical microscopy (SNOM) amplitude maps directly visualize the delocalized real-space polariton modes across the coupled cavities, providing further confirmation of hybridization. Notably, the observed coupling strength $J$ scales linearly with the intrinsic linewidth of single-cavity resonances below threshold, consistent with theoretical predictions. Furthermore, systematic lithographic tuning of cavity lengths enables precise control over polariton mode energies, validated by rigorous coupled-wave analysis (RCWA) simulations in the strong-coupling regime. Finally, extended linear arrays of contiguously coupled HCG cavities demonstrate substantial threshold reduction for polariton condensation, along with an enhanced spatial and temporal coherence, as confirmed by interferometric measurements. In contrast to geometries with structured condensates in vertical Bragg reflector cavities, these experiments give access to polariton physics where all losses through the mirrors are entering adjacent polariton cavities, an important step towards larger circuits of integrated polaritonic devices. Moreover, the results showcase the robustness and scalability of HCG microcavities, which constitute a fascinating platform for exploring polariton condensation and highly engineerable lattice architectures. In addition, the demonstrated tunability and CMOS-compatible fabrication process lay the groundwork for advanced applications in scalable integrated all-optical logic gates, polaritonic neurons, and quantum simulation devices [3].

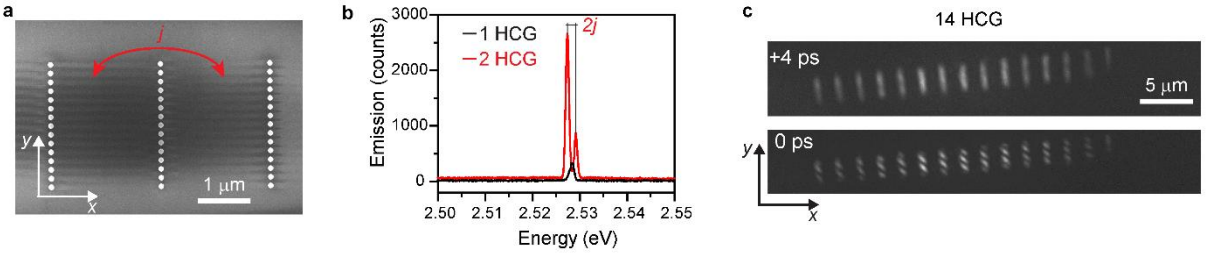


**Fig. 1**

**a**, Top-view scanning electron microscopy image of two contiguous high-contrast-grating (HCG) microcavities. Three equally spaced HCG mirrors are visible, each composed of 15 Si pillars (diameter 110 nm, pitch 165 nm). The inter-cavity coupling rate $J$ acts along the x-direction and is indicated by the red double arrow. The active polymer layer that is deposited on top of the structures is not shown in this image. **b**, Above-threshold emission spectra from a single cavity (black) and from the coupled pair (red). The coupled system exhibits a mode splitting of $2J$, confirming hybridization of the polaritonic states. **c**, Real-space Michelson interferograms at 4 ps (above) and 0 ps time delay (bottom) showing spatial coherence for a system of 14 HCG cavities excited above threshold.

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# Dynamics of multi-valley excitonic complexes in heavily doped $WSe_2$ monolayer

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**Abstract**: We present time resolved photoluminescence measurements on a charge tunable $WSe_2$ monolayer in the unexplored high electron doping regime where multi-valley excitonic complexes govern the optical properties.

Monolayers of transition metal dichalcogenides (TMDs), such as $MoS_2$ and $WSe_2$, exhibit strong Coulomb interactions, leading to large exciton binding energies. These two-dimensional semiconductors can be integrated into van der Waals heterostructures which allow electrostatic tuning of the charge carrier density. Additionally, carriers can occupy distinct valleys in the Brillouin zone, split by spin-orbit coupling. This unique combination of properties makes TMD monolayers an ideal platform for exploring a wide variety of excitonic complexes, including bright, dark, momentum-indirect excitons, trions, biexcitons … [1].

This is particularly evident in $WSe_2$ monolayers, where the sign of the conduction band spin-orbit splitting gives rise to a rich spectrum of excitonic transitions, as identified through various optical spectroscopy techniques [2]. For example, Fig. 1a shows the absorption (measured via reflectivity contrast) as a function of carrier density. In the moderately n-doped regime, two types of negative bright trions—$X_S^-$ and $X_T^-$—are observed, depending on whether the resident electron occupies the same or opposite K valley as the photogenerated electron-hole pair.

Until now, most studies have focused on carrier densities below a few $10^{12}$ $cm^{-2}$. In this work, we fabricated a charge-tunable device enabling access to unprecedented electron densities exceeding $10^{13}$ $cm^{-2}$. In this high-density regime, carriers begin to populate both the first and second conduction bands at the K points, leading to the formation of multi-particle excitonic complexes: six-particle (H, "hexciton") and eight-particle (O, "oxciton") states [3] (Fig. 1b). At the highest doping levels, a new transition (labeled M) emerges, which we interpret as a multi-valley complex involving electrons in the Q valleys.

We will present continuous-wave and time-resolved photoluminescence (PL) measurements in these high doping regimes, revealing strong dependencies on both doping level and excitation power. Notably, we find that the quantum efficiency increases linearly in the H and O regimes, and the integrated PL intensity scales linearly with excitation power, ruling out significant Auger recombination.

Our results underscore the potential of multi-valley excitonic complexes in the high-doping regime for use as efficient light emitters and for integration with optical cavities in future polaritonic applications.

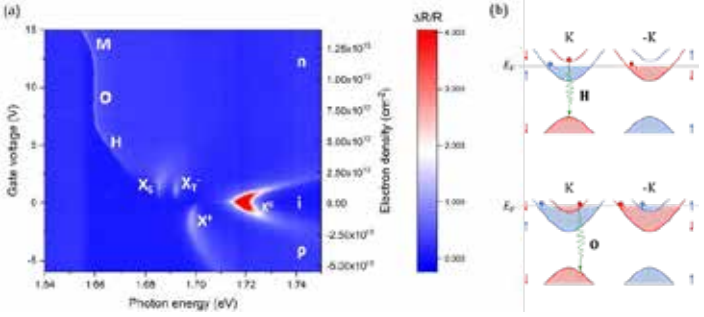


**Fig. 1** (a) Reflectivity contrast of a $WSe_2$ monolayer as a function of doping density. $X^0$ is the bright neutral exciton, $X^+$ the bright positive trion, $X_S^-$ and $X_T^-$ are the singlet and triplet negative trions. At high electron doping densities, the hexciton (H), oxciton (O) and a multivalley complex M appears. (b) Sketch of the hexciton and oxciton.

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# Observation of a dynamical solid-solid transition in a polaritonic condensate

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**Abstract**: Dissipation-induced, elastic to inelastic transformation of the density modulation in a polaritonic condensate as a direct analogue of a solid-solid transition.

Progress in condensed matter physics and chemistry has been intimately tied to our increasing understanding of the crystalline structure in manybody electronic systems. Understanding the static and dynamic behaviour of the crystalline structure of materials is one of the most important aspects in such studies. Time-resolved studies are particularly challenging due to the nonlinear nature of the structural dynamics and the short timescales involved. Here, we use an exciton-polariton condensate in a photonic crystal waveguide that allows us to observe the dynamical evolution of a density modulation associated with supersolidity in real-time [1]. The driven-dissipative, nonlinear, multistate nature of our system leads to rich phenomenology that arises from the delicate balance of energy flowing between the condensed states and the reservoir, and goes beyond the typical paradigm of crystalline materials. We map the free-evolution trajectories in the energy-momentum phase-space and directly observe the system as it undergoes a solid-solid transition. This dynamical transition is purely intrinsic to the system and is governed by its interaction with the environment and not by the variation of external parameters. The direct, real-time observation of the dynamics in an energy-momentum-resolved manner paves the way for a deeper understanding of these intricate phenomena, that are intimately connected to open questions in modern solid-state physics.

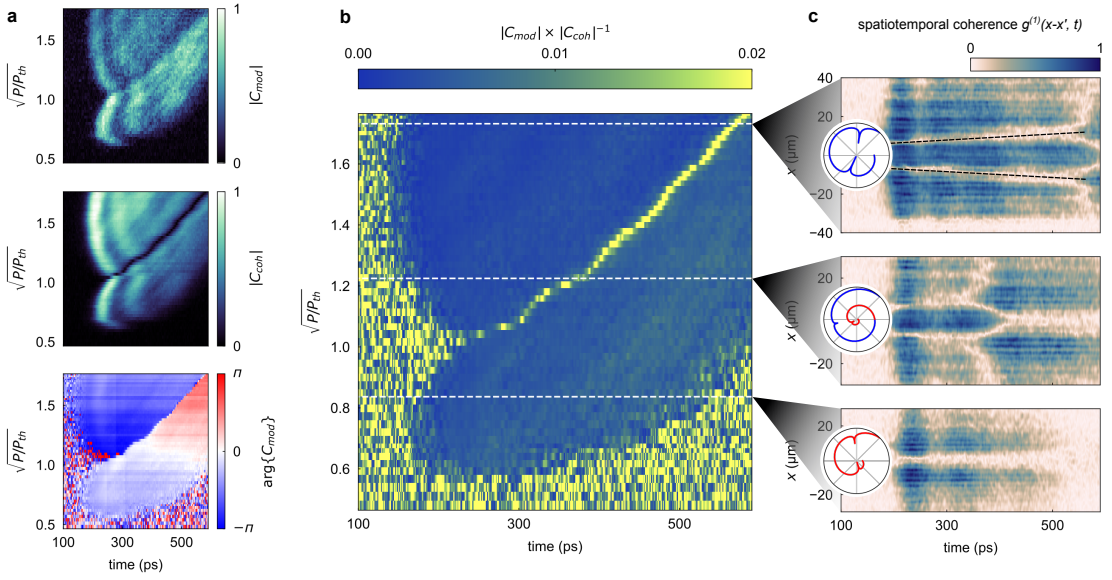


**Fig. 1 Coherence through the solid-solid transition. a.** the dynamic dependence of modulation and coherence as a function of power. The modulation amplitude is lower by a few percent when the first excited state is in the gap due to the change in parity as shown by the phase (bottom panel). **b.** A phase diagram of the solid-solid transition. The abrupt drop in coherence at the dislocation line leads a transition width of about 30ps in which the density modulation is only slightly affected however the system does not show extended coherence any more. **c.** The coherence drop can be clear seen in the $g^{(1)}(x\text{-}x', t)$ dynamics for different powers. For low powers a single coherent state exists that shows relaxation oscillations. For medium power the coherence length abruptly drops at 370ps to 10μm, comparable with the central lobe of the first excited state. For large powers the transition shifts to 560ps. The trap relaxation can be seen in the dynamical behaviour of the poles of the first excited state (black dashed lines).

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# Condensation of cavity exciton-polaritons in perovskite nanocrystals at room-temperature

**Darius Urbonas**[1], Ioannis Georgakilas[1, 2], David Tiede[3], Rafał Mirek[1], Clara Bujalance[3], Laura Caliò[3], Virginia Oddi[1, 4], Rui Tao[4, 5], Dmitry N. Dirin[4, 5], Gabriele Rainò[4, 5], Simon C. Boehme[4, 5], Juan F. Galisteo-López[3], Rainer F. Mahrt[1], Maksym V. Kovalenko[4, 5], Hernán Miguez[3], and Thilo Stöferle[1]

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**Abstract**: We realize room-temperature exciton-polariton condensation by embedding $CsPbBr_3$ colloidal quantum dots in a Gaussian-defected microcavity and show condensation of cavity exciton-polaritons.

Strong light-matter coupling and exciton-polariton condensates offer a promising approach to introduce robust interactions and nonlinear effects into a wide array of photonic technologies, spanning from high-speed all-optical logic to low-threshold topological lasers. The integration of colloidal semiconductor quantum dots, which are distinguished by their pronounced three-dimensional confinement and exceptional optical properties, as the active medium within microcavities, has been demonstrated to enhance polaritonic interactions through quantum confinement. However, the realization of exciton-polariton condensation in microcavities at room temperature has remained elusive for both epitaxial and colloidal quantum dots.

In this work [1], we demonstrate room-temperature polariton condensation by embedding a thin film of monodisperse colloidal CsPbBr3 quantum dots within a tunable optical resonator. This resonator incorporates a deformation that is Gaussian in shape, thereby creating a potential well for polaritons on the wavelength scale. Under pulsed optical excitation, the emergence of polariton condensation was observed, as indicated by a superlinear increase in emission intensity, a narrowing of the emission linewidth, a blueshift (Fig. 1a), and an extension of temporal coherence (Fig. 1b). The results of this study underscore the promise of perovskite-based colloidal quantum dots, which are renowned for their exceptional optical properties and high degree of tunability, as a pioneering platform for the development of next-generation polaritonic devices.

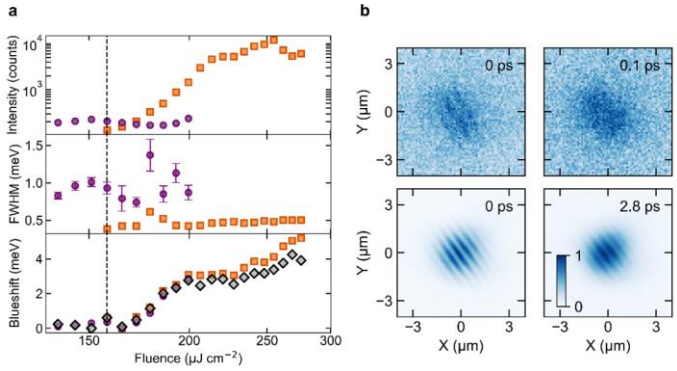


**Fig. 1. a**, Measurement of the condensation threshold, illustrating how emission intensity (top), emission linewidth (middle), and blueshift (bottom) evolve as excitation fluence increases. The uncondensed ground-state polariton emission is marked by purple circles, the ground-state condensate by orange squares, and the non-condensing first-excited state by gray diamonds. **b**, Real space interferograms of the emitted signal below (top panels) and above (bottom panels) threshold are shown. At Δt = 0 ps, interference fringes appear in both regimes. Below threshold, these fringes diminish within about 0.1 ps, whereas above threshold, they persist for as long as 2.8 ps.

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# Charge transfer excitons at lateral MoSe2-WSe2 interfaces

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**Abstract**: We study MoSe2-WSe2 lateral heterostructures and observe interfacial charge transfer excitons with strong in-plane dipoles. Gate tuning reveals discrete photoluminescence peaks, indicating exciton quantization perpendicular to the interface via electric field confinement.

