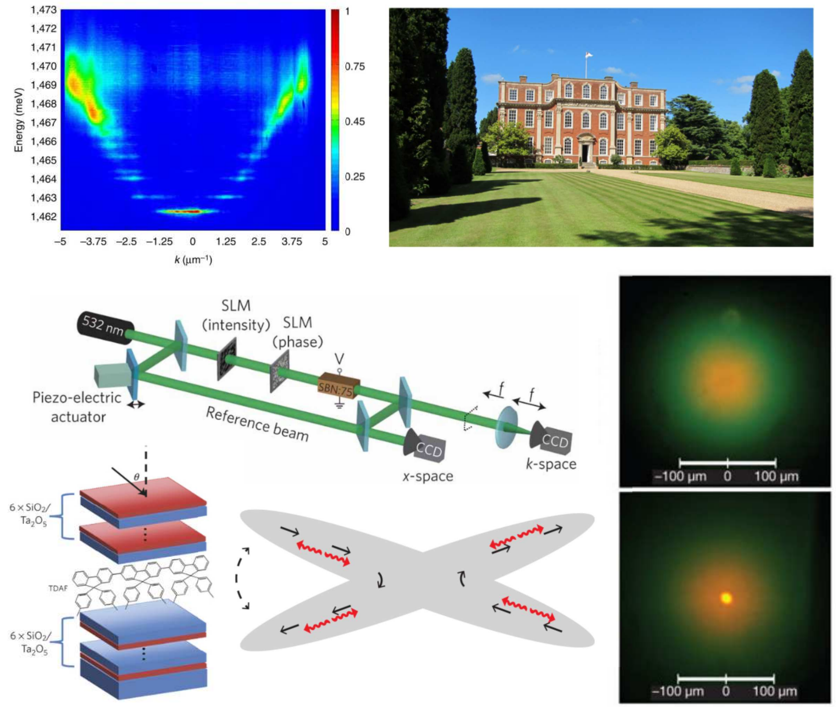
Condensates of Light

Chicheley Hall, Buckinghamshire, UK



13th–15th January 2016

Welcome to the January 2016 workshop on Condensates of Light. This booklet contains some useful information as well as abstracts and the conference program. Other information can be found on the workshop website http://condensates-of-light.org/

To get to Chicheley Hall, the most obvious route is a taxi from either Milton Keynes Central or Bedford train stations. Rail information is here: http://nationalrail.co.uk. For those who are flying into the UK, you might like to know that Luton airport is close to Chicheley Hall and has frequent trains to Bedford. London Gatwick airport has slow direct trains to Bedford. Birmingham and Stansted airports are both closer to Chicheley Hall than London Heathrow, but public transport links are not necessarily better.

Morning and afternoon coffee, tea and snacks will be provided as well as lunches. For those of you staying overnight at Chicheley Hall, there will also be dinner from 7 pm, including on the 12th.

Many of you will be arriving on the evening of the 12th January. While there is no formal reception event, at least some of the organisers will spend that evening at the Chester Arms that which is very close to Chicheley Hall (see map on the next page). Reception at Chicheley Hall is normally open until 10pm, but if you inform them in advance that you will arrive later, they will stay open later for you.

The organisers are:

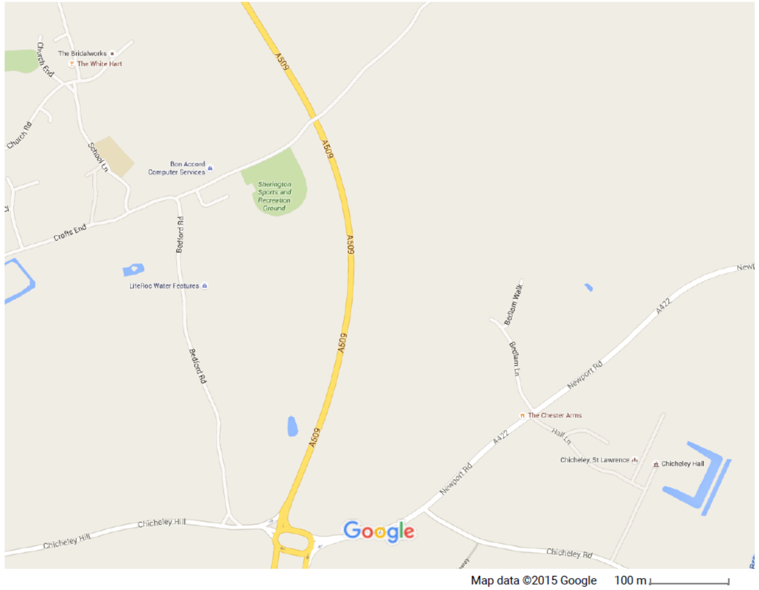
- Rob Nyman (Imperial College London)
- Peter Kirton (University of St Andrews)
- Jonathan Keeling (University of St Andrews)
- Martin Weitz (University of Bonn)

If you need to contact us you can email condensatesoflight@gmail.com. You can also contact the venue directly on +44 (0) 871 222 4843 or +44 (0) 1234 868 650.

The workshop has been paid for by the UK Engineering and Physical Sciences Research Council as part of fellowships awarded to Rob Nyman and to Peter Kirton.

Map

Here is a map of part of the area within walking distance of Chicheley Hall. Chicheley Hall itself is in the bottom right, as is the nearest pub, the Chester Arms. It is possible that some of you will be staying at the White Hart in Sherington, which is in the top left.



You can also search Google maps for the Chicheley Hall postcode MK16 9JJ.

For speakers

Keynote talks are 50 minutes (including discussion), invited talks are 35 minutes (also allowing for questions) and contributed talks are 25 minutes (with comments). If you wish to use slides but are unable to supply your own computer to connect to the in-house audio-visual equipment, please email a PDF of your slides in advance to condensatesoflight@gmail.com .

For poster presenters

Posters will be A0 vertical (that's $2^{1/4}$ metres high by $2^{-1/4}$ metres wide). You will be able to put them up in the atrium on the poster boards provided. Poster numbers are listed along with the abstracts, and numbers will be on the boards. You will be able to put your posters up from 9am on Thursday 14th, and they need to be removed again by 9am on Friday 15th.

KEYNOTE TALKS

Four light-condensate weddings and a "funeral"

Jason Fleischer

Princeton, USA

It is well known that coherent light displays wave dynamics that are similar to that of any other coherent system, such as superfluids and cold atoms. It is less appreciated that statistical light (e.g. random-phase, thermal, or even quantum light) can be used to explore more general statistical physics, especially when nonlinear interactions are involved. Here, we will explore the interplay between coherent and partially incoherent dynamics in nonlinear optical systems, with an emphasis on the approach to equilibrium (e.g. condensation), the evolution from equilibrium (e.g. instabilities and phase transitions), and other types of dynamic steady state (e.g. turbulence). The benefits of physics by analogy will be discussed, along with the role of experiment in light of the increasing success of numerical simulation.

