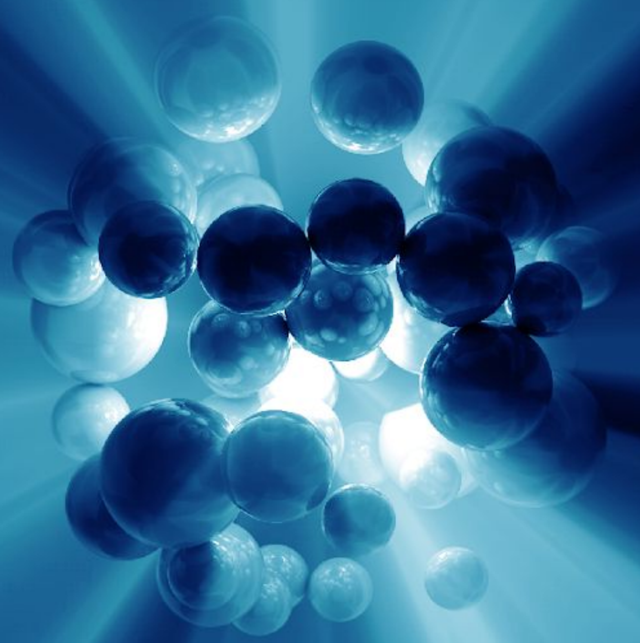
Complex Nanophotonics Science Camp

BRINGING TOGETHER EARLY CAREER SCIENTISTS TO BRIDGE NANOPHOTONICS, PLASMONICS, METAMATERIALS & BIOPHOTONICS OF COMPLEX MEDIA



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List of contributions

Keynote talks

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Anat Levin

Technion, Israel

Seeing deep inside scattering tissue using efficient, noise-robust wavefront shaping

Scattering limits our ability to see inside biological tissue, as light penetration is severely distorted by tissue components with varying refractive indices. One promising method to overcome scattering aberration is wavefront shaping. This technique involves placing a spatial light modulator (SLM) in the microscope's optical path to correct the wavefront emitted from a point deep within the tissue. The goal is to bring light photons from a single target point to a single sensor point, despite tissue aberrations. This technique has the potential to revolutionize tissue imaging by enabling high-SNR imaging deep within scattering biological targets. However, estimating wavefront-shaping modulations in practice is challenging, since the modulations must be estimated in real time, using non-invasive feedback, and under a low photon budget.

In the first part of this talk, I will discuss efforts to derive noise-robust score functions that can identify effective modulation corrections using non-invasive feedback. I will review previous approaches and introduce a new, simple, noise-robust method that uses confocal correction of both incoming and outgoing light with linear single-photon fluorescent excitation. We show that despite the fact that we are only measuring light outside the tissue and have no direct way to measure how well light has focused inside the tissue, maximizing the single-photon confocal intensity guarantees that we also focus all light into a spot inside the tissue.

Given a score function, estimating the desired modulation becomes an optimization problem. However, since the desired modulation depends on the unknown tissue structure, typical optimization strategies involve slow sequential scanning, where each modulation parameter is queried independently. In the second part of this talk, I will present a novel approach for rapid modulation optimization. This method leverages optical computing ideas and uses the optical system to directly measure the gradient of the score function, allowing simultaneous updates of all modulation parameters from a single measurement.

Andreas Tittl

LMU Munich

Photonic bound states in the continuum for ultrafast optical resonance control

Dielectric metasurfaces supporting photonic bound states in the continuum (BICs) offer an exceptional platform for light control and confinement, yet conventional implementations almost universally rely on static geometric symmetry breaking, inherently limiting dynamic applications. In this talk, I will present a departure from static designs by introducing resonance control mechanisms based on dynamic permittivity modulation and temporal symmetry breaking. Central to these approaches is the concept of permittivity-asymmetric quasi-BICs (**ε**-qBICs), which achieve resonance control by modulating material permittivity within a geometrically fixed unit cell. I will first discuss the theoretical framework of **ε**-qBICs, showing their equivalence to geometric asymmetry, followed by their experimental realization in the near-infrared using multi-material resonators. Extending this to dynamic systems, electrically reconfigurable **ε**-qBICs via environmental symmetry breaking can demonstrate robust resonance switching in the 10-20 millisecond range. Pushing into the ultrafast regime, I will describe the all-optical generation of **ε**-qBICs in featureless semiconductor films using transient permittivity gratings, enabling picosecond dynamics and spectrally selective enhancement of third-harmonic generation. Finally, I will introduce a new paradigm for all-optical resonance control based on temporal symmetry breaking in a "restored" symmetry-protected BIC (RSP-BIC): a system that is geometrically asymmetric but is engineered with cancelling dipoles to exhibit perfect photonic symmetry (i.e., a dark state). Selective ultrafast pumping instantaneously breaks this restored symmetry, granting sub-picosecond control over radiative loss for dynamic resonance creation, annihilation, broadening, and sharpening at will. Together, these concepts demonstrate a powerful shift from fixed geometric asymmetry to dynamic permittivity and ultrafast resonance control for active nanophotonics.