Interfaces in condensed matter systems often host novel physical phenomena due to their distinct symmetry, dimensionality, and energy scales compared to the bulk. Here, we investigate a unique, atomically sharp interface formed between monolayer MoSe2 and WSe2 [1], creating a one-dimensional heterojunction predicted to support charge transfer (CT) excitons—bound electron-hole pairs confined to the interface [2-4]. Using photoluminescence (PL) spectroscopy at cryogenic temperatures, we observe a distinct excitonic state emerging below the emission energies of bulk MoSe2 and WSe2. This interfacial state appears exclusively along the heterojunction and matches the energy range predicted for CT excitons [2]. Remarkably, its energy exhibits strong sensitivity to in-plane electric fields, revealing a large permanent dipole moment with an estimated dipole length on the order of 10 nm. Additionally, we observe narrow, discrete spectral lines, indicative of quantization of the exciton's center-of-mass motion perpendicular to the interface. These findings, overviewed in Fig. 1, provide clear evidence for the formation of dipolar interfacial excitons in atomically sharp TMD heterostructures. They open promising avenues for both fundamental studies of low-dimensional excitonic physics and future applications in electrically tuneable optoelectronic and quantum devices.

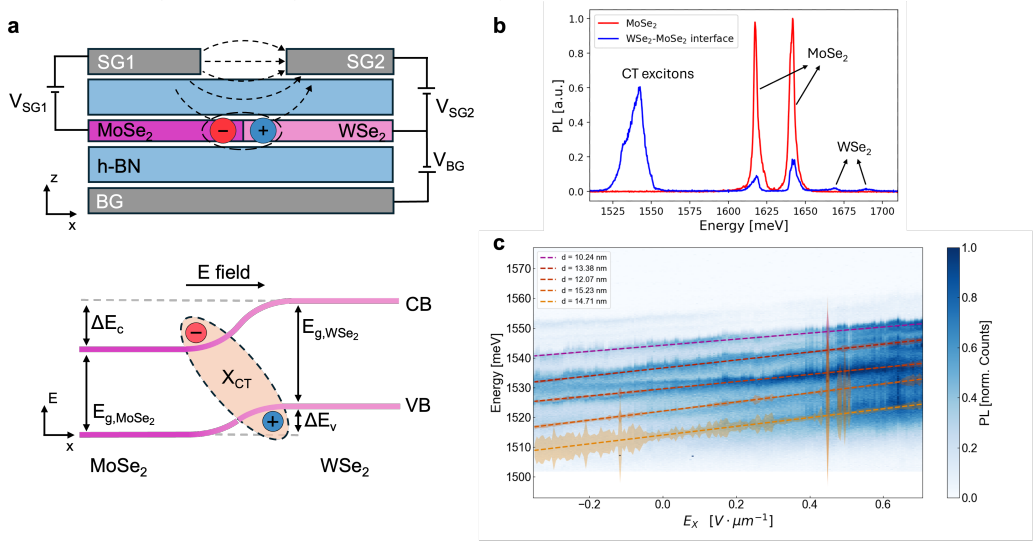


**Fig. 1, (a)** Triple-gated device schematic and band structure diagram of the lateral heterostructures samples.**(b)** Photoluminescence spectra: in red the neutral exciton and trion of $MoSe_2$ far from the interface, in blue a spectrum taken at the interface with peaks of $WSe_2$, $MoSe_2$ neutral excitons and trions, as well as the CT Exciton peak around 1,530 eV. **(c)** In plane electric field dependence of the CT exciton states, fitted by the colour dashed lines. The shaded area corresponds to fitting errors. We extract from the fit a permanent dipole moment of about 14nm for the lower energy state. The splitting of the CT state comes from quantization in the orthogonal to the interface direction.

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# Multicomponent Kardar-Parisi-Zhang Universality in Degenerate Coupled Condensates

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**Abstract**: Gapless phase modes in non-equilibrium condensates fall within the Kardar-Parisi-Zhang (KPZ) universality class, but key single-component symmetries do not generalise to the multicomponent case. In the following, we fully characterise the phase diagram of coupled KPZ equations in one dimension describing the low-energy theory of a $Z_2$ degenerate driven-dissipative condensate with global $U(1) \times U(1)$ symmetry, revealing a spacetime vortex regime, an unstable fragmentation regime, and KPZ-like regimes foliated into distinct universality classes. We then extend the multicomponent discussion to higher dimensions where we discuss the behaviour of coupled condensates in two spatial dimensions, exploring how the addition of experimentally relevant transverse-electric transverse-magnetic terms result in a KPZ-like mode coupled to a critical Ising mode with a new symmetry group $SO(2) \rtimes Z_2$.

The Kardar-Parisi-Zhang (KPZ) universality class is shown to describe a host of non-equilibrium critical phenomena. In particular it is renowned for its distinct departure from diffusive dynamics with a gapless mode with dynamical exponents $z = 3/2$ and roughness exponent $\chi = 1/2$ in the single component and one-dimensional case. Remarkably as a classical equation, it has been shown to arise in non-equilibrium quantum systems, such as within a semiclassical description of driven-dissipative condensates such as exciton-polaritons [1], but also in the transport properties of the Heisenberg spin chain [2-3]. In one-dimension, the KPZ equation is largely considered solved, with its statistical properties determined by symmetries. In our work, we consider how the framework of multicomponent KPZ applies to driven-dissipative condensate. In stable regimes where the density can be integrated out, we show that we map onto a multicomponent KPZ theory previously studied by Ertaş and Kardar in the context of directed polymers [4-5]. We show that under specific parameters relevant to exciton-polaritons, the RG fixed point coincides with a decoupling transformation to decoupled KPZ equations. Tuning away from this manifold, the two point correlations do not decouple to independent KPZ equations and the one particle distributions differ from those predicted by Tracy-Widom random matrix theory, suggesting a whole foliation of universality classes along a manifold where there is an emergent fluctuation dissipation theorem [6]. In fact, the phase can also map onto regimes which give rise to large deviations due to instabilities driven by the non-linearity, which when interpreted at the level of the compact phase manifold corresponds to a spacetime vortex phase with exponentially decaying two-point correlations at the level of the fields [6]. Finally, as previously discussed in Ref. [7] and is well-understood in the context of equilibrium BECs, the coupled system also supports a condensed phase which is fragmented with large density fluctuations.

These results are important in characterising the theory of one-dimensional multicomponent KPZ for exciton-polaritons, but the two-dimensional case is largely unexplored since perturbative results are not expected to give valid results. We therefore additionally discuss the phenomena of multicomponent KPZ in the context of two-dimensional KPZ where key properties such as a Cole-Hopf transformation and a fluctuation dissipation relation are not valid. We discuss experimental details such as the addition of transverse-electric transverse-magnetic (TE-TM) splitting. This breaks the $Z_2$ symmetry explicitly but additionally results in a new symmetry group describing the theory $SO(2) \rtimes Z_2$. This gives rise to a new dynamical theory where we have a KPZ-like mode coupled to a critical driven Ising mode.

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# Sensitivity and topology of exceptional rings in nonlinear non-Hermitian planar optical microcavities

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**Abstract**: We report on the existence of exceptional rings in planar optical resonators. We present a rigorous analysis of topology and report enhanced and adjustable perturbation response in the nonlinear regime.

Exceptional points (EPs) of $n^{\mathrm{th}}$-order are singularities in the parameter space of non-Hermitian systems at which $n$ eigenvalues and their corresponding eigenvectors coalesce [see Fig. 1(a)]. Exceptional rings (ERs) form a gapless loop of coalescing eigenvectors, offering a promising platform to drive a system to an exceptional point. Over the last decade, EPs have attracted significant attention with their intriguing spectral topology, with potential applications in sensing driving much of the current research in this field [1]. In the last few years, there has been a growing interest in the interplay of nonlinearities and EPs. A promising platform to systematically study EPs in the nonlinear regime is exciton-polariton systems. Exciton polaritons are hybrid light-matter quasiparticles that form in semiconductor microcavities, pairing finite lifetimes and thus non-Hermiticity with strong nonlinearity [2,3]. With the possibility to control loss, gain and nonlinearity by optical means, this system allows for a comprehensive analysis of the interplay of nonlinearities with topological properties and non-Hermiticity [4].

Here, we report the observation of ERs in planar optical resonators and investigate the impact of nonlinearities on ERs. Transitioning from linear to nonlinear regime, we use bifurcation theory and show that each EP on the ER is the organizing point of a universal elementary bifurcation (elliptic umbilic) in the nonlinear parameter space [5]. We find that when Kerr-type nonlinearity or saturable gain is introduced, the linear ER splits into two concentric ERs, with the larger-radius ring being a ring of $3^{\mathrm{rd}}$-order (nonlinear) EPs. We present a rigorous analysis of resilience and topology, and report enhanced and adjustable perturbation response in the nonlinear regime. Our results on non-Hermitian spectral topology and nonlinearity-enhanced perturbation response are generic and equally relevant to a broad class of other nonlinear non-Hermitian systems, providing a universal framework for engineering ERs and EPs in nonlinear non-Hermitian systems [6].

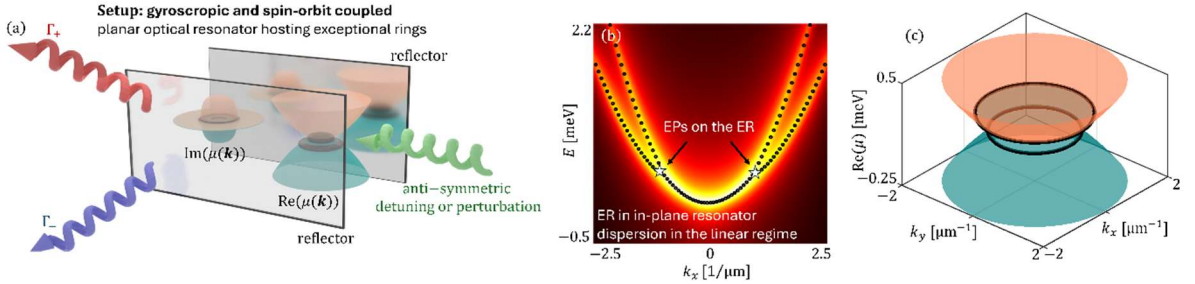


**Fig. 1** (a) Sketch of a planar resonator hosting an ER centered at k = 0 in reciprocal space. (b) Exceptional ring in in-plane resonator dispersion in the linear regime. (c) Exceptional rings (black circles) in the complex-valued energy spectra in the nonlinear regime.

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# Controllable fusion of electromagnetic bosons in 2D semiconductors: toward efficient sources of strongly-correlated photons and quantum chemistry of light

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In this presentation, we will provide an overview of microscopic mechanisms that enable control over the interactions of identical electromagnetic bosons $\alpha_\sigma$[1] in two-dimensional semiconductors. The pursuit of such mechanisms has been inspired by the success of Feshbach resonances in ultra-cold atoms [1]. The fundamental ingredient is a coherent link between the "open" scattering channel of interest, $\alpha_\sigma + \alpha_{\sigma'}$ (a pair of bosons whose interaction one aims to control), and the "closed" bound state (biexciton), $X_\uparrow X_\downarrow$. For instance, merely having a two-body bound state, as it occurs in the "polaritonic Feshbach resonance" based on the giant oscillator strength model [2], is insufficient to obtain the genuine Feshbach resonance and the associated phenomenology discussed in this presentation. As viable alternatives, where the coherent interconversion process

$$\alpha_\sigma + \alpha_{\sigma'} \leftrightarrow X_\uparrow X_\downarrow \qquad (1)$$

is indeed feasible, we shall present the shape resonance in the case of dipolar bosons [3-5], and our most recent proposal of a fully controllable Feshbach resonance due to the long-range electron-hole exchange [6,7]. From the perspective of nonlinear optics, the reaction (1) behaves similarly to the second-order nonlinear susceptibility [$\chi^{(2)}$] for electromagnetic waves. Notably, unlike the conventional second-order susceptibility, reaction (1) does not require any specific symmetry of the medium with respect to inversion because the exciton molecule $X_\uparrow X_\downarrow$ corresponds to a scalar field: a bound pair of polarization waves. In certain cases, the bosons exhibit quantum mechanical squeezing at unitarity and may form quantum halos, possessing non-trivial entanglement properties. If the timing permits, we will also briefly discuss the exotic collective behavior of resonantly paired bosons and their molecules in the regime of quantum degeneracy.

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[1] Either "bright" excitons, $\alpha = X$, or "lower" microcavity polaritons, $\alpha = L$, the label $\sigma$ standing for the projection of the photon spin on the transverse direction.

# Highly Efficient Thermally Activated Delayed Fluorescence (TADF) OLED under Strong Exciton-Photon Coupling Showing Narrowband and Tunable Emission

**So-Young Boo**[1], Andreas Mischok[1], Francisco Tenopala-Carmona[1], Julia Witt[1], and Malte C. Gather[1, 2]

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**Abstract**: Strong exciton-photon coupling was employed in a TADF-based microcavity OLED using an assistant strong coupling layer, achieving narrowed, tunable, and angle-independent emission with high external quantum efficiency.

Polariton organic light-emitting diodes (POLEDs) leverage strong light-matter coupling to generate quasiparticles known as exciton-polaritons [1]. Under the right conditions, this results in narrowed and angle-independent emission compared to conventional microcavity OLEDs [2]. A promising strategy to enter the strong coupling regime is to embed the OLED stack and an assistant strong coupling layer (SCL) within a planar microcavity. The resulting upper and lower polariton branches can be controlled by adjusting optical cavity thickness, refractive index, and molecular orientation [3-5]. Despite these advances, realizing POLEDs with efficiencies comparable to state-of-the-art TADF OLEDs remains challenging.

In this study, efficient TADF POLEDs were realized using SpiroAC-TRZ as a blue TADF emitter and BSBCz as SCL, both exhibiting horizontal orientation in thin films. The resulting POLEDs showed distinct polariton branches, exhibited angle-stable emission with EQEs reaching 20% (blue) and 25% (green), and show tunable emission spectra over a range from 490 to 545 nm with the same emitter.

These results demonstrate the crucial role of orientation control in achieving efficient polariton emission and the realization of high-performance POLEDs in the sky-blue regime enables applications at industry-relevant device efficiency.

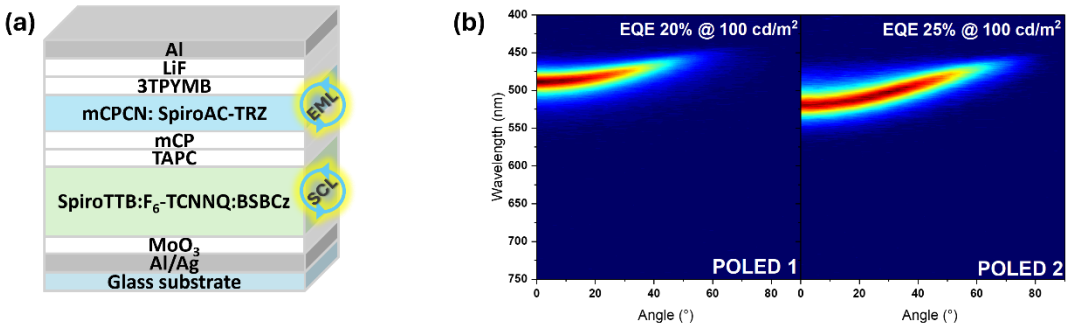


**Fig. 1** (a) Device architecture of POLED with an assistant SCL, positioned at the second maximum of the electric field in microcavity. (b) Angle-resolved electroluminescence spectra with EQEs measured at 100 cd/m$^2$.