Superfluid Light in a microcavity

Elisabeth Giacobino

Laboratoire Kastler Brossel, UPMC, ENS, CNRS, 75005 Paris, France

Quantum coherence in interacting boson systems is at the origin of striking manifestations such as superfluidity. Superfluidity, first discovered in liquid helium in 1937, was studied in various material systems, in particular in ultra-cold atomic ensembles. But it was also realized that in some conditions, photon fluids could be described by Gross-Pitaevskii equations similarly to superfluids and Bose Einstein condensates, and superfluid behaviour was predicted for photons in two-dimensional photon fluids [1]. To observe this, weakly interacting massive photons are needed, which can be achieved in a nonlinear optical cavity, where photons acquire an effective mass, inherited from the parabolic dispersion shape of the cavity, and interact through nonlinear effects. We use semi-conductor microcavities, where the matter particles are bound electron-hole pairs, called excitons. In the strong coupling regime, the eigenstates are polaritons, which are mixed light-matter quasi-particles. Polaritons have a mass, inherited from their photonic component and interact with each other, due to their excitonic component. We have for the first time observed the superfluid motion of resonantly excited polaritons based on the Landau criterion, which states that scattering disappears when superfluidity appears [2]. We have also observed a variety of quantum fluid effects, such as the formation of dark solitons in the wake of an obstacle [3] and of vortex-antivortex pairs due to colliding flows of polaritons. We have demonstrated the formation of ensembles of same-sign quantized vortices when orbital angular momentum is injected by the exciting laser [4]. These properties of polaritons open the way to a new understanding of quantum phenomena, and to promising methods for quantum simulation.

[1] I. Carusotto, C. Ciuti, PRL 93, 166401 (2004) R. Chiao et al. PRA 60 4114 (1999);
[2] A. Amo et al. Nature Phys.5, 805 (2009)
[3] A. Amo et al. Science, 332, 1167 (2011)
[4] R. Hivet et al, Phys. Rev. B 89, 134501 (2014); T. Boulier et al. Sci. Rep.5, 9230 (2015)

Table-top condensate physics with organic polaritons

Stéphane Kéna-Cohen

Polytechnique, Montreal, Canada

Organic polaritons are quasiparticles that form in organic microcavities where the exciton-photon interaction rate exceeds that due to dissipation from the individual exciton and photon components. Polaritons obey Bose statistics at moderate densities and inherit a very light effective mass from their photon component. In addition, they interact repulsively through their exciton matter component. At high enough densities, polaritons can condense into their energetic ground state and form a macroscopic coherent state termed a polariton condensate. This state obeys the rich physics of the driven-dissipative Gross-Pitaevskii equation (GPE) in analogy with certain cold atom systems, but under ambient conditions.

In contrast to many low-temperature systems, however, coherent light emitted by the condensate can be used to directly probe the phase of the underlying quasiparticles. In this work, we will explicitly show how the emitted light can be used to probe the emergence of long-range spatial coherence, the spontaneous formation of vortices, and the various regimes of stability that can occur as a function of the pump conditions. Remarkably, the structural disorder present in organic microcavities plays very little role in the observed physics. Our findings are supported by numerical solutions to the Gross-Pitaevskii equation (GPE) under the various experimental pumping conditions. We will also show how repulsive interactions between excitons and polaritons cause a ballistic flow of polaritons away from the pump spot. The polariton propagation length can be orders of magnitude longer than that of bare excitons, which may be interesting for applications that rely on energy transfer in molecular systems. In addition to practical applications as coherent light-sources, the ease with which organic microcavities can be fabricated and characterized makes them ideal systems for studying the rich physics of the GPE.

The Sound of Light

H.T.C. Stoof

Utrecht, Netherlands

The recent achievement of Bose-Einstein condensation of photons offers the exciting possibility to study the superfluid properties of light, both for fundamental light-matter research as well as for ultimately applying these properties to the creation of new optoelectronic devices. In particular, the nonconservation of the number of photons leads to new fundamental questions about the intimate relationship between superfluidity and spontaneous symmetry breaking, which we address by studying the (global) phase dynamics of the Bose-Einstein condensate in an interference experiment. Second, we discuss the so-called scissors mode of the Bose-Einstein condensate, which provides a smoking gun for the superfluid nature of the light fluid. Finally, we also discuss the superfluid-Mott-insulator transition in this case, which due to the intrinsic dissipative nature of the Bose-Einstein condensate turns out to have distinct properties from the case of an atomic Bose-Einstein condensate.

Bose-Einstein condensation of photons and grand canonical number statistics

Martin Weitz

University of Bonn, Wegelerstr. 8, 53115 Bonn, Germany

Bose-Einstein condensation has previously been observed in cold atomic gases, exciton-polaritons, and magnons [1]. Photons usually show no Bose-Einstein condensation, since for Planck's blackbody radiation the particle number is not conserved and the photons at low temperatures vanish in the system walls. I here describe experiments with a dye-filled optical microresonator observing Bose-Einstein condensation of photons [2,3]. In the dye microcavity system, thermalization is achieved by absorption re-emission processes on dye molecules. The cavity mirrors provide a trapping potential and a non-vanishing effective photon mass, making the system formally equivalent to a two-dimensional gas of trapped massive bosons. More recently, we have investigated the condensate statistics of the photon gas, which reveals evidence for Bose-Einstein condensation in the grand canonical statistical regime due to possible effective particle exchange with the photo-excitable dye molecules [4]. In my talk, I will begin with a general introduction and give an account of current work and future plans of the Bonn photon gas experiment.

[1] See, e.g.: Novel superfluids, Vol. 1, K. H. Bennemann and J. B. Ketterson (eds.)
(Oxford University Press, Oxford, 2013).
[2] J. Klaers, J. Schmitt, F. Vewinger, M. Weitz, Nature 468, 545 (2010).
[3] J. Marelic, R. A. Nyman, Phys. Rev. A 91, 033813 (2015).
[4] J. Schmitt, T. Damm, D. Dung, F. Vewinger, J. Klaers, M. Weitz, Phys. Rev. Lett.
112, 030401 (2014).

INVITED TALKS

Stochastic polarisation oscillations of a polariton laser

Alberto Amo

Marcoussis, France

Polaritons are spinor quasiparticles that can spontaneously form a macroscopic coherent state known as polariton condensate or laser. The transition to the condensed state is accompanied by the spontaneous breaking of the U(1) symmetry, setting-up a global phase (as in a scalar atomic Bose-Einstein condensate), and by the establishment of a well-defined internal phase that spontaneously fixes the polarisation of the emission. The order parameter of the system is, thus, a vector.

In this presentation I will show our recent results on the dynamics of the vector symmetry breaking in a polariton laser with unprecedented time resolution. Using an ultrafast single shot photon counter we show that the photon statistics of total emitted intensity, regardless its polarisation, presents a poissonian behaviour ($g^{(2)}(0) \sim 1$). This high degree of second order coherence is preserved when crossing the threshold to standard photon lasing in the weak coupling regime.