Roarke Horstmeyer

Duke University, USA

Parallelized optical sensing for next generation bioimaging

This talk presents about two ongoing research areas at the Computational Optics Lab at Duke University that develop and use new optical architectures for highly parallelized measurement and processing.

First, this talk will discuss a new format of computational microscope that is uses arrays of compact cameras to simultaneously capture many dozens of high-resolution, high-speed synchronized video streams. Presented applications of this new type of microscope within high-throughput bio-discovery include examining the dynamic behavior and morphology of small model organisms, cells, and organoids. The microscope architecture, termed a "multi-camera array microscope" (MCAM), contains up to 96 synchronized digital image sensors and associated lenses to capture gigapixel-scale snapshot measurements. Co-designed software allows users to quantitatively analyze captured imagery. Example results show how we can use the MCAM to 3D track dozens of freely swimming zebrafish, jointly track and measure T-cell phenotype and genotype at extremely high throughput, and study the unique temporal dynamics of cortical and cardiac organoids, among others.

Second, this talk will discuss new methods to improve a technique termed diffuse correlation spectroscopy (DCS), which is a label-free, non-invasive optical method to measure blood flow deep within tissue, To date, the signal-to-noise ratio (SNR) of DCS has limited its ability to non-invasively measure cerebral blow flow beneath the skull in adults. Over the past several years, our team has developed methods for parallelized DCS (PDCS), which improves the SNR of DCS by a factor of ~500X to now non-invasively measure cerebral blood flow in healthy adults. Our setup employs an innovative sensor with hundreds of thousands single photon avalanche diodes (SPAD) in a 500x500 array to measure a rapidly decorrelating speckle field emerging from the scalp. This talk will discuss how PDCS works and show results on several large (20+ subject) neuro-measurement trials.

Hui Cao

Yale University, USA

From taming to harnessing multiple scattering in disordered media

Light propagates diffusively through disordered media, including biological tissue, clouds, and paint, due to multiple scattering. Recent advances in optical wavefront shaping have transformed our ability to control coherent light transport in such complex environments. By overcoming the diffusion limit, we enhance light transmission, reflection, and energy deposition in multiple-scattering systems through spatial wavefront engineering. Extending this control to both spatial and spectral degrees of freedom further enables the manipulation of short pulse propagation through diffusive media.

Conversely, rather than mitigating the effects of multiple scattering, we can harness them as a computational resource. We leverage multiple light scattering inside a disordered cavity to perform nonlinear optical encoding and computation. The passive nonlinear optical transformations through multiple scattering enable rapid and energy-efficient information processing. High-order structural nonlinearity fosters the generation of low-dimensional latent feature space and facilitates strong data compression. We demonstrate high computing performances across tasks from classification, image reconstruction, keypoint detection and object detection, with the optically compressed output fed into a digital decoder.

Amanda Foust

Imperial College London, UK

Learning to see through scattering tissue: physics informed deep learning for high-speed volumetric imaging

Optical imaging often involves difficult trade-offs: we can image with high spatial precision, across large three-dimensional volumes, or at high speed, but rarely all at once. This trade-off is especially severe in biological tissue, where scattering scrambles light and makes it difficult to recover clean images from deep within the sample.

In this lecture, I will describe our efforts to combine optics, computational imaging and deep learning to address this challenge. The biological motivation is to record the electrical and chemical activity of many neurons at high speed, in three dimensions, inside living brain tissue. The optical challenge is that two-photon microscopy provides excellent image quality and robustness to scattering, but is limited by sequential scanning. Light-field microscopy, by contrast, captures an entire volume in a single camera exposure, but the resulting images degrade rapidly in scattering tissue.

Our approach uses the strengths of both methods. We train deep neural networks using paired two-photon and light-field images, so that high-quality but slower measurements can teach the network how to interpret fast but scattering-corrupted light-field data. The deep learning is physics-informed: rather than treating reconstruction as a black-box mapping from image to volume, the network embeds a wave-optics model of light-field image formation within an unrolled, sparsity-promoting reconstruction.