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# Ballistic and shift currents in the interband photogalvanic effect with coulomb coupling

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**Abstract**: We develop a theory for the linear interband photogalvanic effect in semiconductors, incorporating Coulomb interaction. Both shift and ballistic photocurrent contributions are analyzed, with the latter dominating when Coulomb effects are included.

In semiconductor structures with broken spatial inversion symmetry, direct currents can emerge under non-equilibrium conditions—even when the time-averaged external force is zero. In macroscopically homogeneous systems, this phenomenon is known as the photogalvanic effect. Here, we present a theoretical study of photocurrents generated by direct optical transitions in semiconductor structures taking into account the Coulomb interaction. We develop a theory of the linear interband photogalvanic effect that rigorously accounts for electron-hole Coulomb interactions to all orders of perturbation.

Interband optical transitions generate a linear photocurrent through two distinct mechanisms: (i) the shift contribution, caused by real-space displacement of electron wave packets during quantum transitions, and (ii) the ballistic contribution, originating from momentum-space asymmetry in the photoelectron distribution. Although recent studies of the linear photogalvanic effect have been primarily focused on the shift contribution [1, 2], Ref. [3] highlights the dominance of the ballistic contribution in interband transitions. We present calculations comparing both contributions within a unified band-structure model for systems of different dimensions.

We develop a detailed microscopic theory for both shift and ballistic currents, employing a self-consistent approach to fully account for Coulomb correlations between photoexcited electrons and holes to all orders of perturbation [4]. This theory is used to compute the linear photogalvanic effect in two distinct systems: (i) bulk zinc blende semiconductors and (ii) two-dimensional materials based on monolayers of transition metal dichalcogenides of the $D_{3h}$ symmetry. Our analysis reveals that the Coulomb interaction enhances the shift photocurrent through an increase in optical absorption due to excitonic effects, though this current exist even when electron-hole scattering is neglected. In contrast, the ballistic contribution to the linear photogalvanic effect for direct optical transitions necessitates additional scattering processes, here the Coulomb scattering of a photoexcited electron by a hole. To quantify this ballistic contribution, we calculate the matrix elements of the velocity operator between two-particle Coulomb functions of the continuous spectrum, including its components off-diagonal in the wave vectors.

We calculate the frequency dependence of both photocurrent contributions for bulk semiconductors and two-dimensional monolayer structures. It is demonstrated that the ballistic photocurrent can dominate over the shift current in both material systems. Specifically, the ratio of ballistic to shift contributions follows scaling law $l/a_B$, where $l$ is the charge carrier mean free path and $a_B$ is the exciton Bohr radius. Consequently, across a broad frequency range where $l > a_B$, the ballistic mechanism becomes predominant.

This work was supported by the Russian Science Foundation (project 25-72-10031).

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# Second-Order Correlation Properties of Confined Polariton Systems

**Wojciech Bukalski**[1], Yannik Brune[2], Elena Rozas[2], Paolo Comaron[1,3], Ken West[4], Kirk Baldwin[4], Loren N. Pfeiffer[4], Jonathan Beaumariage[5], Hassan Alnatah[5], David W. Snoke[5], Marc Aßmann[2], Marzena Szymańska[1]

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**Abstract**: The experimentally observed hopping in the equal-time second-order correlation of an exciton-polariton condensate, undergoing incoherent pumping with an annular geometry, is analysed theoretically using both the Truncated Wigner and Positive-P methods.

Recently, a significant amount of experimental effort has been devoted to the study of exciton-polariton condensates driven by incoherent lasers featuring annular geometries [1,2]. These setups are advantageous due to the spatial separation guaranteed between the condensate and the reservoir; an effect deemed to enhance the coherent properties of the hybrid system [2]. As a result, these platforms have the potential to boast the provision of coherent resources highly sought after in quantum information applications [2,3].

Interestingly, equal-time second-order correlation measurements, $g^{(2)}(0)$, carried out on a small-ring geometry, approximately 10 μm in diameter, display interesting hopping behaviour around the condensation threshold. They suggest a sharp, definitive switching between a thermal and condensed state over the long-time dynamics of the system [2]. Leveraging these platforms to their full potential thus requires us to gain a full understanding of this behaviour, both experimentally and theoretically.

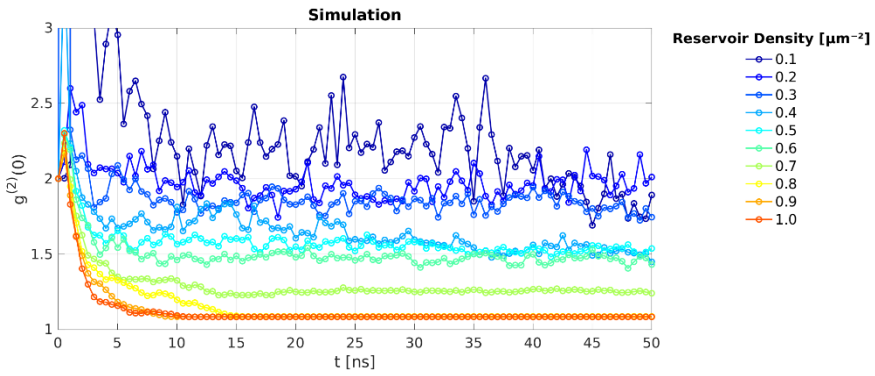


**Fig. 1** The equal-time second-order correlation displaying a crossover between thermal and condensed behaviour as the pumping threshold is swept through.

To model the fluctuating coherence dynamics computationally, a coupled open dissipative Gross-Pitaevskii equation is solved using phase-space techniques [1,4]. Specifically, a comparison is drawn between the Truncated Wigner and Positive-P methods, both of which calculate system observables by averaging over stochastic realisations. This enables the evaluation of $g^{(2)}(0)$ at pump values just below, at, and just above the condensation threshold, where the hopping effect emerges and is most pronounced.

The relatively low condensate densities in the region of interest, along with the need to spatially resolve the small system, present challenges for the Truncated Wigner method. At the same time, both factors favour and play into the validity of Positive-P [5], which is theoretically exact and shows a preliminary computational speedup in comparison to its counterpart. Ensuring both accuracy and efficiency is essential for employing such numerical methods in the exploration of confined polariton systems, especially if we desire to exploit their coherent properties in quantum technologies.

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# LONG RANGE HOPPING IN A DIPOLAR BOSE HUBBARD SIMULATOR

**Corentin Morin**[1,2], Camille Lagoin[1,2], Kirk Baldwin[3], Loren Pfeiffer[3], François Dubin[1,2]

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**Abstract**: Please include a 35-word abstract that will be used to briefly describe your contribution.

Indirect excitons in GaAs double quantum wells are excellent candidates to simulate the Bose Hubbard Model. By the mean of a periodic trapping and their permanent dipole, which gives rise to a quasi long range interaction, we were able to characterize quantum solids : Mott insulators and Checker board solids [1].

In the mean time excitons are the optical polarization in semiconductors. In the dipolar blockade regime, where a lattice site cannot be occupied by more than one exciton, an occupied site is equivalent to the excited state of a two level system while an empty site is equivalent to its ground state. A sub-wavelength array of dipolar excitons then allows to explore photon mediated collective effects in lattices. The dissipative part of the photon exchange leads to subradiance while the excitation exchange between sites is associated to a long range hopping [2].

We present here our recent results [3] where we observe a strong increase in the temporal coherence of spatially ordered phases. We also characterize subradiance by a decrease by 50 folds of the emission rate of the radiative recombination and decay dynamics with algebraic components. We believe this is a strong indication of the realization of a spatially ordered and coherent phase of matter : the supersolid.

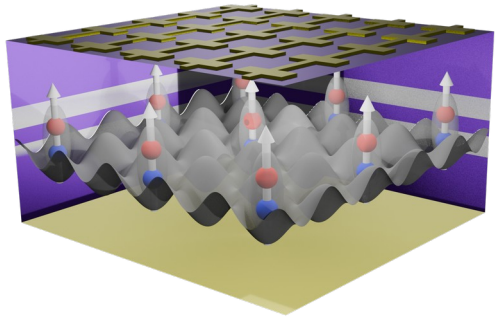

**Fig. 1** : Artistic view of a Checker Board quantum solid of dipolar excitons in samples similar to the ones used in [1,3].

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# Observation of 2D Kardar-Parisi-Zhang universal scaling

Simon Widmann[1], **Siddhartha Dam**[1], Johannes Düreth[1], Christian G. Mayer[1], Romain Daviet[2], Carl Philipp Zelle[2], David Laibacher[1], Monika Emmerling[1], Martin Kamp[1], Sebastian Diehl[2], Simon Betzold[1], Sebastian Klembt[1], Sven Höfling[1]

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**Abstract**: Universality provides a powerful framework for grouping systems with different microscopic details into common macroscopic behaviors. Here, we present the experimental evidence of 2D Kardar-Parisi-Zhang (KPZ) universal scaling in exciton-polariton condensates.

One of the most well-known examples in nonequilibrium physics is the Kardar-Parisi-Zhang universality class [1], which describes growing interfaces in various dimensions. While one-dimensional KPZ phenomena - such as forest fire spread or bacterial colony fronts - have clear analogues in nature, true two-dimensional KPZ behavior can only arise far from equilibrium. Quantitative results of 1D KPZ have been shown in many platforms, including exciton-polariton condensates [2]. Although exciton-polaritons are nonequilibrium by nature, this condition is not tied to KPZ scaling in one dimension. The scenario is completely different in two dimensions, since KPZ physics cannot exist in equilibrium systems. Even though theoretical studies have predicted the existence of 2D KPZ in exciton-polaritons [3,4], no experimental studies have been reported so far.

Here, we present the experimental evidence of 2D KPZ scaling in driven-dissipative exciton-polariton condensates, quantum fluids of light confined in semiconductor microcavity lattices [5]. By engineering square and triangular lattice geometries, we condense at negative effective-mass states, suppressing vortices and obtaining large, coherent condensates. With space and momentum-resolved photoluminescence and space-time interferometry, we map out the first-order coherence $g_1(\Delta\mathbf{r}, \Delta t)$.

When rescaled, our data collapse onto the universal 2D KPZ scaling function obtained from numerical solutions of the KPZ equation (**Fig. 1**), yielding critical exponents and a universal curve in precise agreement with theory. This unambiguous collapse distinguishes the nonequilibrium KPZ dynamics from any equilibrium analogue and firmly establishes 2D exciton-polariton condensates as a versatile platform for probing universal scaling in two dimensions, extending nonequilibrium universality far beyond the realm of interface growth.

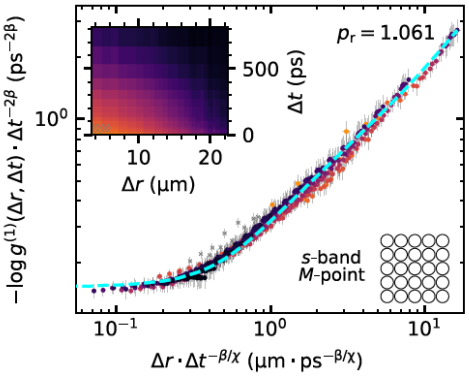


**Fig. 1** Scaling collapse of $g_1(\Delta\mathbf{r}, \Delta t)$ obtained for a square lattice onto the the theoretically obtained KPZ scaling function.

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# Weak Disorder and Modulational Instability in Polariton Condensates

L. Eaton[1], S. Lovett[1], P. Walker[1], **A. Ferrier**[2], H. Alnatah[3], J. Beaumariage[3], K. Baldwin[4], L. N. Pfeiffer[4], M. H. Szymanska[2], D.W. Snoke[3], D. Krizhanovskii[1]

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**Abstract**: We investigate how different driving profiles enhance or suppress modification of the spatial distribution of polariton condensates by a weak disorder potential. Simulations show how experimental observations result from interaction between the condensate and reservoir.

Defects in semiconductor microcavities impose a disordered potential landscape for the cavity photons [1], which can have varied and often undesirable effects on the resulting exciton-polariton condensates, such as altering the spatial distribution and propagation, pinning vortices, or limiting the extent of spatial coherence [1–3]. For incoherently driven polariton condensates, the interaction between the condensate polaritons and the reservoir leads to a self-focusing effect, where the reservoir population acts as a potential for the polaritons and is in turn locally depleted by them, which can lead to a modulational instability at intermediate drive powers just above the condensation threshold [4]. We investigate here how the interplay between these two processes may either emphasise or suppress the effects of a relatively weak disorder potential on the spatial distribution of the polariton condensate.

As in [4], we numerically simulate the coupled polariton condensate and reservoir population, driven via the reservoir. This allows us to observe how the distribution of the reservoir gives rise to the behaviours seen in our associated experimental results. We observe (see Fig. 1) that with a broad Gaussian excitation, the modulational instability results in the reservoir population reinforcing the potential landscape given by the disorder, pinning the condensate to the disorder potential; meanwhile, for a more focused ring-shaped excitation the reservoir provides a trapping potential that overwhelms that from the disorder, giving a more uniform spatial distribution of polaritons within.

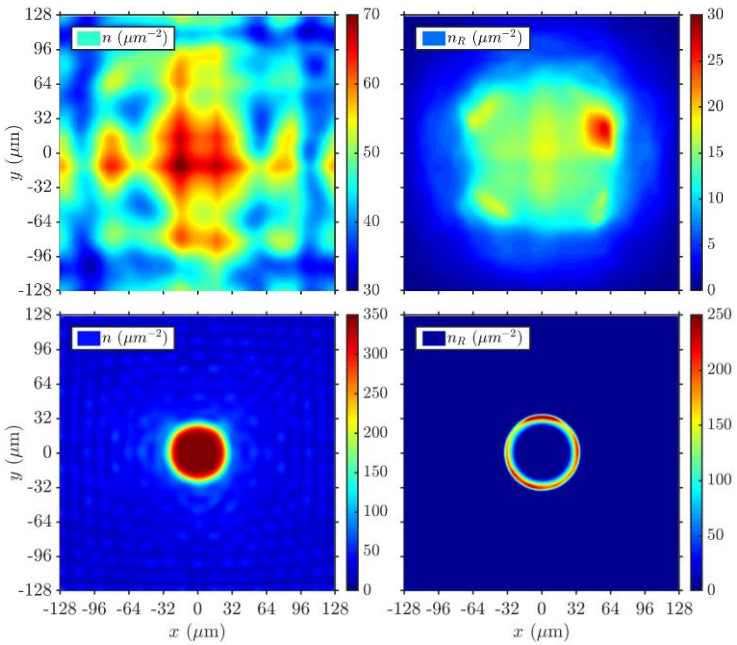


**Fig. 1.** Numerical results for polariton occupation (left) and reservoir occupation (right) for 150$\mu m$ diameter Gaussian drive (top) and 60$\mu m$ diameter ring-shaped drive (bottom) under weak disorder potential.

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# Quantum Assistance on the Route to Coherence: Rigorous Analysis of Open-System Oscillator Networks for Combinatorial Optimisation

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**Abstract**: We demonstrate that transient quantum dynamics in driven-dissipative oscillator networks can enhance global minimum search efficiency, offering up to 35% success improvement over classical description and enabling design of quantum-assisted photonic optimizers.