When analysing the polarisation of emission, we observe that the initial polarization is stochastic, taking any possible direction in the Poincaré sphere (linear, elliptical or circular). Once the polarization direction is established, subsequent oscillations of the emission probability witness the presence of an intrinsic polarization.

Our results show that the initial polarisation of a polariton laser is random and it can be linear, elliptical or circular, changing from shot to shot. This implies that the initial polarisation is neither set by the spin-dependent polariton-polariton interactions nor by intrinsic polarisation splittings as conjectured in a number of experimental reports.

Polariton Simulators

Alexis Askitopoulos

University of Southampton

NO ABSTRACT

Discrete vortex solitons in polariton lattices

Natasha Berloff

Cambridge, UK/Moscow, Russia

Exciton-polariton condensates arranged in lattices are capable of supporting novel types of vortex states such as spontaneous discrete vortex solitons. Such discrete vortex states describe spatially localized circular energy flows that carry a nontrivial angular momentum between the lattice sites. The winding of discrete vortices spontaneously establishes depending on the lattice geometry and the pumping strength. The phase difference between lattice sites establishes due to the stimulated coupling that maximises the number of particles in the system. The transition between a vortex free and vortex states of different winding numbers can be controlled by changing the pumping strength or the distance between the lattice sites. I illustrate this by considering six condensates arranged in a circle where the interactions between distant condensates can not be neglected. As the distance between the sites changes at the constant pumping the system goes through vortex free state to the vortex states with winding one, two and three.

Driven-dissipative and Conservative Fluids of Light

Iacopo Carusotto

Trento, Italy

In this talk I will give an overview of recent works on the theory of quantum fluids and condensates of light in different platforms.

I will first focus on cavity set-ups where condensation arises as a non-equilibrium phase transition and I will discuss how an effective thermalization may appear such a driven-dissipative context.

In the second part of the talk, I will review our recent works on the theory of quantum fluids of light in cavity-less bulk nonlinear media, where the propagation dynamics can be recast in terms of a conservative evolution. The novel quantum effects that occur in this regime will be highlighted, as well as the promising perspectives in the direction of studies of non-equilibrium quantum statistical mechanics and quantum dynamics past quantum quenches.

Driven Markovian Quantum Criticality

Sebastian Diehl

Institute for Theoretical Physics, University of Cologne

We identify a new universality class in one-dimensional driven open quantum systems with a dark state. Salient features are the persistence of both the microscopic non-equilibrium conditions as well as the quantum coherence of dynamics close to criticality. This provides a non-equilibrium analogue of quantum criticality, and is sharply distinct from more generic driven systems, where both effective thermalization as well as asymptotic decoherence ensue, paralleling classical dynamical criticality. We quantify universality by computing the full set of independent critical exponents within a functional renormalization group approach.

Classical laser light condensation phenomena

Baruch Fischer

Department of Electrical Engineering, Technion, Haifa 32000, Israel

Light condensation has become an important research topic in two major fields, photonics (many-body photonics) and statistical mechanics (many-body physics). In this presentation we summarize theoretical and experimental work on classical light condensation (LC) phenomena that were demonstrated in pulsed (mode-locked) and CW lasers [1-5]. LC is based on weighting the laser modes or pulses, in a loss-gain scale in loss traps compared to a photon energy (frequency) hierarchy in quantum-thermal Bose-Einstein Condensation (BEC) in a potential trap [7]. The "ground-state energy" is the lowest-loss mode or pulse, and the noise has the role of temperature [8,9]. LC is characterized by a sharp transition from multi- to single-mode or single-pulse oscillation, similar to the BEC transition but classical. As in BEC, there is no explicit pulse ("particle") interaction, but a global constraint on the overall modes or pulses power. We will also discuss new possibilities in quantum based photon-BEC in laser cavities.

1. R. Weill, B. Fischer, and O. Gat, Phys. Rev. Lett. 104, 173901 (2010).
2. R. Weill, B. Levit, A. Bekker, O. Gat, and B. Fischer, Opt. Express, 18, 16520-16525 (2010).
3. G. Oren, A. Bekker, and B. Fischer, Optica 1, 145-148 (2014).
4. B. Fischer and R. Weill, Opt. Express 20, 26704-26713 (2012).
5. B. Fischer, and A. Bekker, Optics & Photonics News 24, 40-47 (2013).
6. J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature 468, 545-548 (2010).
7. V. Bagnato, and D. Kleppner, Phys. Rev. A 44, 7439-7441 (1991).
8. A. Rosen, R. Weill, B. Levit, V. Smulakovsky, A. Bekker, and B. Fischer, Phys. Rev. Lett. 105, 013905 (2010).
9. A. Gordon and B. Fischer, Phys. Rev. Lett. 89, 103901 (2002).

Thermalization of Photons in Strongly Driven Double Quantum Dot

Michael Gullans

National Institute of Standards and Technology, Gaithersburg, Maryland USA

Embedding a double quantum dot (DQD) in a low loss microwave resonator results in a large electric dipole interaction between the charge states of the DQD and single microwave photons in the resonator. In the regime of a few electrons and photons, this system is reminiscent of well-known models of cavity quantum electrodynamics from atomic physics; however, there are important deviations due to the strong coupling of the DQD to the electronic reservoirs in the leads, as well as phonons in the lattice. In this talk we show that simply driving the DQD with a periodic voltage can lead to thermalization of the cavity photons into a state with a temperature given by the phonons and a chemical potential given by a harmonic of the drive frequency. Such a tunable chemical potential has utility for quantum simulation with photons. As an example, we show how several DQDs embedded in an array of microwave resonators can induce a phase transition to a Bose-Einstein condensate of light.

Spatial dynamics, thermalisation and breakdown of thermalisation in photon condensates

Jonathan Keeling

University of St Andrews

I will discuss photon condensation [1], as observed in a dye-filled microcavity by the Weitz group. These experiments pose several questions about the relation of condensation and lasing, about the role of vibrational modes in the physics of photon condensation, and about pattern formation dynamics and relaxation.

I will present our microscopic model [2], which can explain the crossover between lasing and condensation, and which can lead to a thermalised condensate via a mechanism closely related to traditional lasing, but which avoids the need for inversion. Recent experiments on photon condensates [3,4] have begun to explore how spatial properties of the condensate are controlled by the shape and location of the pump spot. I will show how these results can be understood theoretically [4], and explain how this leads to connections between gain clamping and the establishment of thermodynamic equilibrium.