This framework enables high-throughput volumetric imaging of neural activity, reducing signal mixing between neighbouring neurons and improving reconstruction quality compared with conventional light-field processing. I will show examples of calcium activity recorded from tens of neurons across a volume at 100 volumes per second, and voltage activity recorded in vivo at nearly 1000 volumes per second.

More broadly, this lecture will use neural imaging as a case study in a question relevant across complex nanophotonics: how can physical models, prior information and machine learning be combined to recover meaningful signals from measurements that are fast, compressed and distorted by complex media?

Caroline Muellenbroich

University of Glasgow, UK

From photons to physiology: high-speed lifetime sensing in beating heart cells

Excitation–contraction coupling in cardiomyocytes is a multi-millisecond cascade of membrane depolarisation and cytosolic Ca^{2+} flux, and resolving it optically with a contact-free, motion-immune readout has been a longstanding instrumentation challenge: standard intensity-based voltage and calcium indicators are confounded by sample motion, uneven dye loading, and photobleaching, all of which alter detected photon counts independently of the underlying physiology. Fluorescence lifetime is largely insensitive to these variables, since it is set by the excited-state decay rate rather than by photon flux, but achieving lifetime imaging at the frame rates needed to track an action potential has required dedicated SPAD hardware. Here, I will present a gated SPAD-array (SwissSPAD3) platform performing synchronous time-integrated and time-gated dual-modality acquisition at up to 192 fps over a wide field of view, sufficient to recover single-shot, per-pixel photon-weighted lifetime estimates without temporal averaging across beats. Applied to hiPSC-derived cardiomyocyte monolayers, this yields spatially resolved, motion-decoupled voltage and calcium maps and reveals cell-to-cell heterogeneity and previously unreported lifetime dynamics during late-phase repolarisation.

Even at 200 fps, however, full-frame FLIM falls short of the kilohertz rates needed to resolve the fastest features of the cardiac cycle, such as the action potential upstroke. We recover this bandwidth by deliberately discarding spatial information, aggregating photon arrival times across all 1024 channels of a parallel-TCSPC SPAD array (PF32, Photon Force Ltd) into a single global decay histogram per frame rather than forming a spatial image — obtaining sufficient photon statistics for full-curve lifetime fits at ≥1 kHz, and reframing FLIM as a high-bandwidth photometric measurement rather than an imaging modality. Applied to spontaneously contracting hiPSC-CM monolayers, this yields concurrent intensity and lifetime traces through the calcium transient, with intensity providing high-SNR, high-bandwidth tracking and lifetime acting as a motion-robust, calibratable reference. This validates massively parallel TCSPC as a route to kilohertz-rate, calibration-ready lifetime photometry, with direct applicability beyond cardiomyocytes to other excitable systems such as neurons.

Tom Siday

University of Birmingham, UK

Subcycle terahertz microscopy: from the micro- to the atomic scale

Measuring light-matter interactions at the shortest possible length and timescales has been a long-standing goal across condensed matter physics, optics, and ultrafast science. By exploiting evanescent fields confined to nanometre-scale structures, near-field microscopy has made it possible to probe optical responses far below the diffraction limit, while ultrafast implementations have added femtosecond and even subcycle temporal sensitivity. In this talk, I will first discuss recent applications of terahertz near-field microscopy for probing ultrafast dynamics in functional and quantum materials, with particular emphasis on how field-resolved nanospectroscopy can reveal non-equilibrium charge motion and transient transport on deeply sub-wavelength length scales.

I will then discuss a fundamentally new paradigm for ultrafast microscopythat leverages strong atomic nonlinearities hidden within optical near-fields. In conventional near-field microscopy, the achievable spatial resolution is ultimately constrained by the finite size of the probe apex. By contrast, when the tip-sample separation is controlled on the scale of atomic wavefunctions and driven by intense THz transients, an additional non-classical optical response emerges that is localized to atomic dimensions. This response arises from electromagnetic radiation emitted by ultrafast tunnelling currents driven by the instantaneous THz electric field. The resulting mechanism, termed near-field optical tunnelling emission (NOTE), provides simultaneous atomic-scale spatial resolution and subcycle temporal resolution for the first time.