Recent advances in unconventional computing have inspired novel architectures tailored to solve complex optimization problems by leveraging diverse physical mechanisms that aim to efficiently explore the energy landscape of an objective function, minimizing the risk of being trapped in local minima - an issue particularly pronounced in NP-hard problems where the number of local minima scales exponentially with system size. Driven–dissipative networks of coupled photonic, polaritonic and opto-electronic oscillators are rapidly gaining traction as *physics-based optimisers*: hard combinatorial or continuous problems are encoded in the couplings $J_{ij}$, while the system "computes" by relaxing toward a coherent steady state that minimises an effective energy or loss function [1-4]. Conventional modelling treats the dynamics classically using Kuramoto or Stuart–Landau equations thus overlooking the fact that the initial stages of the evolution are genuinely quantum and through the processes of condensation, evolve into a collective state well described by semiclassical equations. Here we provide a mathematically precise assessment of **how that transient quantumness influences the probability of reaching the true global minimum.**

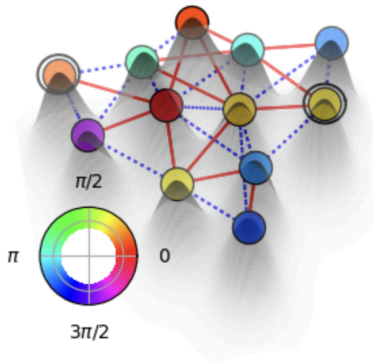


**Fig. 1** System of coupled exciton-polariton condensates (shown in gray) with spatial overlaps, and the corresponding schematic representation of a network of oscillators coupled through ferromagnetic (solid red) and antiferromagnetic (dashed blue) interactions. The colors of the oscillators represent their phases in the steady-state solution of the XY problem.

To assess the influence of possible quantum effects during the evolution of the quantum system, we consider networks of exciton-polariton condensates as open quantum systems coupled to an environment represented Fig. 1. and described by the Lindblad master equation:

$$\frac{d\rho}{dt} = -i[H,\rho] + \sum_i \mathscr{D}[L_i]\rho$$

where $\rho \in \mathcal{H} \otimes \mathcal{H}$ is the density matrix, $\mathbf{H}$ is the Hamiltonian defined by $\mathbf{H}|\psi\rangle = E|\psi\rangle$ for states $|\psi\rangle \in \mathcal{H}$, and $E$ is the system energy. The superoperator $\mathcal{D}[A]\,\rho$ takes the standard form: $\mathcal{D}[A]\,\rho = 2A\rho A^{\dagger} - A^{\dagger}A\rho - A^{\dagger}\rho A$ .

One system of particular interest is governed by a drive $H = \sum_{ij} J_{ij}(e^{i\theta_i} a^{\dagger}_j - e^{-i\theta_j} a_i)$, a pump $L^{P}_{i} = P^{1/2} a^{\dagger}_i$, and nonlinear self-interactions $L^{NL}_{i} = \varkappa^{1/2} a^{\dagger}_i a_i$. The evolution of the expectation values in this system yields $d\langle a_i\rangle/dt = P\langle a_i\rangle - \varkappa |\langle a_i\rangle|^2 \langle a_i\rangle + \sum_{ij} J_{ij} e^{i\theta_j}$, which coincides with the classical Stuart-Landau model with internal mechanism aligning amplitudes in steady state.

In the long-time limit $t \to \infty$, the quantum system reproduces the classical solution of the problem.
Using hundreds of randomly generated problems with three or more local minima encoded by $J_{ij}$, we demonstrated that these quantum effects can positively impact the system's ability to find the global minimum, increasing the success probability compared to standard Kuramoto networks and gain-dissipative Stuart-Landau networks as schematically represented in Fig. 3.

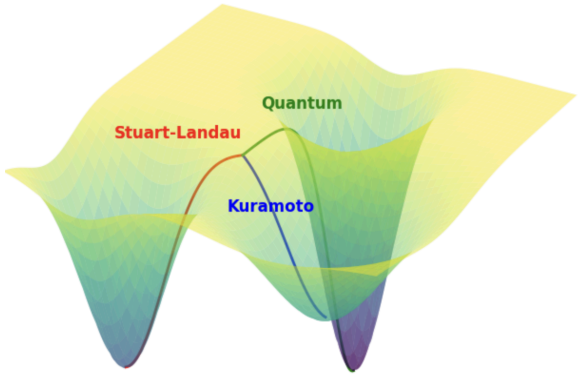


**Fig. 3** Schematic representation of the trajectories for a classical Kuramoto system (blue), a coupled condensate system governed by Stuart-Landau equations (red), and an open quantum system (green) experiencing quantum effects during its evolution prior to decoherence, ultimately relaxing into a classical state corresponding to the global minimum.

Our key findings are**: (i) Quantum transients boost success probability.** Across > 300 randomly generated coupling matrices the probability of reaching the global minimum is enhanced by 10–35 % relative to purely classical Kuramoto and gain–dissipative Stuart–Landau simulators. (ii) **Robustness to dissipation.** The quantum benefit persists up to decoherence rates γ comparable with the characteristic coupling scale J, indicating feasibility in experimentally accessible regimes for polariton condensates and fiber-laser networks. (iii) **Guidelines for hardware.** We identify a "quantum-assisted window" defined by pump-to-loss ratio P/κ where coherent dynamics is long enough to exploit tunnelling yet short enough to avoid excessive noise accumulation.

Our study provides the first systematic evidence that the unavoidable quantum stage in gain-based oscillator networks can be a resource, not a nuisance. By casting the optimisation trajectory as an open-system quantum walk in a tunable Lindblad landscape we reveal mechanisms such as tunnelling through classically forbidden saddles and entanglement-enabled collective flips that accelerate convergence to the ground state. The results offer concrete design rules (coupling symmetry, pump schedule, controlled dissipation) for next-generation coherent Ising and XY machines that purposefully **retain** partial coherence to surpass their classical counterparts, and they delineate benchmarking protocols where quantum advantage is most likely to appear.

Our framework bridges quantum annealing and nonlinear photonics, paving the way toward hybrid architectures that combine quantum-enhanced exploration with scalable optical gain.

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# Calibration and Optimization of a Spatial Photonic Ising Machine for Full Scalability

**P. S. Karavelas**[1,2,3], L. Mouchliadis[1], Dimitrios Karanikolopoulos[1], N. Pitanios[1,2], A. K. Spiliotis [1,3], P. G. Savvidis[1,3]

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**Abstract**: We propose a solution to phase distortions and beam curvature in spatial photonic Ising machines, along with optimized encoding schemes that enable arbitrary larger, denser systems—unlocking scalability beyond current encodings.

Spatial photonic Ising machines (SPIMs) use spatial light modulators (SLMs) to encode and solve combinatorial optimization problems[1,2]. However, optical aberrations caused by imperfections in optical components distort the wavefront, resulting in inaccuracies in the spin representation (Figure 1b). These distortions become more problematic as the system size increases, limiting the accuracy and efficiency of SPIMs. Additionally, as the system size increases, the curvature of the illuminated beam emerges and disturbs the interaction encoding (Figure 1e). Retrieving the wavefront at the SLM plane (Figure 1a, 1d) compensates for system aberrations and calculates an interaction normalization term that counters beam curvature [3]. These calibrations allow for precise encoding of the problem across the entire SLM region, addressing a significant obstacle to SPIM scalability (Figure 1c, 1f). Furthermore, we use an optimized version of spin product encoding[2], which unlocks the system's encoding scalability to non-sparse systems. These advancements lay the groundwork for optimizing SPIMs for large-scale, reliable combinatorial optimization tasks.

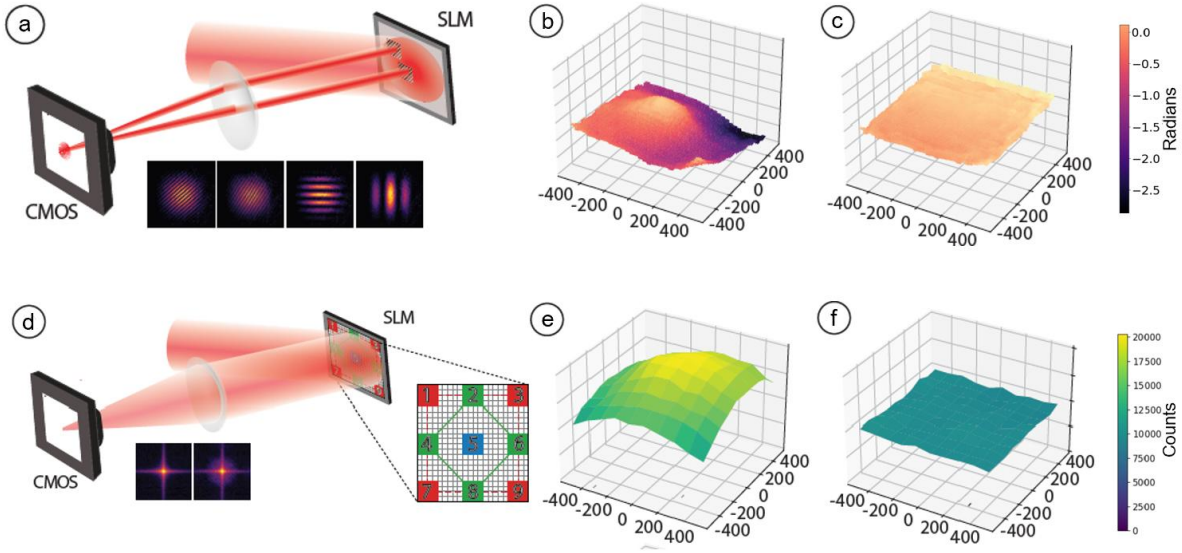


**Fig. 1** Illustration of the two retrieval and correction procedures for the wavefront at the SLM plane. a) Experimental procedure of phase retrieval, by the interference of two apertures on the SLM plane, a central reference and a sampled signal, the local phase of the field is retrieved and after scanning the whole SLMs surface, the fields phase is reconstructed. b) Opposite of the reconstructed phase for aberration compensation. c) Reconstructed Phase after aberration compensation. d) Experimental procedure of amplitude retrieval, from a ferromagnetic interaction ground state by flipping one of the spins and calculating the energy difference the spins contribution is retrieved. For ferromagnetic interaction J = 1 is equal to the local field intensity. By scanning the whole SLM the amplitude profile is reconstructed. e) Reconstructed amplitude profile. f) Normalized interactions encoding for a ferromagnetic J = 1 Ising model where now all spins are contributing equally, cancelling the effect of the beams curvature.

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# Novel Quantum Key Distribution Protocols on Realistic Quantum Dot based Single Photon Sources with Superior Performance and Enhanced Secure Key Rate

**Yuval Bloom**[1], Yoad Ordan[1], Tamar Levin[1], Kfir Sulimany[1], Eric G. Bowes[2], Jennifer A. Hollingsworth[2], Ronen Rapaport[1]

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**Abstract**: Y.B. fabricated the samples, conducted the experiments including both protocols characterization and QKD experimental demonstration, and performed the analysis on the experimental results.

The original proposal of quantum key distribution (QKD) was based on ideal single photon sources, which 40 years later, are still challenging to develop. Therefore, the development of decoy state protocols using weak coherent states (WCS) from lasers, set the frontier in terms of secure key rates.

We propose and experimentally demonstrate two simple-to-implement protocols that allow practical, far from ideal sub-Poissonian photon sources to outperform state-of-the-art WCS [1]. By engineering the photon statistics of a quantum dot's biexciton-exciton (BX-X) cascade, we show that either a truncated decoy state protocol or a heralded purification protocol can be employed to achieve a significantly increased performance in terms of the maximal allowed channel loss for secure key creation, which can exceed that of WCS by more than 3dB.

This is a particularly attractive route to improve the performance of current QKD systems, using available excitonic quantum emitters. We have shown that even room temperature, on-chip, compact, and easily integrated SPS devices, such as those based on giant colloidal quantum dots (gCQD) coupled to nano-antennas [2-4], are already well within the parameter range for superior performance over WCS with decoy states by employing either protocol. Both protocols have very simple requirements and their application is general, thus we believe they can be employed efficiently on a vast range of sub-Poisson, quantum emitters.

This opens a practical and realistic way to implement novel photon sources with superior QKD performance, without the stringent requirements that hindered their practical integration into real-world QKD systems.

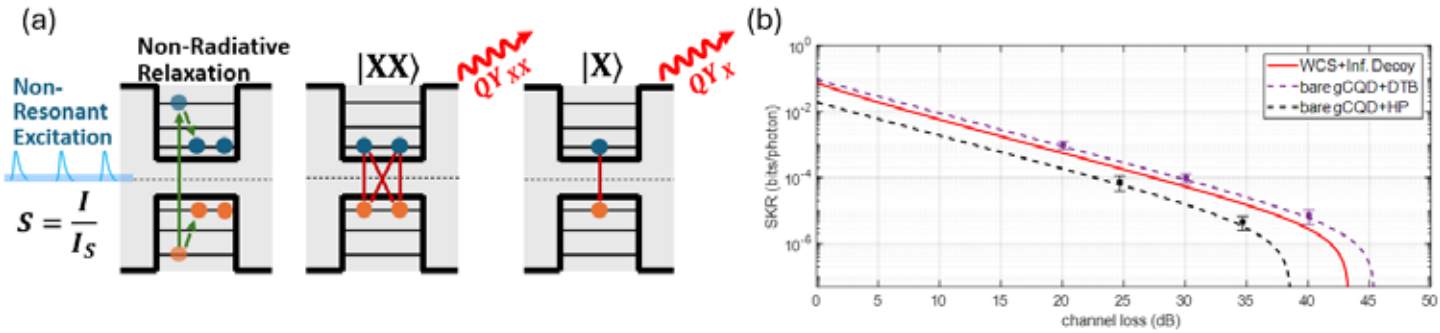


**Fig. 1** (a) Schematic of the BX-X cascade in an optically excited gCQD, using a non-resonant pulsed excitation with a normalized intensity $S = I/I_S$. (b) Secure key rate performance analysis and experimental demonstration for a bare gCQD source, showing an improvement compared to WCS with decoy states (red).

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# Room Temperature Fiber Coupled Single Photon Source Emitting Ultrafast and Highly Collimated Radially Polarized Photons

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We demonstrate an important step toward on-chip integration of single-photon sources at room temperature. Excellent photon directionality is achieved with a hybrid metal–dielectric bullseye antenna, while back-excitation is permitted by placement of the emitter in a subwavelength hole positioned at its center. The unique design enables a direct back-excitation and very efficient front coupling of emission either to a low numerical aperture (NA) optics or directly to an optical fiber. To show the versatility of the concept, we fabricated devices containing either a colloidal quantum dot (gQD) or a nanodiamond containing silicon-vacancy centers, which are accurately positioned using two different nano-positioning methods. Both of these back-excited devices display front collection efficiencies of ~70% at NAs as low as 0.5. The combination of back-excitation with forward directionality enables direct coupling of the emitted photons into a proximal optical fiber without any coupling optics, thereby facilitating and simplifying future integration.