[1] Klaers et al, Nature 468 545 (2010)
[2] Kirton and Keeling, Phys. Rev. Lett. 111, 100404 (2013);
Phys. Rev. A. 91, 033826 (2015)
[3] Marelic & Nyman, Phys. Rev. A. 91, 033813 (2015);
Schmitt et al, PHys. Rev. A 92 011602(R) (2015).
[4] Keeling and Kirton, arXiv:1506.00280 (2015)

Bose-Einstein Condensation in a Polymer: Towards Quantum Simulation

Johannes Plumhof, Lijian Mai, Darius Urbonas, Thilo Stöferle, Ullrich Scherf and Rainer F. Mahrt

IBM Research, Zurich Research Laboratory

During recent years polaritonics has emerged as a new field of solid-state physics based on the unique quantum properties of mixed light-matter quasiparticles, so called exciton-polaritons. Recent discoveries of Bose-Einstein condensation (BEC) and superfluidity provide opportunities to harness these coherent quantum effects in a new generation of opto-electronic devices. Until now, BECs have been realized either with laser-cooled gases at nano-Kelvin temperatures or with high-quality semiconductor crystals produced by only a few laboratories worldwide. By utilizing the extremely large oscillator strength, exciton binding energy and saturation density of organic semiconductors we demonstrate BEC at room temperature with an amorphous spin-coated polymer film embedded in a Fabry-Pérot microcavity. Since no crystal growth is involved, our approach radically reduces the complexity of experiments to investigate BEC physics and paves the way for a new generation of opto-electronic devices, taking advantage of the processibility and flexibility of polymers. Finally, experiments on sub-micron sized defect cavities and possible ways towards quantum simulation will be discussed.

Vortex Turbulence and Rogue Waves in Laser Systems

Gian-Luca Oppo

Department of Physics, University of Strathclyde, Glasgow, UK

We discuss externally forced complex Ginzburg-Landau and Swift-Hohenberg models that describe gas and solid state lasers under the action of an external field. Spatially periodic structures with bound phase lose stability to phase unbound turbulent states dominated by the creation and annihilation of optical vortices. The statistics of the singularities and the probability distribution functions of the peak intensities demonstrate the occurrence of unusual rogue waves close to turbulent and interacting optical vortices. Long tail distributions typical of rare-events statistics are found when collisions of multiple vortices take place. The spatio-temporal scales of these laser sources makes it possible to study vortex turbulence and rogue waves in small aspect ratio configurations with applications to the understanding and prediction of rare events in oceanography.

We will connect the onset of vortex turbulence in these models with unusual conservation laws in systems outside thermodynamic equilibrium.

The research work has been done in collaboration with Alison Yao and Christopher Gibson

Wave turbulence description of optical waves

Antonio Picozzi

CNRS - University of Bourgogne Franche-Comté, Dijon, France

We will review different formalisms describing the dynamics of random nonlinear optical waves: The wave turbulence kinetic equation describing, e.g., thermalization and wave condensation; the Vlasov formalism describing large scale collective incoherent structures in analogy with long-range gravitational effects; the weak Langmuir turbulence formalism describing, e.g., spectral incoherent solitons, as well as shock and collapse spectral singularities. We will also discuss the regime of strong turbulence through the spontaneous emergence of phase correlations and long-range interactions.

Formation and coherence of an extended polariton condensate

C. Sanchez Munoz, D. Ballarini, D. Caputo, M. De Giorgi, L. Dominici, F. Laussy and D. Sanvitto

Lecce, Italy

The out-of-equilibrium nature of Bose-Einstein condensates of exciton polaritons [1,2], that require an external pumping to compensate for constant losses, makes basic questions on their coherence still the topic of ongoing investigations [3,4,5] with varying views on the kind of long range order that should be observed [6,7].

Up to now experiments on polariton coherence in 2D have been performed either directly under the external pumping, that constantly feeds the condensate, or using confining potentials that allow for the build up of a highly dense population in a localised region of space. In all these schemes polaritons are usually coexisting with a highly dense population of excitons in the reservoir and can only extend for a few tents of microns due to laser power constrains. In this work, we study the coherence of a polariton state highly extended in space (more than 100 microns), outside of the pumping area, thanks to exceptionally long lifetimes and high homogeneity of the microcavity sample. The spatial correlation function of the extended condensate thus formed shows, as a function of the distance, a transition between a power law and an exponential decay, apparently uncorrelated to the density of the condensate. A theoretical simulation which takes into account the peculiar experimental conditions of polariton formation, describes this system to include its key features, namely, inhomogeneous pumping providing a gradient cooling mechanism, stochastic noise and some relaxation dynamics.

[1] J. Kasprzak et al. Nature, 443, 409 (2006).
[2] T. Byrnes et al. Nat. Phys., 10, 803 (2014).
[3] G. Roumpos et al. Proc. Natl. Acad. Sci., 109, 6467 (2012).
[4] W. H. Nitsche et al. Phys. Rev. B, 90, 205430 (2014).
[5] K. S. Daskalakis et al. Phys. Rev. Lett., 115, 035301 (2015).
[6] G. Dagvadorj et al. Phys. Rev. X, 5, 041028 (2015).
[7] E. Altman et al. Phys. Rev. X, 5, 011017 (2015).

Are microcavity polaritons much more strongly interacting than we thought?

David Snoke

Pittsburgh, USA

We have performed careful measurements of the polariton-polariton interaction strength at low density, using long-lifetime polaritons which are far from any bare excitons. We find that the interaction strength is two orders of magnitude stronger than predicted based on theoretical calculations of the exciton-exciton interaction. At high density, when the polariton condense into a coherent state, the behavior of the system changes dramatically. Theoretical explanations for the strong effective interaction at low density have begun to focus on the role of disorder in the microcavity structures. I will discuss some of the proposed explanations, and why this strong interaction has not been seen in previous experiments.

Non-equilibrium Phase Transition in a Two-Dimensional Dissipative-Driven Quantum Fluid

Marzena Szymanska

University College London

The Berezinskii-Kosterlitz-Thouless mechanism, in which a phase transition is mediated by the proliferation of topological defects, governs the critical behaviour of a wide range of equilibrium two-dimensional systems with a continuous symmetry, ranging from spin systems to superconducting thin films and two-dimensional Bose fluids, such as liquid helium and ultracold atoms. We show here that this phenomenon is not restricted to thermal equilibrium, rather it survives more generally in a dissipative highly non-equilibrium system driven into a steady-state. By considering quantum fluid of polaritons, in the so-called optical parametric oscillator regime, we demonstrate that it indeed undergoes a phase transition associated with a vortex binding-unbinding mechanism. Yet, the exponent of the power-law decay of the first order correlation function in the (algebraically) ordered phase can exceed the equilibrium upper limit: this shows that the ordered phase of driven-dissipative systems can sustain a higher level of collective excitations before the order is destroyed by topological defects. Our work suggests that the macroscopic coherence phenomena, observed recently in interacting two-dimensional light-matter systems, results from a non-equilibrium phase transition of the Berezinskii-Kosterlitz-Thouless rather than the Bose-Einstein condensation type.