A key signature of NOTE is that the emitted field is phase shifted by approximately $\pi/2$ with respect to the conventional near-field response, reflecting its origin in the ultrafast motion of tunnelling electrons. This phase-resolved optical signal enables direct sampling of tunnelling-current transients rather than inferring them indirectly from time-integrated rectified currents. In this sense, NOTE goes beyond lightwave-driven scanning tunnelling microscopy by providing a model-independent, all-optical route to resolving subcycle electronic motion. Recent work has shown that this emergent response is confined on atomic length scales, can reveal defects that are nearly invisible in conventional topographic channels, and can directly clock ultrafast transport in semiconducting van der Waals materials. In particular, measurements on monolayer and trilayer WSe_2 demonstrate that NOTE can expose transient tunnelling pathways and field-driven carrier motion that remain hidden to steady-state or time-integrated probes, including transport signatures appearing even within the nominal bandgap.

These results establish NOTE as a new platform for ultrafast microscopy at the ultimate spatio-temporal limits. More broadly, they open a route to subcycle videography of atomic-scale quantum dynamics and create new opportunities for studying strong-field and non-equilibrium phenomena in conductive and insulating quantum materials alike.

Georgia Papadakis

ICFO, Spain

Tailoring thermal radiation for lighting and energy

Thermal photonics explores strategies for harnessing and controlling thermal radiation and has emerged over the past two decades as a close relative of classical nanophotonics. The same concepts used to tailor light–matter interactions and light scattering in complex media—such as metamaterials, metasurfaces, and photonic crystals—can be leveraged to control the absorption of thermal radiation, which peaks in the mid-infrared according to Wien's law, by micro- and nanostructured materials. By virtue of Kirchhoff's law of thermal radiation, these approaches can also be used to engineer thermal emitters with spectral and spatial properties that depart significantly from those of an incoherent blackbody.

In this talk, I will introduce the fundamentals of thermal radiation and review the blackbody limit and Kirchhoff's law as cornerstones of thermal photonics. I will present scenarios in which the thermal radiation can attain directional, chiral, and actively tunable characteristics. This becomes possible by leveraging interference effects, twisted low-dimensional crystals, and actively tunable materials (e.g. transparent conductive oxides, phase-change materials, and liquid crystals). These advances can address key technological gaps in mid-infrared lighting and other optical components, enabling new paradigms for energy and light generation based on engineered incandescence.

Sebastien Popoff

ESPCI Paris, France

Memory effects in multimode fibers

The ideal geometry of a perfect fiber leads to symmetries that can be exploited for imaging. This manifests itself through the existence of memory effects, i.e., operations that have the same effect on the output field whether applied before or after propagation through the fiber (they commute with the propagation operator). Analogously to scattering media, these effects can be harnessed for imaging even without access to the distal facet. However, small distortions and imperfections of the fiber tend to destroy these effects. Moreover, the fiber geometry admits an obvious transformation that yields a memory effect: rotation. Yet this transformation lacks radial information, limiting its utility for imaging. We present a new framework for generating and exploiting random memory-effect operators that harness the orbital angular momentum of the fiber modes for image reconstruction.

Iñigo Liberal

UPNA, Spain

Synthetically rotating crystals

The interaction of light with rotating bodies has traditionally been restricted to rotation frequencies far below optical frequencies. In our talk, we will discuss synthetically rotating crystals —spatiotemporal modulations that emulate the rotation of an anisotropic crystal and enable access to much higher effective rotation frequencies. These modulations fundamentally alter the symmetries of the electromagnetic field, breaking both temporal and rotational invariance while preserving a combined spatiotemporal rotational symmetry. This symmetry leads to the conservation of a quantity that couples energy and spin angular momentum (SAM). When optical pulses scatter from synthetically rotating crystals, they acquire a spatiotemporal structure characterized by intrapulse variations of SAM. In the frequency domain, the response exhibits sidebands with locked frequency and SAM content, as well as transitions to negative-frequency sidebands when the rotation frequency is sufficiently large. These findings reveal qualitatively new regimes of light–matter interaction that become accessible through synthetic rotations.

Tom Vettenburg

University of Dundee, UK

Phase-contrast microscopy from scattered speckle

Biology's dark ages ended with the advent of the microscope. Specifically, Zernike's invention of the phase contrast microscope in 1934 facilitated the study of thin, transparent living microorganisms. Although phase contrast microscopy has turned into the work horse of many life scientists, light-scattering scrambles its phase and hampers the study of larger living organisms. Conventional wavefront shaping and adaptive optics are limited by the optical memory effect. Here, we demonstrate how phase contrast can be recovered directly from the speckle-field scattered by an optically thick lipid layer.