Furthermore, we demonstrate a similar on-chip, room-temperature device, which generates highly directional radially polarized photons at very high rates. The photons are emitted from a gQD accurately positioned at the tip of a metal nanocone centered inside the hybrid metal-dielectric bullseye antenna. We show that due to the large and selective Purcell enhancement specifically for the out-of-plane optical dipole of the gQD, the emitted photons can have a very high degree of radial polarization (>93%), based on a quantitative metric. Our study emphasizes the importance of accurate gQD positioning for optimal radial polarization purity through extensive experiments and simulations, which contribute to the fundamental understanding of radial polarization in nanostructured devices and pave the way for implementation of such systems in practical applications using structured quantum light.

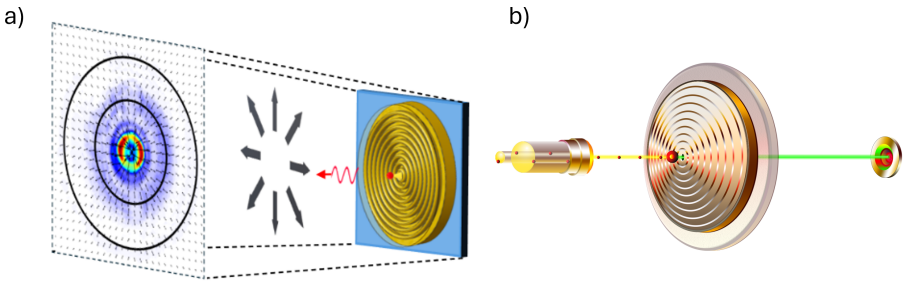


Figure 1: (a) Schematic sketch of the SPS emitting radially polarized single photons, with an experimental back focal plane image exhibiting a 'donut' shape structure associated with radial polarization. (b) Sketch of fiber coupled SPS with back excitation and forward directionality emission.

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# Polarons and Exciton-Polarons in Two-Dimensional Polar Materials

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We present a macroscopic theory of carrier coupling to long–wavelength longitudinal optical (LO) phonons in genuine two–dimensional (2D) polar monolayers. All results are expressed through three experimentally accessible parameters: the low– ($\alpha_0$) and high–frequency ($\alpha_\infty$) 2D polarizabilities and the transverse optical (TO) phonon energy $\hbar\omega_{\rm TO}$. The LO phonon dispersion—a 2D analogue of the Lyddane–Sachs–Teller relation—is

$$\omega^2_{\rm LO}(k) = \omega^2_{\rm TO}\,\frac{\varepsilon + r_0 k}{\varepsilon + r_\infty k}, \qquad r_{0,\infty} = \frac{\alpha_{0,\infty}}{2\varepsilon_0}, \tag{1}$$

with $\varepsilon$ the dielectric constant of the environment.

A Lee–Low–Pines variational treatment yields an upper bound for the Fröhlich polaron energy and reveals a highly non-linear dependence on the lattice polarizability, in stark contrast to the 3D case. Extending the variational scheme to an electron-hole pair dressed by LO phonons we obtain an effective interaction

$$V_{\rm eff}(r) \simeq V_{\rm KR}(r, r_0) + E_0\left[\frac{m_h}{\Delta m}\,\Phi_{\tilde\sigma_h}\!\left(\frac{\varepsilon r}{r_\infty}\right) - \frac{m_e}{\Delta m}\,\Phi_{\tilde\sigma_e}\!\left(\frac{\varepsilon r}{r_\infty}\right)\right], \tag{2}$$

where $V_{\rm KR}$ is the Keldysh–Rytova potential, $E_0 = e^2/(4\pi\varepsilon_0 r_\infty)$, $\Delta m = m_h - m_e$, and

$$\Phi_\nu(x) = \frac{\sigma_0 - 1}{2(1+\nu^2)(\sigma_0^2+\nu^2)}\Big[2(\nu^2-\sigma_0)K_0\Big(\frac{x}{\nu}\Big) + \pi\nu(\sigma_0+1)\Big(I_0\Big(\frac{x}{\nu}\Big) - L_0\Big(\frac{x}{\nu}\Big)\Big)\Big]. \tag{3}$$

Here $K_0$, $I_0$, and $L_0$ are modified Bessel and Struve functions. Equation (2) continuously interpolates from the unscreened Coulomb limit ($r \ll r_\infty$) to the fully statically screened potential $V_{\rm KR}(r, r_0)$ for $r \gg r_0$, resulting in a substantial (30–40%) reduction of the exciton binding energy in strongly polar materials such as $HfSe_2$ and $HfS_2$.

The closed analytic expressions derived here enable rapid estimates of polaronic and exciton-polaronic effects in novel 2D polar crystals without demanding *ab initio* calculations.

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## Emulating Bose-Fermi mixtures in lattices with dipolar excitons

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Dipolar excitons of GaAs double quantum wells provide unique resources to emulate lattice models, notably the Bose-Hubbard Hamiltonian extended by nearest neighbor interactions [1]. Here, we show that the concentrations of excitons together with the one of excess free holes are accurately controlled in electrostatic lattices of GaAs double quantum wells. Hence, we explore experimentally the quantum insulating phases accessible to an exciton-hole (Bose-Fermi) mixture. We show that extended exciton-hole and exciton-exciton interactions yield a rich variety of dual density waves at 330 mK [2].

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# Reservoir Processing with Single Photons

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**Abstract**: We use single photons propagating on an interferometer programmable on demand to experimentally implement a photonic reservoir processor able to perform a classification task with very high accuracy and to show quantum advantage over classical classifiers.

Optical reservoir processing is often based on a set of interconnected nodes that receive a photonic input signal and undergo a specific dynamics, which can then be used to perform a task. By construction, the nodes of the reservoir develop correlations that can be captured by simple measurements of their emission, such as from the intensity of the emission from each node. While a certain degree of nonlinearity in the dynamics of the nodes is required to perform useful tasks [1, 2], such a nonlinearity does not need to come from the nodes themselves. Instead, they could also arise from the way in which the nodes are connected.

Inspired by recent technological developments of single-photon sources, and the ability to encode on-demand arbitrary unitary matrices on an interferometer setup [3], we show that it is possible to implement a quantum reservoir computer operating with single photons. The data is encoded into photonic qubits that are set at the input of the interferometer. The latter can be programmed to implement any unitary matrix $U(n)$ (of rank $n \leq 24$), and the particular choice of matrix does not change the accuracy of the classification. Finally, at the output of the interferometer, we find the probabilities to obtain the state $|n_1, n_2 \cdots n_k\rangle$, such that $\sum_{j=1}^{k} n_j = N$. Here $N$ is the number of input qubits and $k$ the number of modes used in the interferometer. These probabilities are then passed through a linear neural network that provides the final result of the classification. Our results show that the classification of a pair of 2D intertwined spirals (cf. Fig. 1(a)) can be done with very high accuracy and demonstrates quantum advantage over the classical counterparts, as shown in Fig. 1(b).

The outstanding experimental results obtained for the classification suggest that it would be possible to use this setup to classify harder datasets. In fact, theoretical simulations indicate that the hardest three digits of the MNIST dataset (3, 5 and 8) can be classified with our setup, achieving an accuracy several percentual points better than classical classifiers.

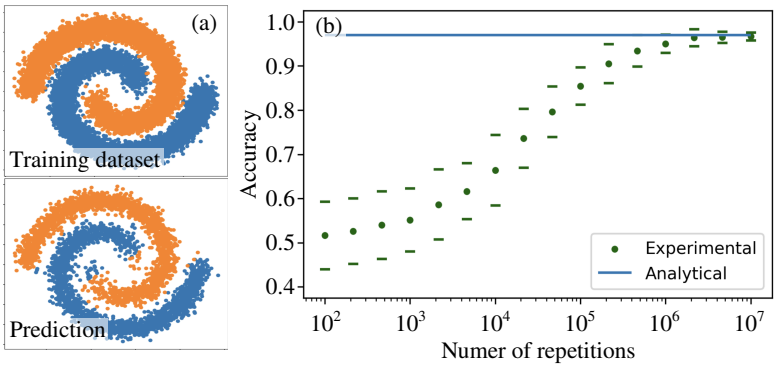


**Fig. 1** (a) Training data set that was encoded as qubits, and was set as the input of the interferometer. The lower panel shows the prediction done over points that were unseen during the training phase. (b) Accuracy obtained when measuring the coincidences with four detectors. The solid line indicates the accuracy obtained with the analytical probability distribution; i.e., in the limit of infinite repetitions. Each point (in green) corresponds to the average of the accuracy obtained in 20 realisations, and the error bars indicate three standard deviations.

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# On the spatial coherence of luminescent exciton ensembles in $MoSe_2/WSe_2$ heterostructures

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**Abstract**: We present various experiments on the spatially coherent luminescence of ensembles of interlayer excitons in van-der-Waal heterostructures as a function of bath temperature and exciton density.

We discuss the spatial coherence of interlayer exciton ensembles as formed in $MoSe_2/WSe_2$ heterostructures and characterized by Michelson-Morley interferometry; with a particular emphasis on point-inversion interferometry. Below 10 K, the measured spatial coherence length of the interlayer excitons can reach values equivalent to the lateral expansion of the exciton ensembles [1,2]. In this regime, the light emission of the excitons turns out to be homogeneously broadened in energy with a high temporal coherence. At higher temperatures, both the spatial coherence length and the temporal coherence time decrease, most likely because of thermal processes. The presented findings point towards a spatially extended, coherent many-body state of interlayer excitons at low temperature [1-4]. Moreover, we discuss various aspects of the spatially coherent luminescence of such ensembles as a function of bath temperature and exciton density.

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# Towards applicable topological vertical-cavity laser arrays

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Abstract: We investigate topological interface modes in quantum well-based III-V microcavities, studying interface-to-bulk ratio and geometry. Sub-threshold measurements with optical or electrical excitation demonstrate progress toward topologically phase-locked, electrically injected, coherent vertical laser arrays.

By utilizing the concept of topology through spatial symmetry breaking, new designs of coherent laser arrays can be realized. In particular, the topological nature of optical interface modes in non-trivial lattice geometries [1] can enforce phase locking between multiple, individual vertically emitting lasers, causing large arrays of emitters to behave as a single coherent light source [2,3].

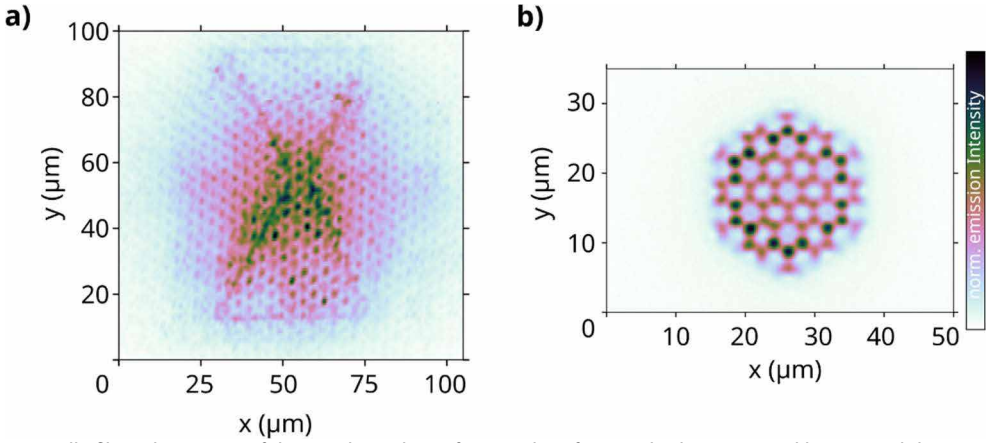


Fig. 1 Spectrally filtered emission of the topological interface modes of a stretched-compressed honeycomb lattice in the sub-threshold regime. (a) Using a non-resonant laser pumping scheme with a large Gaussian excitation spot, highlighting the existence of the interface mode, even with a high interface-to-bulk ratio. (b) Demonstration of the emission of the interface mode by using electrical pumping at room temperature.

Utilizing this concept, we use the emerging interface mode between trivial and topological non-trivial gapped graphene lattices, fabricated based on a III-V semiconductor microcavity. Building on the previous results, we investigate further the influence of the interface-to-bulk ratio and interface geometry such as corner angles on the formation and stability of the topological state. We study the ratio between the topological interface and the surrounding bulk area and its influence on the spectral and spatial properties of confined modes in the linear regime (see Fig. 1a).

Quantum wells serve as the gain medium in the microcavities, and experiments are conducted at both cryogenic and room temperatures. To selectively excite the interface mode, a spatial light modulator is used for non-resonant optical pumping, allowing flexible spatial control of the excitation. As an important step toward the technological integration of vertically emitting surface lasers phase-locked via a topological mode, we further demonstrate the excitation of the interface mode under electrical injection in quantum well-based devices (see Fig. 1b).

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# Superfluid fraction of interacting bosonic gases

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**Abstract**:

Leggett's bounds tightly bracket the superfluid fraction of bosonic gases. Using Gross-Pitaevskii and diffusion Monte Carlo methods in 2D potentials, we show these bounds closely capture experimental regimes of ultracold quantum fluids.

In two remarkable papers, Leggett noticed that a key property prompting the reduction of the superfluid fraction of a many-body system at zero temperature is the presence of density modulations (spontaneous or induced) which break translation or Galilean symmetries [1,2]. The superfluid fraction $f = \rho_s/\rho$ is a dynamical property, but surprisingly Leggett derived simple lower and upper bounds directly from the ground state density $n = |\psi|^2$, which is real and carries no information about the velocity field of the condensate and therefore, a priori, about dynamical properties.

$$f^+ = \frac{1}{\bar{n}}\left\langle \frac{1}{\langle n\rangle_{\mathbf{r}_\perp}}\right\rangle_{||}^{-1} \qquad f^- = \frac{1}{\bar{n}}\left\langle \left\langle \frac{1}{n}\right\rangle_{||}^{-1}\right\rangle_{\mathbf{r}_\perp}$$

In this work, we extend previous studies on 1D optical lattices to fully 2D systems. Our investigation encompasses periodic, disordered, and hybrid potentials—ordered along one direction and disordered along the other—as shown in Fig. 1, thereby generalizing earlier analyses to more complex scenarios. We compare the 2D Gross–Pitaevskii model with numerically exact diffusion Monte Carlo (DMC) simulations of 3D Bose gases under strong transverse confinement.

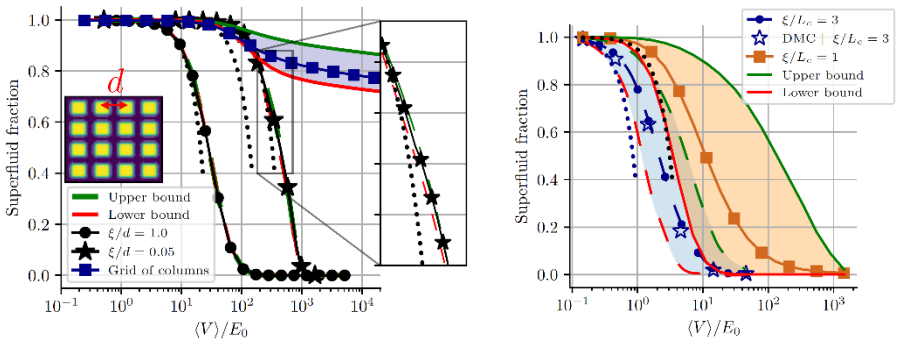


**Fig. 1**. Superfluid fraction in a 2D optical lattice and in a regular grid of repulsive square columns (left) and in 2D speckle disorder (right) plotted as a function of the mean value $\langle V\rangle$ of the potential.