CONTRIBUTED TALKS

Stability and spatial coherence of nonresonantly pumped exciton-polariton condensates and adiabatic approximation

Nataliya Bobrovska, Elena A. Ostrovskaya, and Michał Matuszewski

Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Exciton-polaritons are promising candidates to investigate one of the fundamental physical phenomenon a Bose- Einstein condensation, observed in inorganic and organic semiconductor microcavities at the room-temperature. Such systems can be described by a number of phenomenological models, in particular, based on different variations of Gross-Pitaevskii or Ginzburg-Landau equations. We investigate the stability and coherence properties of 1D exciton-polariton condensates under nonresonant pumping within the open- dissipative Gross-Pitaevskii (ODGP) model including a separate equation for the reservoir. In the case of spatially homogeneous pumping, we find that the instability of the steady state leads to significant reduction of the coherence length. This instability is predicted to occur in the physically relevant case when the loss rate of the exciton reservoir is lower than the loss rate of the exciton polaritons. We consider two effects that can lead to the stabilization of the steady state, i. e. the polariton energy relaxation and the influence of an inhomogeneous pumping profile.

Additionally, we study the relation between the complex Ginzburg-Landau model described by a single equation and the ODGP model. We focus on the validity of the adiabatic approximation, that allows to reduce the coupled condensate-reservoir dynamics to a single partial differential equation.

Superfluidity and superfluid instability in propagating nonlocal photon fluids

Daniele Faccio, David Vocke, Kali Wilson, Iacopo Carusotto, Francesco Marino

Heriot-Watt, UK

We will present experimental and numerical studies showing the superfluid behavior of a photon fluid generated in a thermo-optic defocusing medium. By shining a CW laser beam in a solution of methanol and graphene flakes we can control the thermo-optic defocusing nonlinearity and thus generate a photon fluid that exhibits the clear hallmarks of superfluidity. These studies are mainly aimed at developing an experimental platform for analogue gravity but may be used also for example in nonlinear hydrodynamical turbulence studies. We will first present two methods used to experimentally determine the acoustic dispersion relation of the superfluid, one derived from an oceanic technique, the other is a more precise pump-probe method. We then show how the system provides an appealing route to studying superfluid flow around an extended obstacle and observation of quantized vortex nucleation above a certain critical fluid flow speed. We also discuss the nonlocal nature of this superfluid and the impact of nonlocality on the vortex dynamics. Finally, we discuss recent studies where the photon superfluid has been applied to nonlocal hydrodynamics and the observation of a novel collective shock phenomenon. Time permitting, we will finally show how these studies may be extended to include high-amplitude nonlinear phonon perturbations in the superfluid - a novel, purely geometrical interpretation of shock formation follows from the connection with General Relativity physics.

A new spin for exciton-polariton condensates

H. Ohadi, A. Dreismann, Y. G. Rubo, F. Pinsker, Y. del Valle-Inclan Redondo, S. I. Tsintzos, Z. Hatzopoulos, P. G. Savvidis and J. J. Baumberg

University of Cambridge

While condensation of polaritons spontaneously breaks the phase-symmetry [1,2], an analogous effect in the spin degree of freedom has not yet been observed. Here we report the first instance of spontaneous symmetry breaking in the spin degree of freedom in a polariton condensate [3].

We create optically trapped polariton condensates in the centre of a four-spot confining potential by spatially patterning a non-resonant excitation beam. Separating condensate and excitonic reservoir allows the stochastic formation of left- or right-circularly polarised condensates under linear excitation, demonstrating spontaneous breaking of the parity symmetry. The resulting spin-up or spin-down condensates remain stable for seconds, but can be switched by applying 100-fold weaker resonant gate pulses with opposite circular polarisations. We show how thermal excitation can induce spin flips, and theoretically describe the observed phenomena with a new theory that describes spin bifurcation at a critical condensate density.

[1] H. Deng et. al. Science 298, 199 (2002).
[2] J. Kasprzak et. al. Nature 443, 409 (2006).
[3] H. Ohadi et. al. Phys. Rev. X 5, 031002 (2015) .

Synthetic dimensions in integrated photonics

Hannah Price

INO-CNR BEC Center and University of Trento, Italy

Recent technological advances in integrated photonics have spurred on the study of topological phenomena in engineered bosonic systems. Indeed, the controllability of silicon ring-resonator arrays has opened up new perspectives for building lattices for photons with topologically non-trivial bands and integrating them into photonic devices for practical applications. We propose how to push these developments further by exploiting the different modes of a silicon ring-resonator as an extra dimension for photons. Tunneling along this ”synthetic” dimension is implemented via an external time-dependent modulation that allows for the generation of engineered gauge fields. We present how this approach can be used to generate a variety of exciting topological phenomena in integrated photonics, ranging from (i) a topologically-robust optical isolator in a spatially 1D ring-resonator chain to (ii) a driven-dissipative analogue of the 4D quantum Hall effect in a spatially 3D resonator lattice. Our proposal paves the way towards the use of topological effects in the design of novel photonic lattices supporting many frequency channels and displaying higher connectivities

Quenched Polariton Condensation Dynamics

Nick Proukakis (presenter) and Paolo Comaron

Joint Quantum Centre (JQC) Durham-Newcastle, Newcastle University, UK

We present our recent findings for the dynamics of quenched 2D polariton systems. Our modelling is based on a semi-phenomenological driven-dissipative stochastic Gross-Pitaevskii equation [1], which has already been shown to accurately reproduce equilibrium properties. Here, we extend its numerical application to dynamical cases, considering in particular finite-duration quenches from a noisy thermal initial state below the pumping threshold for ‘condensation’ to above the critical value which results in the formation of a quasi-long-range order state.

By counting the number of spontaneously-generated defects (vortices), we demonstrate explicitly that our findings agree with the 2D XY model predictions of Cugliandolo et al. [2], being also in qualitative agreement with (unpublished) results of Szymanska’s group (based on a coupled exciton-photon equation system), thus making direct connections to the universal Kibble-Zurek scenario. We also investigate the long-term dynamics of those vortices, casting our findings in the contexts of universal phase-ordering dynamics.

Our work is conducted with Iacopo Carusotto, in collaboration with the group of Marzena Szymanska. We also acknowledge funding by the EPSRC.

[1] A. Chiocchetta, I. Carusotto, EPL (Europhysics Letters) 102, 67007 (2013)

[2] A. Jelic and L. F. Cugliandolo, J. Stat. Mech., P02032 (2011)

Grand-canonical condensate fluctuations in weakly interacting Bose-Einstein condensates of light

Cristoph Weiss and Jacques Tempere

Durham University

Grand-canonical fluctuations of Bose-Einstein condensates of light are accessible to state-of-the-art experiments [1]. We phenomenologically describe these fluctuations by using the grand-canonical ensemble for a weakly interacting Bose gas at thermal equilibrium. For a two-dimensional harmonic trap, we use two models for which the canonical partition functions of the weakly interacting Bose gas are given by exact recurrence relations [2, 3]. We find that the grand-canonical condensate fluctuations for weakly interacting Bose gases vanish at zero temperature, thus behaving qualitatively similar to an ideal gas in the canonical ensemble [4] (or micro-canonical ensemble [5-8]) rather than the grand-canonical ensemble. For low but finite temperatures, the fluctuations remain considerably higher than for the canonical ensemble, as predicted by the ideal gas in the grand-canonical ensemble.