Dorian Bouchet

Université Grenoble Alpes, France

Scanning near-field microscopy with resonant probes: from quantum emitters to acoustic bubbles

Scanning near-field optical microscopy is a powerful tool for investigating light--matter interactions beyond the diffraction limit. In these techniques, the spatial resolution is determined by the size of a local probe rather than by the wavelength, enabling super-resolved imaging. In optics, quantum emitters are particularly attractive probes because of their nanometric dimensions and their ability to characterize the local photonic environment through fluorescence lifetime measurements. In this talk, we will show how this idea can be transposed from optics to acoustics. To achieve super-resolved acoustic imaging underwater, air bubbles can act as local probes, playing a role analogous to that of quantum emitters in optical microscopy owing to their subwavelength size and resonant behavior. At first sight, however, such an approach may appear impractical, as controlling and scanning a free air bubble in water seems a rather difficult task. Experimentally, we overcome this challenge by trapping the bubble inside a miniature cage fabricated by 3D printing. By scanning this caged bubble in the vicinity of structured samples and by monitoring its acoustic response, we reconstruct images with a spatial resolution that is two orders of magnitude smaller than the acoustic wavelength. These results illustrate that resonant probes can be used for near-field imaging across different wave systems, from photons to sound waves.

Dennis Scheidt

ICFO, Spain

Digital Holographic Microscopy of Dense Brain Tissue Samples

with Alejandro V. Arzola, Fabian Gasper, Katrin Amunts, Markus Axer

Understanding brain function and behavior requires detailed insight into microscopic neuronal architecture and densely packed nerve fiber networks. Optical imaging provides a valuable compromise between acquisition speed, data volume, and spatial resolution. Digital holographic microscopy (DHM) has recently gained increasing relevance in biological imaging, but its application remains largely restricted to optically thin samples with minimal scattering and wavefront distortion. Here, we apply in-line DHM with double-sideband filtering to 100 μm thick brain tissue sections to recover the complex optical field, including amplitude and phase, from both unstained and stained samples. Double-sideband filtering is used during hologram acquisition to suppress the virtual twin image by analogue filtering in the Fourier plane. From a single hologram, amplitude and phase distributions are reconstructed and further processed using digital phase-contrast and dark-field filtering to enhance qualitative information on cellular and vascular tissue components. In addition, digital propagation of the reconstructed light field is used to probe the three-dimensional organization of the tissue. Our approach resolves the three-dimensional arrangement of unstained crossing fiber bundles and enables depth-resolved localization of stained cells from a single hologram by refractive-index matching between tissue and mounting medium. These findings demonstrate that in-line holography is a promising method for 3D analysis of labeled and unlabeled thick brain tissue. They further establish complex light-matter interactions in heterogeneous biological tissue as an accessible field of investigation.

Ernesto Pini

Istituto Nazionale di Ricerca Metrologica, Italy

Anisotropic light scattering in bio-inspired and biobased photonic materials

with Jeremy Werle, Vincenzo Spinoso, Ruggero Rossi, Diederik S. Wiersma, Lorenzo Pattelli

Understanding light transport in scattering media with an anisotropic structure is a fundamental challenge with direct implications for the design of high-performance optical materials. The scales of the Cyphochilus white beetle represent a compelling model system due to the exceptional reflectance efficiency of its disordered anisotropic internal structure: despite extensive study, reports on the degree of optical anisotropy of this remarkable biological structure remains inconsistent, particularly within the plane of the scales. In this work, we address this gap using time- and space-resolved transient imaging with sub-picosecond resolution, which allows us to fully resolve the spatiotemporal distribution of transmitted intensity and characterize light transport along all spatial directions. These measurements are combined with FDTD simulations and a newly developed anisotropic Monte Carlo model, providing a comprehensive and quantitatively consistent picture of anisotropic transport in this system. The insights gained on the role of structural anisotropy in governing total reflectivity are then applied to functional anisotropic materials. Delignified and densified wood serves as a primary case study: bleaching suppresses lignin-related absorption, while mechanical densification is expected to enhance total solar reflectance and thereby improve passive radiative cooling performance. Beyond wood, we extend this framework to another prominent class of fibrous anisotropic media such as electrospun membrane, with the broader aim of establishing anisotropy as a design parameter for high-reflectance sustainable materials.