Correctly understanding when the Leggett's bounds are applicable and when they are accurate is of great interest to the cold atom community, since these bounds provide a direct way to estimate superfluid fraction by the sole *in-situ* observation of the particle density [3]. On the other hand, to measure the actual superfluid fraction one would need to read out the response of the system to an infinitesimal perturbation, which is often experimentally impractical .

Our analysis readily generalizes to systems such as supersolids [4,5] or dipolar gases [6] which have become increasingly popular in recent years. Moreover, natural extensions of our work relate to the analysis of strongly interacting systems where the mean-field approach breaks down or the extension of the Leggett's bound to finite temperatures.

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# Toward Practical Boson Sampling using Frequency-Resolved Resonance Fluorescence and Quantum reservoir computing

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**Abstract**: We show that resonance fluorescence enables a practical application of boson sampling for quantum reservoir computing. Analyzing cross-correlations of multiple photon streams, we explore the potential for quantum advantage in boson-sampling-based quantum reservoir computing.

We propose that emitted photons through frequency-resolved resonance fluorescence provides a natural and physically grounded platform for implementing boson sampling. To do so, we employ the quantum-jump Monte Carlo technique within the cascade formalism, allowing for the simulation of photon emission under coherent driving [1]. In this setting, photon streams are passed through frequency-selective filters, producing frequency-resolved cross-correlation data. The resulting cross-correlations of multiple photon streams reflect the intrinsic computational complexity of boson sampling, revealing how resonance fluorescence can serve as a viable quantum boson sampler.

Extending this framework, we explore a regime where the emission spectrum lies within or beyond the Mollow triplet structure [2,3]. The filtered resonance fluorescence output, together with a network of coupled frequency-resolved detectors, constitutes a quantum reservoir computing system. Into this architecture, we inject external quantum data—also derived from a frequency-resolved fluorescence source—to perform a classification task. We investigate the performance of the reservoir and explore the possibility of a quantum advantage using boson-sampling-based resonance fluorescence [4].

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# Estimation of the second-order coherence function using quantum reservoir and ensemble methods

Dogyun Ko, Stanislaw Swierczesski , Andrzej Opala, Michał Matuszewski, **Amir Rahmani**

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**Abstract**: We introduce a quantum reservoir computing framework to estimate second-order photon correlations from intensity measurements alone, eliminating the need for coincidence detection and enabling nonlinear training with demonstrated generalization across different quantum optical systems.

One of the central parameters in quantum optics is the zero-time second-order correlation function $g^{(2)}(0)$, which provides important information about photon statistics (e.g. photon bunching and antibunching). However, measuring $g^{(2)}(0)$ can present several challenges, especially for bright quantum light sources with low intensity, where it may take a considerable amount of time to gather enough photons for accurate measurements. Additional difficulties arise from low collection efficiency due to insufficient timing resolution or the presence of background noise. In this context, we propose a machine learning framework, enhanced by quantum reservoir computing (QRC), to estimate $g^{(2)}(0)$ using intensity measurements only in the inference phase. This approach offers a potentially resource-efficient solution to overcome the measurement challenges associated with the correlation function measurements, some of which have been mentioned above.

Our proposal (depicted schematically in Fig. 1) incorporates quantum states of the source as inputs. These inputs are coupled to nodes within the reservoir, whose dynamics are nonlinear functions of the input state. In the training phase, emission intensity of the nodes is recorded and used in software together with $g^{(2)}(0)$ of the given input state. In the inference phase, intensity measurements allow to estimate $g^{(2)}(0)$ without any direct correlation measurements. Training data is generated by simulating various quantum optical systems, such as squeezed photon-added states, the Jaynes-Cummings model, resonance fluorescence mixed with coherent light, and microcavity polaritons, as a few examples of a broad class of quantum optical sources.

We show that even with a small reservoir (2 nodes) our learning scheme can precisely estimate $g^{(2)}(0)$ without modification of the reservoir. In addition, we show that in some cases the information of occupation number in the source (rather than the full quantum state) can be used for training while still achieving good accuracy. This can be substantially improved by using a quantum reservoir and the full quantum states. We also consider the situation where the trained model is tested on unseen data of the same (or similar) physical system but using different parameters. We find that in some range of parameters, the estimation is exact. Our results suggest that quantum reservoir computing provides an advantageous framework for improving the measurement and estimation of coherence functions in quantum optical systems [1].

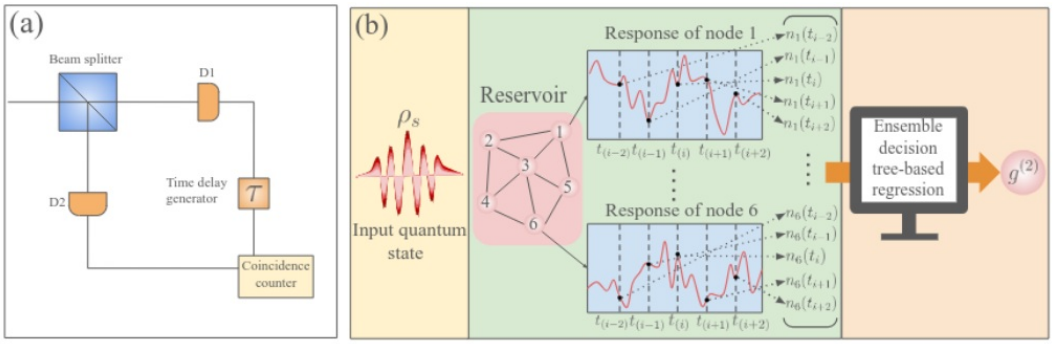


**Fig. 1** (a) Setup for the Hanbury Brown and Twiss experiment to measure second-order coherence. (b) Schematic of our proposal to predict $g^{(2)}(0)$ based on enhanced QRC.

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# Near-Equilibrium Propagation training in nonlinear wave systems

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**Abstract**: Near-Equilibrium Propagation (NEP) is a learning framework for training nonlinear wave systems directly in their physical steady states. It enables local gradient estimation in driven–dissipative, complex-valued systems without requiring an explicit energy functional, making it suitable for photonic platforms.

In this work [1], we introduce Near-Equilibrium Propagation, a generalization of Equilibrium Propagation to complex-valued, driven–dissipative wave dynamics. The method relies on a two-phase protocol in which the system first reaches a free steady state under an input drive and is then weakly nudged in the output region according to the output error. Parameter updates are obtained from steady-state contrasts between the free and nudged configurations, allowing in-situ learning through purely local measurements. Unlike conventional EP, NEP operates near equilibrium in weakly dissipative regimes and does not require a well-defined energy function. The formalism applies to both discrete and continuous systems and allows training of local physical parameters, such as spatial potentials or pump strengths, rather than explicit inter-node weights.

We demonstrate the approach numerically using driven–dissipative exciton-polariton condensates governed by a generalized Gross–Pitaevskii equation. The learning dynamics are tested on benchmark tasks, including a one-dimensional XOR logic gate and two-dimensional MNIST digit classification. Stable convergence is observed in both cases, with the XOR task converging within approximately 10 training epochs and MNIST classification reaching up to 85% test accuracy after about 20 epochs.

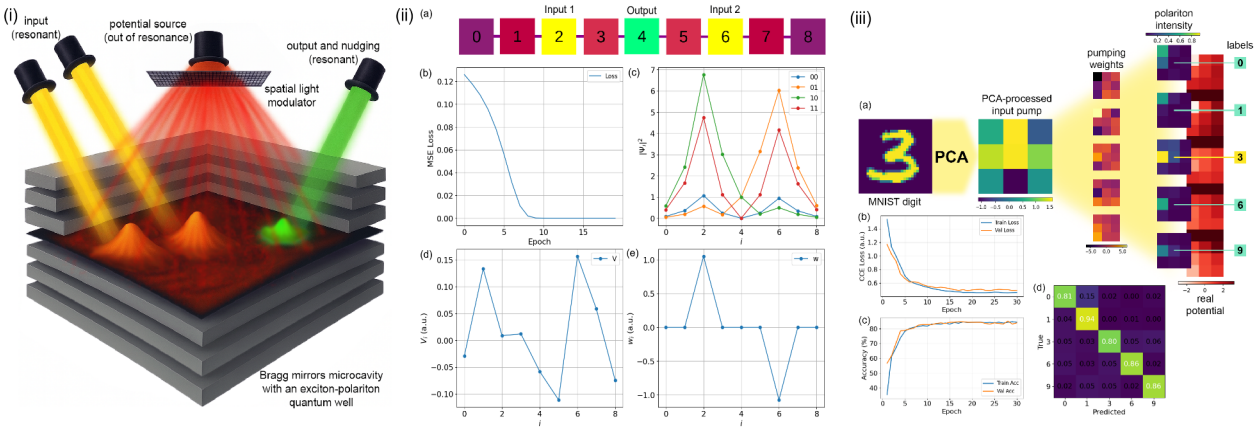


**Fig. 1** Near-Equilibrium Propagation in a nonlinear wave system: **(i)** schematic of the learning protocol in a Bragg-mirror microcavity with an exciton–polariton quantum well, showing free evolution under input driving, weak output-region nudging, and a trainable potential source; **(ii)** training convergence, final steady state, pumping weights, and potential landscape for the XOR task implemented in a discrete 7-node nonlinear wave system with nearest-neighbor linear couplings; **(iii)** results and schematic illustration of the realization of the MNIST handwritten digit classification task using Primary Component Analysis and NEP.

This work establishes NEP as a physically grounded learning paradigm for nonlinear wave systems, providing a practical route toward ultrafast, energy-efficient, and fully in-situ training of optical and polaritonic neuromorphic hardware.

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# Coherent optical spin Hall transport for polaritonics at room temperature

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**Abstract**: Y.S. prepared the samples, conducted the optical spectroscopy measurements, analysed data and wrote the manuscript.

Spin or valley degrees of freedom hold promise for next-generation spintronics, however macroscopic coherent spin current formations are still hindered by the rapid dephasing due to electron scattering, specifically at room temperature. Exciton polaritons offer excellent platforms for spin-optronic devices via the optical spin Hall effect (OSHE). However, this effect could neither be unequivocally observed at room temperature nor be exploited for practical spintronic devices due to the presence of strong thermal fluctuations or large linear spin splitting. Here, we report the observation of room temperature OSHE of exciton polaritons, with the spin current flow over 60 μm in $FAPbBr_3$ perovskite microcavity. We provide direct evidence of long-range coherence in the flow of polaritons and the spin current they carry. Leveraging the spin-Hall transport of polaritons, we further demonstrate two polaritonic devices, namely a NOT gate and a spin-polarized beam splitter, advancing the frontier of room-temperature polaritonics in perovskite microcavities [1].

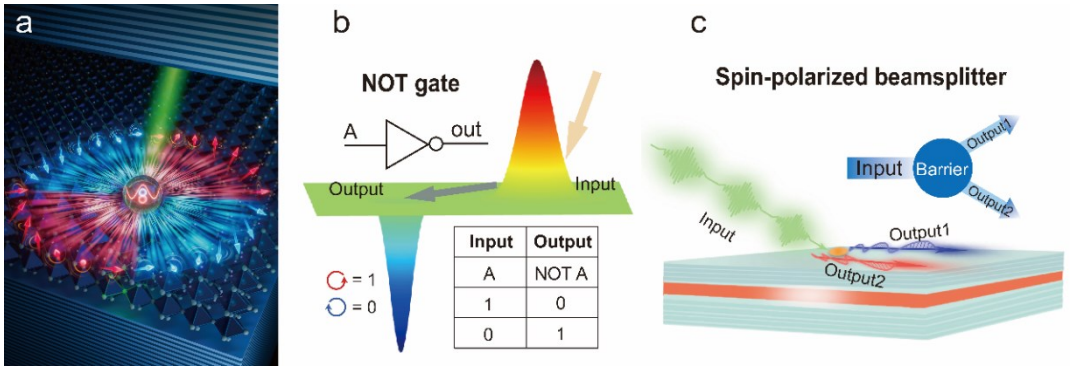


**Fig. 1** Optical spin Hall transport in FAPbBr3 perovskite microcavity and related polaritonic devices.

## References

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# Chirality of magnetism in transition metal dichalcogenide monolayers

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**Abstract**: We demonstrate theoretically that spin-valley locking in transition metal dichalcogenide monolayers leads to chiral ordering of magnetic adatoms. This chirality gives rise to the anomalous Hall effect and valley splitting of the exciton fine structure.

The discovery of magnetism in atomically thin crystals [1] rises the question of how to combine it with the outstanding excitonic properties of transition metal dichalcogenide monolayers (TMDC MLs). To answer it, we study an ensemble of magnetic impurities deposited on a TMDC monolayer (ML).

First, we develop a theory of the Ruderman–Kittel–Kasuya–Yosida (RKKY) exchange interaction and demonstrate that the peculiar spin-valley locking in these materials results in the chiral magnetic ordering of the impurities. Specifically, the ground state is an antiferromagnetic 120° Néel state, as illustrated in Fig. 1(a). The helicity of this state is controlled by the sign of the conduction band spin splitting. This chiral antiferromagnetic configuration stands in sharp contrast to the previously reported ferromagnetism in van der Waals MLs.

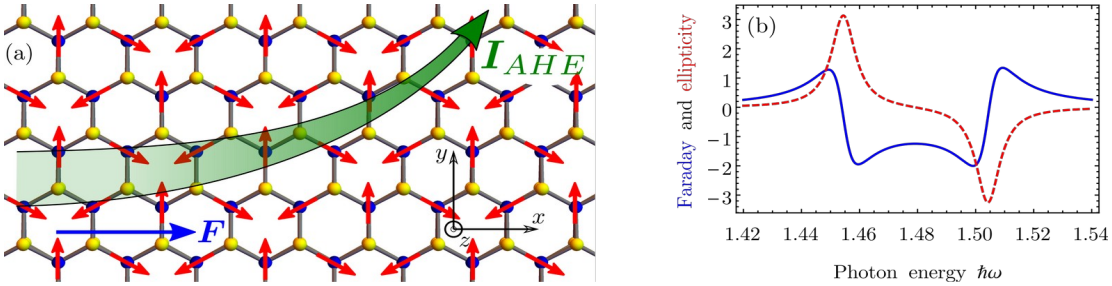


**Fig. 1** (a) Chiral magnetization (red arrows) of magnetic adatoms on a TMDC ML (blue and yellow spheres). The green arrow illustrates the anomalous Hall current caused by this magnetization in the presence of an electric field **F**. (b) Spectra of magnetically-induced Faraday rotation and ellipticity of probe light in the vicinity of the valley-split exciton resonance.

Second, we investigate magnetic excitations and thermodynamic properties numerically using Monte Carlo simulations for the XY model [2]. This reveals an interplay between the RKKY interaction and direct antiferromagnetic exchange, which generates domains of opposite chirality in the system at finite temperatures.