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Relationship of ordered coherent phenomena in semiconductor electron-hole-photon systems

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A semiconductor electron-hole-photon system can exhibit a variety of ordered coherent phases because of the interaction between the Fermions and the Bosons. On the one hand, the Bose-Einstein condensation (BEC) of excitons, photons, and polaritons is one of such coherent phases which can potentially cross over into the Bardeen-Cooper-Schrieffer (BCS) type ordered phase at high densities under quasiequilibrium conditions. On the other hand, the semiconductor laser, superfluorescence (SF) and superradiance are also known as the coherent phenomena achieved under nonequilibrium conditions. However, the relationship of these phenomena is still not well understood.

In this study, we show a theory that can describe the above-mentioned coherent phenomena in a unified way. As a result, we find that the Fermi-edge SF recently demonstrated by Kim et al [Sci. Rep. 3, 03283 (2013)], which is inherently a transient phenomenon, is directly connected to the electron-hole (e-h) BCS phase. This is striking because the presence of the e-h BCS phase is a subject of long-time active interest not yet evidenced experimentally. Our result promisingly foresees the experimental observation of the e-h BCS phase in the context of the Fermi-edge SF [Yamaguchi et al., Phys. Rev. B 91, 115129 (2015)].

POSTERS

Dissipative Self-trapping in Bose-Einstein Condensates

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Self-trapping of condensate modes is a key focal point for population control, symmetry breaking, as well as frequency tuning in strongly coupled devices. Typically, the interaction energy is manipulated for mode-trapping however this is heavily dependent on the type of structure and the level of the disorder within a system for which the interaction strength should exceed any tunneling (J). Alternatively, we propose a dissipative self-trapping method which could be controlled via external pumping and initial conditions.

We analytically solve a modified Gross-Pitaevskii treatment for a double well (left-right) system in order to characterize coupled condensate modes under an asymmetrically driven pump. We discover three stable states as a function of pumping of the left well and decay of the unpumped, right well. There also exists a two-state region for which the double well can be either on-resonance via the blueshift detuning with identical populations in each well or off-resonance. We derive the limits for each transtion within the state map and demonstrate the localization of the majority of the population in one well as a function of the level of dissipation, i.e. gain and loss, while relaxing conditions placed on the interaction potentials and system disorder.

Macroscopic quantum electrodynamics as a realistic framework for studying condensates of light?

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Macroscopic quantum electrodynamics is a powerful effective theory for describing the electromagnetic field in the presence of dielectric media of arbitrary shapes. Traditionally developed specifically for absorbing media, the theory has been extended to amplifying media in meta-stable inversion-populated states [1]. This presents the first step towards a description of scenarios for condensates of light which take into account the nontrivial geometry as well as the measured response to the involved light-emitting and absorbing elements.

In its current form, macroscopic quantum electrodynamics allows for the description of Casimir forces on amplifying plates. We show that these forces can be made repulsive [2, 3], offering a means to overcome the notorious problem of stiction in nanotechnology.

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Quantum thermalization of light in a cavityless nonlinear optical medium

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A generalized quantum theory of paraxial light propagation has been recently discussed. In this systems, light propagating in nonlinear optical media in cavityless configurations may serve as a quantum simulator of the conservative many-body dynamics of a gas of interacting bosons. In order to validate the quantum theory of paraxial light propagation, we propose a test based on the thermalization properties of light in this setting.

Equilibrium Properties of Light-based Condensates

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We use two complementary stochastic approaches [1,2] to investigate equilibrium properties of Bose-Einstein condensates of polaritons and photons.

In the context of incoherently-pumped polaritons, we use the semi-phenomenological approach of Ref. [1] to study the BKT crossover for realistic experimental parameters, discussing the extent to which our model (which naturally encompasses the Kardar-Parisi-Zhang equation) captures the key BKT transition physics [3]. Our analysis reveals excellent qualitative agreement to the work of Dagvadorj et al. [4] (performed with coupled exciton-photon equations). We also present a favourable comparison to results of the Yamamoto group [5].

Finally, we present preliminary results for equilibrium properties of photon condensates, based on the stochastic equation of Stoof and coworkers [2].

Our work has been conducted in collaboration to the groups of Iacopo Carusotto and Marzena Szymanska (polaritons) and Henk Stoof and Rembert Duine (photons), with EPSRC funding.

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Effects of dissipation on the superfluid-Mott-insulator transition of photons

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We investigate the superfluid-Mott-insulator transition of a two-dimensional photon gas in a dye-filled optical microcavity and in the presence of a periodic potential. We show that in the random-phase approximation the effects of the dye molecules, which generally lead to dissipation in the photonic system, can be captured by two dimensionless parameters that only depend on dye-specific properties. Within the mean-field approximation, we demonstrate that one of these parameters decreases the size of the Mott lobes in the phase diagram. By considering also Gaussian fluctuations, we show that the coupling with the dye molecules results in a finite lifetime of the quasiparticle and quasihole excitations in the Mott lobes. Moreover, we show that there are number fluctuations in the Mott lobes even at zero temperature and therefore that the true Mott-insulating state never exists if the interactions with the dye are included.

Controlling the spin of a polariton condensate with electric fields

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A key requirement for the realization of polariton-based spinoptotronic devices is the electrical control of their spin. While the flow of polariton condensates can be guided using all-optical [1], electrical [2] or semiconductor post-processing methods [3], manipulation of their spin has still been restricted to optical means [4]. Here we demonstrate for the first time the electrical control of the spin of polariton condensates.

We create trapped condensates that are spatially separated from the excitonic reservoir by patterning the optical excitation into a 4-spot confining potential. As shown recently [5], this geometry allows the observation of a variety of different polarisation states under linear non-resonant excitation, ranging from the pinned linear polarisation reported in the literature to a strong stochastic circular polarisation. By applying an electrical field perpendicular to the quantum-well plane we can precisely tune the polarisation of the condensate emission, demonstrating the direct electrical control of the polariton condensate spin. By utilising this precise polarization control we further demonstrate an electrical spin switch, operating at record switching energies of the order of 10 attojoule, at a speed which is only limited by the spin dynamics of the condensate.

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Coupled Quantum Gases of Light in Variable Potentials

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Bose-Einstein condensation, the macroscopic ground state occupation of bosonic particles at low temperature and high density, has been observed for cold atomic gases, solid state quasiparticles as exciton-polaritons, and more recently with photons in a dye-filled optical microcavity. Number-conserving thermalzation of photons in the dye-microcavity is achieved by multiple absorption and fluorescence processes of dye-molecules. The microcavity creates a confining potential, providing a suitable ground state and leading to a non-vanishing effective photon mass. Formally, the system is equivalent to a two-dimensional gas of trapped, massive bosons.