Jérôme Don Jayamanne

University of Exeter, UK

Self-configuring linear diffractive optical networks for adaptive multimodal imaging through complex media

with José C. A. Rocha, Unė G. Būtaitė, J. Carpenter and D. B. Phillips

When light propagates through complex media - such as biological tissue, turbulent air, or multimode optical fibre - the wavefront can be highly distorted, scrambling the spatial information it carries. This scrambling corrupts images and limits data transmission in these environments. Wavefront shaping is a versatile technique capable of reversing such distortions: the wavefront of a single spatial mode of light interacting with the complex medium is reshaped (typically using a spatial light modulator) to turn it back into its original state, thus 'undoing' the medium's effects [1,2]. However, uncorrelated spatial modes require different correction wavefront modulations, which cannot be efficiently multiplexed together onto a single-phase modulating surface. Thus, current wavefront shaping methods are often sequential in nature, dynamically correcting each spatial mode one after the other - and as such are yet to reach the full information capacity of data transmission through complex media.

In order to efficiently unscramble multiple uncorrelated modes at once, a 3D multi-modal beam shaping architecture is required [3,4,5]. In this work we explore how a self-optimising linear diffractive optical network can be used to tackle this problem. Our network consists of a cascade of phase modulating surfaces, each separated by free-space propagation – an optical system known as a multi-plane light converter [6,7,8]. To configure our network, we experimentally demonstrate a new technique we refer to as 'multi-plane wavefront shaping' which jointly optimises the phase profile of all phase planes in the network in-situ, to unscramble multiple different spatial modes simultaneously [4,9].

In our system there are tens of thousands of independently tuneable parameters to configure, so we devise a bespoke algorithm based on the transmission matrix formalism [2], that relies on light solely propagating forward through the device [9]. System convergence is accelerated to a timescale of minutes by constructing the network from a recently developed fast-switching piston-action MEMS phase light modulator operating at kHz rates [10,11] – with scope for substantial reductions in optimization time in the future. Our multi-plane wavefront shaping technique represents a versatile 'model-free' approach to the in-situ training of high-speed free-space linear diffractive optical networks [12], in this case enabling them to begin to adaptively reverse the scattering effects of transmissive complex media they are coupled to.

[1] Vellekoop et al. "Focusing coherent light through opaque strongly scattering media." Optics letters 32, no. 16 (2007): 2309-2311.

[2] Popoff et al. "Measuring the Transmission Matrix in Optics: An Approach to the Study and Control of Light Propagation in Disordered Media." Physical Review Letters 104, 10 (2010): 100601.
[3] Būtaitė et al. "How to build the “optical inverse” of a multimode fibre." Intelligent Computing (2022).
[4] Kupianskyi et al. "All-optically untangling light propagation through multimode fibers." Optica 11, no. 1 (2024): 101-112.
[5] SeyedinNavadeh et al. "Determining the optimal communication channels of arbitrary optical systems using integrated photonic processors." Nature Photonics 18, no. 2 (2024): 149-155.
[6] Labroille et al. "Efficient and mode selective spatial mode multiplexer based on multi-plane light conversion." Optics Express 22, no. 13 (2014): 15599-15607.
[7] Fontaine et al. "Laguerre-Gaussian mode sorter." Nature Communications 10, no. 1 (2019): 1865.
[8] Lin et al. "All-optical machine learning using diffractive deep neural networks." Science 361, no. 6406 (2018): 1004-1008.
[9] Rocha et al. "Self-configuring high-speed multi-plane light conversion." Nature Communications 17(73) (2026).
[10] Byrum et al. "Optimizing a micro-electro-mechanical system (MEMS) based phase-only light modulator (plm) for improved system performance." In Emerging Digital Micromirror Device Based Systems and Applications XVI, vol. 12900, SPIE, 2024.
[11] Rocha et al. "Fast and light-efficient wavefront shaping with a MEMS phase-only light modulator." Optics Express 32, no. 24 (2024): 43300-43314.
[12] Momeniet al. "Training of physical neural networks." Nature 645, no. 8079 (2025): 53-61.

Marcus Prado

ESPCI Paris, France

Pseudogaps and localization of light in correlated disordered networks

The suppression of diffusive transport due to destructive interference, known as Anderson localization, is a ubiquitous wave phenomenon in strongly disordered systems. However, localization of electromagnetic waves may be prevented by its vector nature, as near-field effects open new channels of transport that become efficient in dense media. Therefore, the usual strategy of leveraging strong scattering samples by randomly increasing the density of particles breaks down. A viable alternative is to consider disordered media with spatial correlations. Despite their lack of periodicity, they are known to support photonic band gaps, within which localized modes are expected to form.

In this work, we investigate how correlated disordered arrangements of resonators circumvent fundamental limitations in achieving localization of light. We consider networks constructed from stealthy hyperuniform patterns, which interpolate between fully random and periodic structures. Our coupled-dipoles simulations show that strongly correlated but disordered networks support pseudogaps and localized modes at high densities, within the regime that would otherwise be dominated by near-field effects. Moreover, we characterize the phase transition separating extended from localized states within the gap found for three-dimensional structures.