Third, we describe modifications of the transport and optical properties of a TMDC ML driven by the chiral magnetization of impurities. Starting from a six-orbital tight-binding model, we derive an effective **k·p** Hamiltonian that reveals the Berry curvature of conduction band states. We demonstrate that the Berry curvature leads to the antiferromagnetic anomalous Hall effect [3] (Fig. 1(a)) via three mechanisms: anomalous velocity, side jumps, and skew scattering. Furthermore, the chiral magnetization breaks translational symmetry, inducing mixing of K and K' valleys. As a result, the exciton resonance splits into two distinct peaks, observable in the photoluminescence spectra and Faraday rotation (ellipticity) measurements of the linearly polarized light, as shown in Fig. 1(b).

The work is supported by the RSF grant No 25-72-10031.

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# Dynamics and Polarization of Polaron Polariton Emission

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**Abstract—** Quasiparticles formed through interactions between mobile impurities and a quantum many-body environment—known as *polarons*—govern the optical and electronic behavior of low-dimensional materials. When excitons in a two-dimensional electron system strongly couple with cavity photons, they form *polaron–polaritons*, hybrid light–matter quasiparticles that embody many-body interactions within a microcavity [1]. Using gate-tunable monolayer $MoSe_2$ embedded in a high-finesse microcavity, we access the non-perturbative strong-coupling regime and monitor the transition between attractive and repulsive exciton–polaron states [2]. Time-resolved spectroscopy captures the real-time evolution of these quasiparticles, revealing that their lifetimes and interconversion dynamics depend sensitively on the Fermi energy, thus establishing a tunable link between coherence and carrier density in a two-dimensional Fermi system [3]. Building on this understanding, we demonstrate a *polaron–polariton light-emitting diode* that achieves an external quantum efficiency of ~1.1%, an order of magnitude higher than conventional exciton–polariton LEDs [4]. Finally, polarization-resolved measurements uncover a surprising effect: circularly polarized excitation induces linearly polarized emission, while linear excitation does not. This behavior highlights the intricate coupling between spin, coherence, and many-body interactions in polaron–polariton systems.

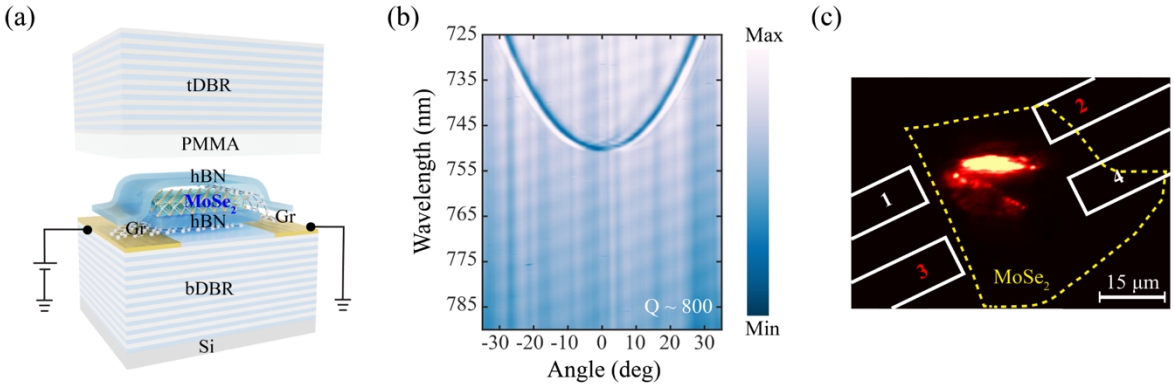


**Figure 1:** Structure, characterization, and EL of the device.

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# Investigation of the polariton condensation threshold in annular optical traps

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**Abstract**: In this work, we have studied both experimentally and theoretically the dependence of the polariton condensation threshold on the exciton-photon detuning and the radius of the ring-shaped pump.

The power threshold is one of the main characteristics of the exciton-polariton condensates; hence, it is of great importance to know its dependence on the physical properties of the system for the newly developing field of polaritonics. Although such research was performed for a Gaussian spot excitation scheme [1], it is necessary to analyse the dependence of the threshold on the detuning and geometry in a similar way for a ring-shaped excitation scheme, in which polaritons are trapped inside the ring due to the polariton-reservoir interactions.

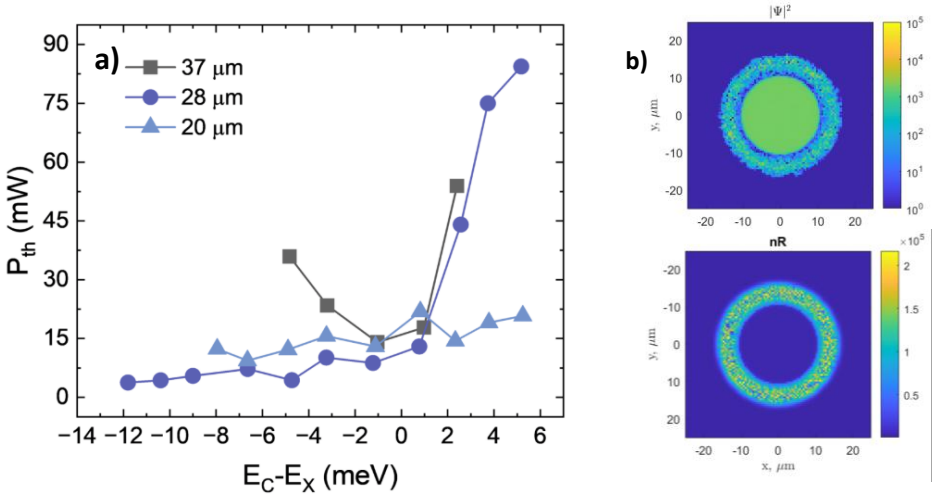


**Fig. 1 a)** Power threshold dependence on the exciton-photon detuning and the diameter of the pump.
**b)** Polariton condensate and reservoir density obtained from the numerical simulations.

In this work, we have experimentally observed the interesting behaviour of the power threshold curve with the decrease of the radius of the pump, as depicted in Fig. 1 (a). In order to explain these results, we are using the open-dissipative Gross-Pitaevskii equation [2,3], as this way of trapping goes beyond the limits of the Semiclassical Kinetic Boltzmann Equation. We discuss the influence of the lifetime and stimulated scattering rate on the physical parameters of the system, as well as the diffusion, which is prevalent for the more excitonic polaritons.

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# Electrostatic Control of Moiré-Exciton Polaritons: Hybridization and Tunable Optical Nonlinearity

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**Abstract**: "We demonstrate electrostatic control of moiré-exciton polaritons in a fiber cavity. A dual-gated device accesses novel electrostatic phases exhibiting excitonic hybridization, charge order, and optical nonlinearity, enabling exploration of strong interaction through light-matter states."

Moiré exciton polaritons, formed by coupling excitons in a moiré potential to cavity photons, offer a versatile platform for exploring strongly correlated light–matter states. Recent advances in electrostatic control are expanding the scope of this platform, enabling access to emergent quantum phases and tunable nonlinear properties. Here, we use electrostatic gating to map the polaritonic phase diagram of a moiré heterostructure and uncover previously unobserved states, characterized by signatures of charge order and exciton hybridization. We observe features consistent with an interaction between polaritons and generalized Wigner crystals at fractional and integer fillings and a gate-tunable hybridization of inter- and intralayer exciton polaritons. Furthermore, we demonstrate active control of a moiré-induced optical nonlinearity via field-driven modification of the moiré potential landscape, enabling reconfigurable nonlinear optical functionality in our device. These results expand the capabilities of nonlinear moiré polaritonics to the device level and establish new regimes of electrically tunable hybrid quantum states.

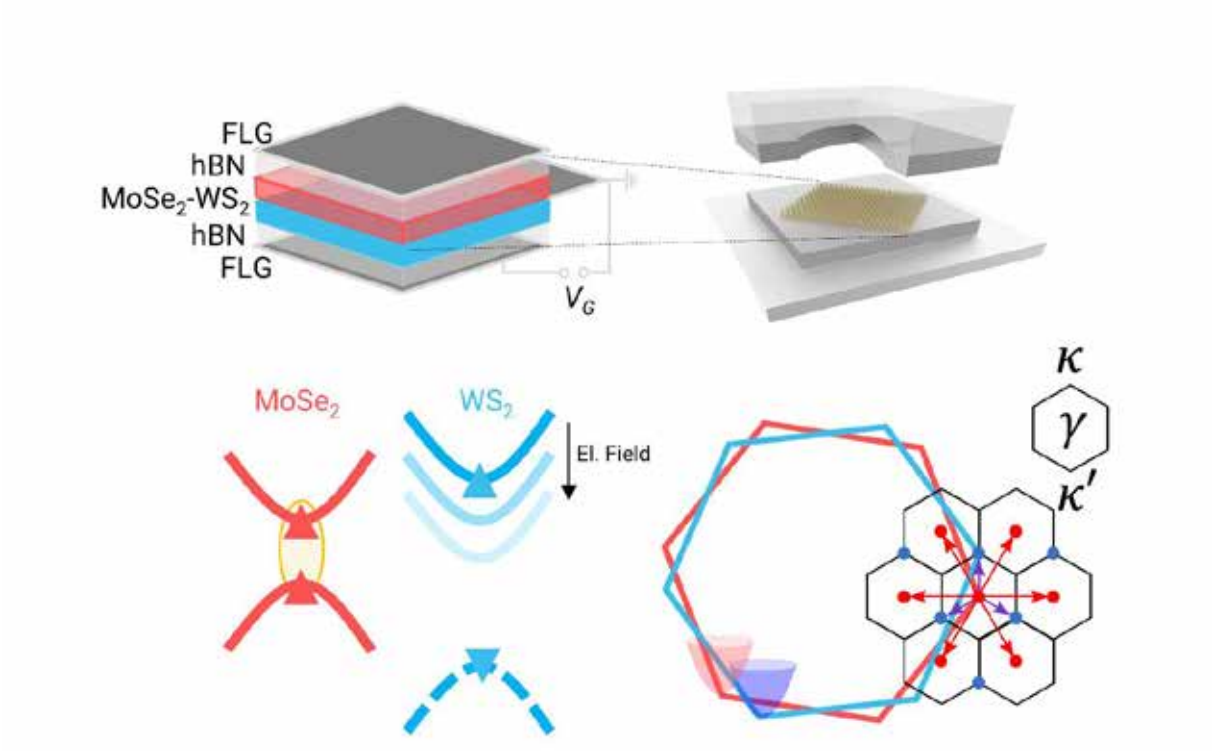


**Fig. 1** Schematic of the dual-gated moiré heterostructure in an open fiber cavity along with a sketch of the band structure alignment and mini-Brillouin zone generated through the moiré potential.

## Exploring the supersolid phase of matter with dipolar quantum gases

Giovanni Modugno, LENS, Dipartimento di Fisica e Astronomia, Università di Firenze, and CNR-INO, Pisa

Supersolids are a fundamental quantum phase of matter combining properties of crystals and superfluids. A supersolid phase was recently discovered in Bose-Einstein condensates of strongly dipolar atoms. I will discuss the exceptional properties of dipolar supersolids, spanning from double symmetry breaking to mixed superfluid and classical dynamics. I will in particular show how a supersolid can behave as a self-induced Josephson junction array, and how it is possible to deduce from the Josephson dynamics the superfluid fraction, which is the universal property quantifying the deviation of supersolids from both crystals and superfluids.

# Probing the bulk topology of one-dimensional Su-Schrieffer-Heeger chains

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**Abstract**: We demonstrate direct experimental access to the bulk topology of a 1D SSH chain by analyzing the far field spectra of coupled exciton-polariton lattices. A topological band inversion is precisely revealed in momentum space, distinct from conventional edge state characterizations.

While topological edge states are abundantly reported in literature for various metamaterials beyond exciton-polaritons, the primary focus of studies is typically set on the investigation of real space signatures of the systems topology [1,2]. Here, we address the bulk topological properties directly. By carefully designing the Su-Schrieffer-Heeger (SSH) chains through controlled sublattice shifting perpendicular to the chain, we can experimentally probe a band inversion at the Brillouin zone edges for topologically non-trivial chains, associated with the appearance of edge states in real space. More precisely, this inversion manifests itself in the symmetry of the Bloch eigenvector $\langle\psi_k|\sigma_x|\psi_k\rangle$, where $|\psi(k)\rangle \equiv (\psi_A,\ \psi_B)$ and the first Pauli matrix $\sigma_x$ (Fig. 1a). $|\psi(k)\rangle$ is the eigenvector if the 1D SSH Hamiltonian

$$H(k) = \begin{pmatrix} 0 & v + we^{-ik} \\ v + we^{ik} & 0 \end{pmatrix}$$

Intuitively, this sublattice symmetry $\langle\sigma_x\rangle$ probes the phase shift between the sublattices $\psi_A$ and $\psi_B$, where $\langle\sigma_x\rangle = 1$ corresponds to a phase shift of $\Delta\theta = 0$ and $\langle\sigma_x\rangle = -1$ to $\Delta\theta = \pi$.

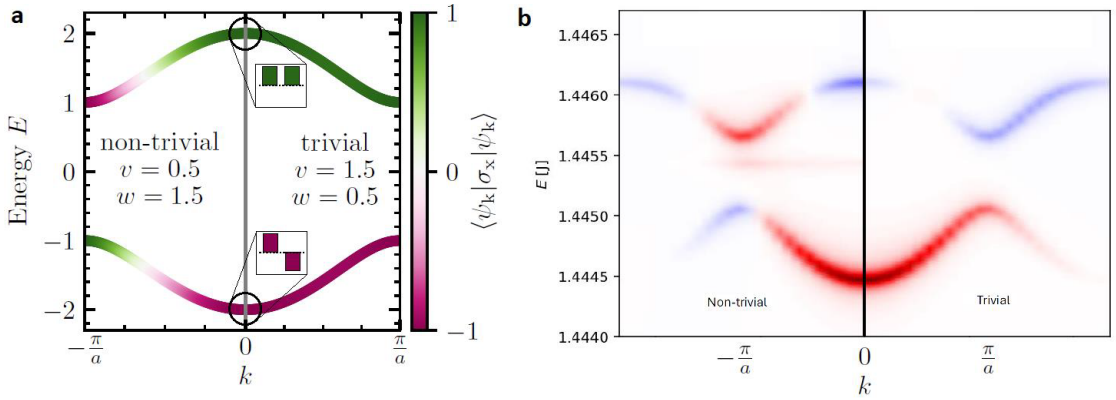


**Fig. 1 a,** Band inversion of the 1D SSH Hamiltonian for a non-trivial and trivial chain. In the non-trivial case, $\langle\boldsymbol{\sigma_x}\rangle$ inverts at the edge of the Brillouin zone. **b**, GPE simulated difference spectrum of the far field emission for phase shifts of $\boldsymbol{\Delta\theta = 0}$ and $\boldsymbol{\Delta\theta = \pi}$ with direct experimental access. The bands encode the system's topology.