Here we report on recent work to create multiple BECs of photons in a single microcavity. The BECs are trapped in variable potentials that are induced by locally changing the refractive index inside the microcavity. In the experiment this is realized by focused laser light that heats an absorptive thin film near the mirror surface. A thermo-responsive polymer mixed with the dye solution will then undergo a phase-transition and thereby change the refractive index. We have determined the range of depths and trapping frequencies one can adjust with this technique. Moreover, we show recent measurements of photon tunneling between neighboring lattice sites. Furthermore, a time-dependence of the lattice site energy can be observed induced by thermooptic photon self-interaction.

Non-equilibrium phase transition in parametrically driven exciton-polariton system

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Using a Keldysh Green's function approach, we study the phase transition to the ”optical parametric oscillator (OPO)” regime of a system of photons strongly coupled to excitonic excitations in a semiconductor microcavity and driven by an external laser. The OPO phase is characterised by the appearance of three largely occupied states, the signal, pump and idler. We show that this non-equilibrium phase transition can be associated with an effective chemical potential, at which the system's bosonic distribution function diverges, and an effective temperature. In particular, as in equilibrium systems, the transition is achieved by tuning this effective chemical potential to the energy of the lowest normal mode. Considering the mean-field and Gaussian fluctuations, we show that the low energy physics of this highly non-equilibrium state is similar to equilibrium condensation. We also determine experimentally observable properties such as the luminescence and absorption spectra, and reveal how the system is choosing the momentum of the macroscopically occupied signal state.

Bose-Einstein condensation of photons in a periodic potential

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In the field of atomic Bose-Einstein condensation, periodic potentials have lead to new and interesting physics. We are working towards Bose-Einstein condensation of photons in a periodic potential. Our starting point is a Bose-Einstein condensate of photons in a dye-filled microcavity. To introduce a periodic potential to our dye-filled microcavity, a photonic crystal is grown on one of the cavity mirrors by self-essembly of nanospheres.

Is a coherently driven microcavity-polariton system a superfluid?

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Experimental studies of microcavity-polaritons have reported phenomena which could be associated with superfluidity, such as reduced scattering [1], in coherently driven systems where the pump-only state is characterised by a gapped spectrum. However, a finite superfluid fraction, as defined by the difference in transverse and longitudinal responses, relies on the existence of a gapless spectrum [2]. Using Keldysh Green's function techniques, we calculate the longitudinal and transverse responses of the coherently pumped polariton system to gain an understanding of the nature of the experimentally observed effects.

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Molecular reconfiguration induced by ultrastrong coupling

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We discuss how (ultra-)strong coupling between organic molecules and microcavity photons can lead to a reconfiguration of the ground state of the molecules [1]. We have considered two aspects of these organic polaritons in detail: the effects of the rotational orientation and the vibrational modes of the molecule. In both cases we see that increasing the strength of the matter-light coupling leads to a reconfiguration of the molecular state, with a consequent signature in the absorption spectrum of the disordered system. Using these models we are able to shed light on the recent experimental results in which the size of the central peak in the absorption spectrum was found to vary with both the strength of the light-matter coupling and temperature[2,3].

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Calorimetry of a Bose-Einstein condensed photon gas

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In recent experimental work, we have precisely determined thermodynamic properties, for example heat content and specific heat, of a photon gas across Bose-Einstein criticality. The system consists of a two-dimensional photon gas in a dye microcavity that undergoes Bose-Einstein condensation, when the critical phase space density is reached. We are able to resolve a cusp singularity in the specific heat analogous to the λ-transition of liquid Helium.

Dissipative Two-Mode Tavis-Cummings Model with Time-Delayed Feedback Control

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We investigate the dynamics of a two-mode laser system by extending the two-mode Tavis-Cummings model with dissipative channels and incoherent pumping and by applying the mean-field approximation in the thermodynamic limit. To this end we analytically calculate up to four possible non-equilibrium steady states (fixed points) and determine the corresponding complex phase diagram. Various possible phases are distinguished by the actual number of fixed points and their stability. In addition, we apply three time-delayed Pyragas feedback control schemes. Depending on the time delay and the strength of the control term this can lead to the stabilization of unstable fixed points or to the selection of a particular cavity mode that is macroscopically occupied. We also introduce an additional thermal bath and address the issue of distinguishing between condensate-like or laser-like system states.

Bright sink-type localized states in exciton-polariton condensates

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The family of one-dimensional localized solutions to dissipative nonlinear equations includes a variety of objects such as sources, sinks, shocks (kinks), and pulses. These states are in general accompanied by nontrivial density currents, which are not necessarily related to the movement of the object itself. We investigate the existence and physical properties of sink-type solutions in non-resonantly pumped exciton-polariton condensates modeled by an open-dissipative Gross-Pitaevskii equation. While sinks possess density profiles similar to bright solitons, they are qualitatively different objects as they exist in the case of repulsive interactions and represent a heteroclinic solution. We show that sinks can be created in realistic systems with appropriately designed pumping profiles. We also conclude that in twodimensional configurations, due to the proliferation of vortices, sinks do not appear.

Spatiotemporal coherence of non-equilibrium photon condensates

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Thermalisation and Bose-Einstein condensation of photons in dye-filled microcavities are well-established phenomena, despite the dissipation inherent in the system. We have studied how the thermalisation is modified by inhomogeneous pumping [J. Marelic and R. A. Nyman, Phys. Rev. A, vol. 91, 033813 (2014)] which can be explained by tracking the molecular excitations as well as the photons [J. Keeling and P. Kirton, arXiv:1506.00280].

We have studied the coherence of photon condensates using an imaging Mach-Zehnder interferometer [J. Marelic, L. F. Zajiczek and R. A. Nyman, arXiv:1510.05562]. Our interferometer permits us to measure coherence as a function of both space and time, above and below condensation threshold pump power. We find that coherence is long range in both time and space above threshold, but short-range below threshold, consistent with thermal equilibrium at room temperature. Far above threshold, the condensate is no longer at equilibrium and is fragmented over non-degenerate, spatially-overlapping modes.

Phase ordering kinetics of a nonequilibrium exciton-polariton condensate

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We investigate the process of coarsening via annihilation of vortex-antivortex pairs, following the quench to the condensate phase in a nonresonantly pumped polariton system. We analyze in detail two distinct cases, corresponding to shorter and longer polariton lifetime. In the case of a short polariton lifetime, we find that the late-time dynamics is a clean example of universal phase ordering kinetics, characterized by scaling of correlation functions in time. The evolution of the characteristic length scale L(t) is the same as for the two-dimensional XY model, described by a power law with the dynamical exponent z=2 and a logarithmic correction. In contrast, in the case of a long polariton lifetime, we obtain the exponent z=1, which agrees with previous studies of conservative superfluids.