Our work contributes to the understanding of the physical mechanisms at the origin of photonic band gaps in amorphous media, and represents one step further towards the full apprehension of the continuous transition between fully uncorrelated and periodic systems.

Lille Børresen

University of Cambridge, UK

Collective emission from coupled dipoles in plasmonic nanocavities

with Rakesh Arul, Jeremy J Baumberg

Plasmonic structures can concentrate light into extremely small mode volumes, creating intense optical 'hot-spots' which massively enhance luminescence from individual molecules [1]. Collective emission is typically associated with low temperatures and well-isolated quantum systems. Here, similar behaviour is developed in dye molecules embedded within densely coupled plasmonic nanocavities at room temperature and in ambient conditions.

Self-assembled monolayer aggregate gold nanoparticle films form sub-nanometre gaps defined by molecular scaffolds [2,3], producing extreme optical confinement within highly uniform cavities. These nanocavities host molecular emitters whilst the close-packed geometry enables interactions between neighbouring cavities across the array. Organic dye molecules within the hot-spots access significant dipole-dipole coupling in such structures.

With increasing excitation power, the emission departs from conventional photoluminescence. A pronounced non-linear power dependence emerges, followed by a distinct change in the spatial distribution of the emitted light [4]. Emission extends beyond the region defined by the pump profile, indicating the onset of collective behaviour mediated by coupling between nanocavities. Spatially resolved photoluminescence measurements help distinguish the roles of local field enhancement, dipole-dipole coupling and structural disorder. Different dye species exhibit distinct power scaling and spatial emission profiles within the same nanocavity architecture, reflecting the influence of their intrinsic photophysics on the collective response. Together these approaches allow the conditions for the emergence of correlated emission to be systematically mapped.

The simplicity of the self-assembled architecture makes it a powerful platform for studying interacting dipoles in extreme electromagnetic confinement. By varying cavity geometry, emitter density, and dipole strength independently, the boundary between enhanced spontaneous emission and genuinely collective regimes can be defined [5]. This work provides a controllable route to exploring dipolar synchronisation and collective emission in extreme electromagnetic environments beyond the conventional good-cavity limit.

[1] Nature 535, 127 (2016); R. Chikkaraddy et al., "Single-molecule strong coupling at room temperature in plasmonic nanocavities,"
[2] ACS Sensors 8, 2879 (2023); D.-B. Grys, M. Niihori, R. Arul, et al., "Controlling Atomic-

Scale Restructuring and Cleaning of Gold Nanogap Multilayers for SERS”
[3] Nature Comm. 15, 2022 (2024); S. Sibug-Torres et al., “In situ electrochemical regeneration of nanogap hotspots for continuously reusable ultrathin SERS sensors”
[4] R. Arul, P. Fowler-Wright, L. Børresen, et al., “Coherent room-temperature dipole synchronization in nanocavity sheets,” submitted (2026).
[5] L. Børresen, R. Arul, J.J. Baumberg, “Collective emission from coupled plasmonic nanocavities” submitted (2026).

Ishita Jena

University of Birmingham, UK

Externally driven quantum dynamics in plasmonic nanocavities

with Angus Crookes, Ben Yuen, Angela Demetriadou

Plasmonic nanocavities facilitate strong light-matter interactions due to their ability to extremely confine electromagnetic fields into subwavelength volumes. The field confinement arises from the excitation of plasmons formed by driving the free electrons of the surface of a metal with external electromagnetic fields. This phenomenon has led to several advances in spectroscopy, non-linear optics and sensing. In particular, the nanoparticle-on-mirror (NPoM) configuration formed by placing a nanoparticle above a metallic film and separated by a dielectric spacer of just a few nanometers, has demonstrated strong coupling with a single molecule even at room temperatures. It was recently shown that such nanocavities hosting multiple QEs are promising candidates to generate subradiant entangled states at ambient conditions, and the high radiative and Ohmic plasmonic losses in these systems enable the generation of the entangled states. However, the system needs to be suitably prepared for the entangled states to emerge, which is experimentally difficult when two or more QEs reside in the same plasmonic nanocavity due to the very close proximity of the QEs of just a few nanometers. Additionally, such systems need to be externally excited to prepare them for generating subradiant states which is not understood very well.