These results provide a unique momentum-space characterization of the bulk topology, significantly complementing conventional edge state-based investigations. Our findings demonstrate the potential of advanced $k$-space techniques as a tool for investigating bulk topology in photonic and polaritonic lattice systems, paving the way towards sophisticated techniques such as direct measurements of topological invariants in one and two dimensions [3].

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# PHOENIX – Paderborn highly optimized solver for two-dimensional nonlinear Schrödinger equations: applications in polariton systems

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**Abstract**: We present PHOENIX, an open-source solver for 2D nonlinear Schrödinger equations, achieving up to 1000× speedup and 99.8% energy savings over MATLAB, with broad applicability in nonlinear optics.

Variations of the Gross-Pitaevskii equation, a form of the nonlinear Schrödinger equation (NLSE), are central to modeling the nonlinear dynamics of exciton-polariton condensates, quantum fluids of light-matter quasiparticles in semiconductor microcavities. Numerically efficiently solving these equations with various extensions is key to advancing theoretical insights and enabling new explorations of complex and large nonlinear systems.

Here, we introduce PHOENIX, an open-source, C++-based solver tailored for two-dimensional nonlinear Schrödinger and Gross-Pitaevskii equations, with direct applicability to exciton-polariton systems. PHOENIX supports execution via MATLAB and Python, enabling seamless integration with pre-existing codebases and familiar post-processing workflows. PHOENIX delivers up to three orders of magnitude speedup and energy savings of up to 99.8% compared to standard MATLAB implementations of fourth-order Runge-Kutta methods. It supports both single and double precision and performs close to theoretical cache bandwidth limits, especially on high-end consumer hardware, demonstrating a highly cache-efficient implementation. Moreover, PHOENIX is designed for straightforward code extensions for integrators and NLSE extensions [1].

Beyond benchmarking, we showcase practical utility of PHOENIX through simulations of exciton-polariton condensates. These applications incorporate extensions such as non-Hermiticity, spin-orbit coupling, and stochastic noise, with the latter facilitating ensemble time evolutions and quantum state tomography. With code example and detailed documentation [2], PHOENIX serves as a powerful, accessible tool for the ICSCE community to explore nonlinear wave dynamics and polariton condensates with unprecedented performance and flexibility.

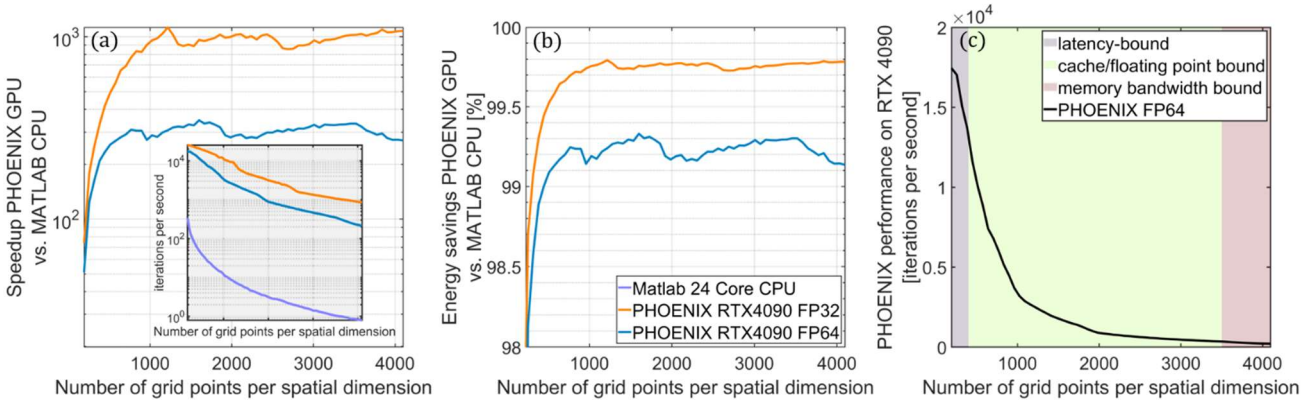


**Fig. 1** Performance comparison on high-end consumer hardware. (a) Speedup and iterations per second. (b) Energy savings of PHOENIX compared to a conventional MATLAB Runge-Kutta CPU implementation for various grid sizes of a square grid. Simulations use MATLAB R2024a, and PHOENIX compiled with GCC and CUDA. PHOENIX achieves microsecond iteration times even for large grids. (c) PHOENIX performance on RTX 4090 in double precision float and computational bounds.

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[2] Code available at: J. Wingenbach, D. Bauch, X. Ma, R. Schade, C. Plessl, and S. Schumacher, GitHub, (June 2025), https://github.com/Schumacher-Group-UPB/PHOENIX

# High stability and low threshold polariton lasing in laterally confined BSBCz microcavities

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**Abstract**: Polariton lasers are a promising tool to enable electrically driven lasing. Therefore, optically pumped lasers were improved in this work by lowering the lasing threshold through lateral confinement and increasing stability through a protective interlayer.

Organic polariton lasers are promising sources of coherent light. They operate at room temperature and, unlike photon lasers, they do not necessarily require population inversion. For this reason, they can potentially have lower lasing thresholds and therefore may require less driving energy.

The blue fluorescent organic dye 4,4-bis[(N-carbazole)-styryl]biphenyl (BSBCz) shows excellent lasing properties in conventional lasers and is highly promising for electrically pumped laser diodes. Here, we realize polariton lasers by sandwiching BSBCz between two highly-reflective Bragg mirrors and analyze the threshold and stability of these lasers. By doping BSBCz at 50wt% into 4,4'-Bis(N-carbazolyl)-1,1'-biphenyl (CBP), we achieve polariton lasing thresholds down to 28 pJ and increase stability during optical pumping.[1] By miniaturizing the active area of the laser and thus introduction lateral polariton confinement, we further lowered the lasing threshold down to 4 pJ. Direct sputter deposition of the top Bragg mirror on the organic layer has been previously reported to be detrimental to the organic layer. Using an ALD-deposited $ZrO_2$ protection interlayer, we were able to realize polariton lasers that can withstand >100,000 excitation pulses above the lasing threshold with minimal degradation. These results demonstrate that BSBCz can be optimized for polariton lasing and how improvements in stability and lasing threshold bring us one step closer to an electrically pumped polariton laser.

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# Tunable polariton condensate pattern in square-shaped perovskite crystals

**Aniela Woyciechowska**[1], Mateusz Kędziora[1], Maciej Zaremba[1] , Maciej Nytko[1], Andrzej Opala[1,2], Barbara Piętka[1]

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**Abstract**: We demonstrate room-temperature polariton condensation in chemically synthesized square-shaped $CsPbBr_3$ perovskite microcrystals, revealing tuneable lasing patterns driven by crystal size and non-Hermitian effects in confined optical geometries.

Exciton-polariton condensation is typically observed in microcavities composed of two Bragg mirrors enclosing a quantum well. However, such a vertical optical confinement is not a strict requirement. Perovskite materials, such as CsPbBr3, naturally form optical resonators due to their high refractive index (n≈2.2). This intrinsic optical confinement, together with a high exciton binding energy, enables exciton polariton condensation, even at room temperature, making the perovskite crystal a promising alternative for exploring polaritonic phenomena without the need for complicated cavity fabrication [1,2]. In such crystals, the geometry of the resonator plays a crucial role in shaping of polariton condensate mode spatial structure. Particularly interesting are square-shaped microcrystals, because of their high symmetry. Control of the crystal size is possible through a specially developed method of chemical synthesis. Our method allows for obtaining high-quality samples and also controlling other parameters, such as the separation of crystals from each other at the sample. The developed method is also faster and cheaper than other popular methods of manufacturing square-shaped perovskite crystals, like chemical vapour deposition. Additionally, we analysed how the crystal size affects the nature of the polariton emission. We verified that for bigger crystals, the lasing concentrates at the edges and for smaller ones, the lasing has the highest intensity at the corners. Analysis of the photoluminescence spectra showed that the observed phenomena are a consequence of polariton condensation, and the emission pattern is strongly determined by the non-Hermitian nature of the system. It opens the way for further research on nonlinear and non-Hermitian effects in polariton condensates at room temperature in confined geometry.

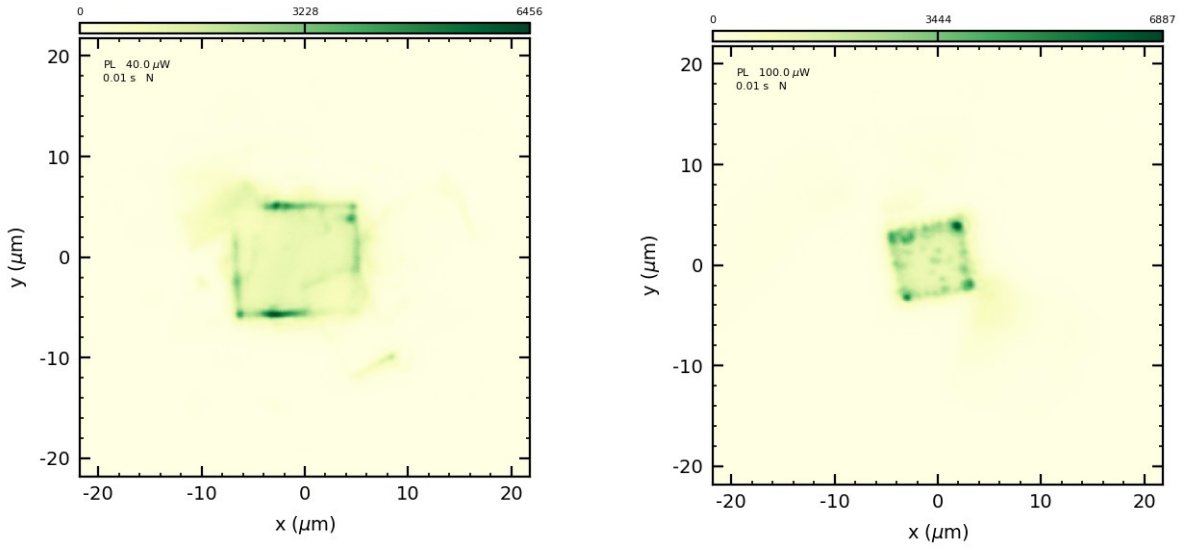


**Fig. 1** Polariton lasing in CsPbBr3 perovskite microcrystal from the edge (left) and corners (right).

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# Kardar-Parisi-Zhang scaling in Bose-Einstein condensates of photons

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**Abstract**: Photon condensates are an out-of-equilibrium driven-dissipative condensate which hosts Kardar-Parisi-Zhang scaling, present in systems like interfaces in bacterial colonies [1], and nonequilibrium polariton BEC's [2]. We investigate scaling by using a classical field model to model the system [3].

Photon Bose-Einstein-condensates could provide a novel platform for the study of out-of-equilibrium systems exhibiting Kardar-Parisi-Zhang dynamics. The KPZ equation is a nonlinear stochastic partial differential equation that was originally derived to describe the roughening of a crystal interface during its growth. Presently it is well known that many more unrelated systems; the shape of fire fronts, interfaces in bacterial colonies [1], alongside nonequilibrium polariton BEC's [2], fall into the KPZ universality class. Photon condensation is achieved in coupled optical cavities filled with dye molecules which ensure thermalization of the photons through repeated absorptions and reemissions. The unavoidable photon losses that are a consequence of the finite reflectivity of the cavity mirrors require continuous laser pumping to achieve a driven-dissipative steady state. This system is described by a classical field model [3]. We use both numerical and analytical approaches to investigate KPZ scaling. In particular, the most favourable system parameters are identified for its experimental observation in 1D and 2D setups. For 2D systems an interplay between KPZ and BKT physics is expected.

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# Resonant Light Propagation in Perovskite Waveguides

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**Abstract**: We demonstrate room-temperature light propagation via resonant injection on polariton modes in a $CsPbBr_3$ perovskite waveguide, achieving long-range, energy selective, low-loss propagation and efficient grating-based coupling for integrated photonics and nonlinear optics applications.

We report a study of long-distance signal propagation on polariton waveguide modes at room temperature in microwires of geometry of straight waveguides. Propagating polaritons were resonantly excited in a monocrystalline $CsPbBr_3$ perovskite waveguide. The efficient incoupling and outcoupling of light is assured via PMMA gratings fabricated on top of the perovskite crystal. We observe in-plane polariton-assisted light propagation phenomena based on total internal reflection. Long propagation distances and optical losses are strongly related to the energy of propagating mode and exciton-photon fraction.

We developed a monolithic, room-temperature polaritonic waveguide platform based on single-crystalline $CsPbBr_3$ perovskite microwires. These were fabricated via a microfluidic--assisted pseudomorphic growth technique, ensuring deterministic control over crystal morphology, positioning, and scalability without the need for post--growth processing steps. To facilitate resonant injection and outcoupling of polariton modes, we pattern one-dimensional PMMA diffraction gratings on top of as-grown microwires using electron beam lithography. Each device contains, at least, two gratings, spaced by 20 µm, enabling resonant excitation and efficient light extraction from guided modes.

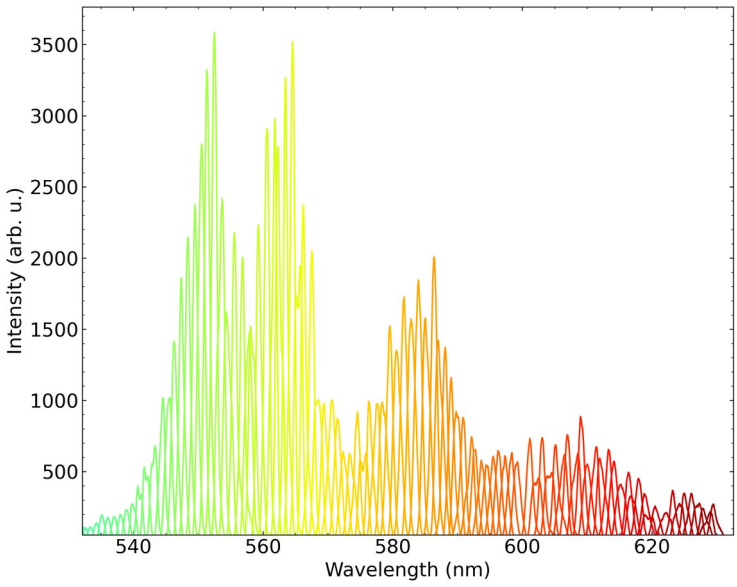


**Fig. 1** Observed energy selective efficiency of light transfer on polariton waveguided modes in perovskite microwire.

We utilize a tunable picosecond laser (530-630 nm) to scan resonances, identifying clear intensity peaks aligned with energy–momentum crossing points in the dispersion, consistent with strong coupling. The emission from subsequent gratings exhibit sharp spectral and spatial features, validating long-range polariton transport.

We interpret the observed enhanced signal intensities as gain-mediated amplification enabled by the intrinsic properties of $CsPbBr_3$. The amplification stems from optical injection, tight waveguide confinement, and strong material gain, further reinforced by constructive interference at the grating sites. Upon increasing the excitation fluence, we observe a blueshift in the lower polariton mode, attributed to strong polariton–polariton interactions. This nonlinear response, exceeding the lower polariton linewidth, highlights the potential for future applications in low-threshold polaritonic devices.