Coherence of a Bose-Einstein Condensed Light Field

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We have experimentally determined first- and second-order coherence properties of a photon Bose-Einstein condensate. The optical condensate is generated in a wavelength-sized dye cavity, with a photon dispersion that equals that of a twodimensional gas of trapped massive bosons [1,2]. Thermalization of the photon gas is reached in a number conserving way by repeated absorption re-emission cycles in the dye molecules. In the system the photo-excitable dye molecules act as a reservoir for the condensate particles, which allows to reach a regime with large "grand canonical" number fluctuations, of order of the total particle number [3-5]. The measured second-order coherence of the dye microcavity emission correspondingly vanishes, as in a thermal (lamp-type) source. To study the first-order coherence time of the condensate, we have examined the temporal interference signal of the photon Bose-Einstein condensate with a narrowband laser source acting as a phase reference [6]. On the other hand, the second-order autocorrelation function of the photon condensate has been obtained by employing a Hanbury-Brown Twiss experiment [5]. Our experimental data demonstrates spontaneous symmetry breaking of the condensate wavefunction and reveals a regime where the Bose-Einstein condensate is phase coherent despite strong photon bunching, in striking difference to the coherence properties of known Bose-Einstein condensed systems.

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The influence of optical material characteristics on strong coupling in organic semiconductors

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Realising applications which exploit strong exciton-photon coupling by using organic materials is a promising strategy since the high exciton binding energies in these materials allow for stable formation and condensation of polaritons at room temperature. However, the wide range of available materials calls for a systematic study as to which material properties are critical to achieving large coupling strengths.

The work presented here discusses fabrication and characterisation of metal-clad, optically probed organic microcavities containing different solution-processable organic materials. The investigated materials range from polymers to J-aggregates. First, we find that it is important to consider the optical anisotropy when designing organic polariton devices. Good agreement between the measured reflectance spectra and spectra predicted by transfer matrix calculations obtained only when this anisotropy was taken into account.

Second, the relatively simple structure of the studied samples allows us to test how the basic optical and excitonic properties of the tested materials influence the coupling strength. We find that the absorptivity of the organic materials is critical for observing large coupling strengths (a large Rabi splitting). Other effects such as different linewidths of the excitonic resonances or photoluminescence quantum yields were found to be much less important.

Phase fluctuations in a Condensate of Light

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We study the spreading of the probability distribution for the condensate phase in a condensate of light in a dye-filled optical micro cavity. To observe this phenomenon, we propose an interference experiment between the condensed photons and an external laser. We determine the average interference patterns, considering quantum and thermal fluctuations as well as dissipative effects due to the dye. Moreover, we show that a representative outcome of individual measurements can be obtained from a stochastic equation for the global phase of the condensate. Finally, we discuss the similarities with recent experiments which resemble our proposal.

Kibble-Zurek Mechanism In Driven Dissipative Systems

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Recently, there has been a lot of interest in understanding phase transitions in far from equilibrium driven dissipative systems. One of the relevant examples is the normal to superfluid transition of exciton-polaritons in semiconductor microcavities in two dimensions. Despite their driven and dissipative nature, recent works suggest that this system undergoes a Berezinskii-Kosterlitz-Thouless type of phase transition for experimentally relevant system sizes [3, 4]. One of the most interesting dynamical phenomenon which reveals universal aspects of critical many body systems is the so called Kibble-Zurek mechanism [1, 2]. In this work we address an open question whether Kibble-Zurek mechanism holds in the case of driven-dissipative systems such as that of polaritons by studying the dynamics of the topological defects, i.e. the vortices. We study the dynamics of the system beyond meand field through the truncated Wigner representation [5,6].

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Schedule

Condensates of Light Workshop, Chicheley Hall 2016

Weds 13th Jan

09:50	Introduction: Rob Nyman and Peter Kirton
10:00	Keynote: **Elisabeth Giacobino** Superfluid Light in a microcavity
10:50	*Break (25 min)*
11:15	Invited: **Natalia Berloff** Discrete vortex solitons in polariton lattices
11:50	Invited: **Alberto Amo** Stochastic polarisation oscillations of a polariton laser
12:25	Invited: **Iacopo Carusotto** Driven-dissipative and Conservative Fluids of Light
13:00	*Lunch*
14:30	Keynote: **Jason Fleischer** Four light-condensate weddings and a “funeral”
15:20	Invited: **Baruch Fischer** Classical laser light condensation phenomena
15:55	*Break (25 min)*
16:20	Invited: **Sebastian Diehl** Driven Markovian Quantum Criticality
16:55	Invited: **Michael Gullans** Thermalization of Photons in Strongly Driven Double Quantum Dot
17:30	Contributed: **Hannah Price** Synthetic dimensions in integrated photonics
17:55	Contributed: **Daniele Faccio** Superfluidity and superfluid instability in propagating nonlocal photon fluids
18:20	

Thu 14th Jan

09:00	Keynote: **Stéphane Kéna-Cohen** Table-top condensate physics with organic polaritons
09:50	Invited: **Rainer Mahrt** Bose-Einstein Condensation in a Polymer: Towards Quantum Simulation
10:25	Invited: **Alexis Askitopoulos** Polariton Simulators
11:00	*Break (25 min)*
11:25	Invited: **Marzena Szymanska** Non-equilibrium Phase Transition in a Two-Dimensional Dissipative-Driven Quantum Fluid
12:00	Invited: **David Snoke** Are microcavity polaritons much more strongly interacting than we thought?
12:35	Contributed: **Hamid Ohadi** A new spin for exciton-polariton condensates
13:00	*Lunch*
14:30	Keynote: **Martin Weitz** Bose-Einstein condensation of photons and grand canonical number statistics
15:20	Contributed: **Christoph Weiss** Grand-canonical condensate fluctuations in weakly interacting Bose-Einstein condensates of light
15:45	*Break (25 min)*
16:10	Contributed: **Nick Proukakis** Quenched Polariton Condensation Dynamics
16:35	Contributed: **Makoto Yamaguchi** Relationship of ordered coherent phenomena in semiconductor electron-hole-photon systems
17:00 To 19:00	Poster session

Fri 15th Jan

09:00	Invited: **Antonio Picozzi** Wave turbulence description of optical waves
09:35	Invited: **Gian-Luca Oppo** Vortex Turbulence and Rogue Waves in Laser Systems
10:10	Contributed: **Nataliya Bobrovska** Stability and spatial coherence of nonresonantly pumped exciton-polariton condensates and adiabatic approximation
10:35	*Break (25 min)*
11:00	Keynote: **Henk Stoof** The Sound of Light
11:50	Invited: **Jonathan Keeling** Spatial dynamics, thermalisation and breakdown of thermalisation in photon condensates
12:25	Invited: **Daniele Sanvitto** Formation and coherence of an extended polariton condensate
13:00	*Lunch*
14:30	*Finish*