In this work, we first studied the dynamics of a QE embedded in a nanoplasmonic system, where the cavity interacts with an external illumination. Ohmic and radiative losses of the plasmonic system are taken into account with the Lindblad master equation (in the Markov approximation). After identifying the conditions for ambient excitation of the QE, we design a nanoplasmonic system composed of two coupled NPoM cavities, each hosting a single QE. The two nanocavities can be separated by several micrometers and coupled with each other via propagating surface plasmon polaritons (SPPs) supported on the flat metallic surface. Since the nanocavity separation is at the micrometer scale, each nanocavity can be selectively excited, therefore initializing only one QE at an excited state as desired.

We start with a single mode plasmonic nanocavity of radius 40 nm and facet width 16.6 nm assembled on a gold mirror hosting. The nanoparticle and the mirror are separated by a dielectric spacer of refractive index 2.5 and thickness 1 nm. The NPoM hosts a QE in its nanogap. We use an open quantum system formalism to account accurately for the Ohmic and radiative loss channels present in the plasmonic system. When the nanocavity is illuminated with an external pulse, we see the emergence of two peaks corresponding to the vacuum Rabi splitting for the upper and lower polariton states, as the central pulse frequency is varied. To further populate the polariton states, we keep the pulse frequency resonant with either of them and increase the pump strength. However, to sustain the population of the polaritons despite the losses, the pulse length should be shorter than the decay scale of the radiative and Ohmic losses of the nanocavity. Thus, the pulse amplitude and envelope can be engineered to determine the final state of the system. We also report results when our system is subjected to pulses of varying temporal shapes. We find that pump fluence which is proportional to the area of the pulse, determines the population of the polaritons, while the phase accumulated during the pulse period determines the Rabi oscillation amplitude between the QE and the plasmonic cavity. In addition, we also use broadband chirped pulse whose frequency varies linearly in time. For a positive chirp, the instantaneous frequency of the pump crosses the lower polariton first and the upper polariton later. So starting from ground state, the pulse first populates the lower dressed state and then the upper one as its frequency sweeps through the two resonances. We find that the delay between the maxima of the two polariton populations is approximately set by the resonance crossing time of the chirped pulse. We also report the influence of the chirped pulse strength on the dynamics of our plasmonic system.

Our new plasmonic system consists of two spherical gold nanoparticles assembled on a gold mirror and each one hosting a QE in its nanogap. We find that the propagating SPPs launched by each nanocavity interfere with each other either constructively or destructively, depending on the separation between the two nanocavities, leading to bonding and anti-bonding modes. We also find that the frequency splitting between the bonding and anti-bonding modes depends on the separation distance between the nanocavities and is also proportional to the propagating SPP field overlap from each nanocavity, demonstrating the destructive and constructive interferences. The quantum dynamics of the coupled system show damped oscillations in the populations of the plasmonic modes and the QE. The population transfer from the initially excited QE to the QE hosted by the coupled NPoM closely follows the variation seen in the different SPP interaction regimes, implying that the system dynamics is dependent on whether the second nanocavity is positioned at a maxima or minima of the electric field overlap. We also report on how one can customize the external pulsed excitation of the two nanocavities to engineer long-lived entangled states.

In conclusion, we report results on the driven quantum dynamics of a two-level QE strongly coupled to a localized plasmonic mode and subjected to time dependent external pulses of various durations, strengths and shapes for both broadband and single frequency pulses, demonstrating that pulse shaping can play a pivotal role in coherent control and quantum state preparation. Further, in order to generate subradiant entangled states from suitably initialized QEs, we design a new nanoplasmonic system of coupled NPoMs interacting through SPPs on a gold surface. We show that the two nanocavities are coupled even if they are separated by several micrometers from each other, due to the long range of propagating SPPs. We show that the interaction between the two nanocavities leads to bonding and anti-bonding modes that emerge from constructive and destructive interaction between the two nanocavities. This coupling between the two nanocavities directly impacts the quantum dynamics of the system, while the configuration of the system allows us to separately excite each NPoM nanocavity, paving the way for the generation of subradiant entanglement and the engineering of quantum states with nanoplasmonics at room temperature.

Antoine Azéma

Université de Toulouse, France

Holistic design of Huygens’metasurfaces using automatic differentiation

with Dalin Soun, Jonas Muller, Guilhem Larrieu, Aurélien Cuche and Peter R. Wiecha

Metasurfaces (periodic arrays of nanostructures with subwavelength spacing) can be engineered to form metalenses, which offer a compact alternative to bulky glass lenses. Conventional metalenses often rely on high-aspect-ratio nanopillars, where weak optical interactions between neighbors allow periodic boundary conditions to be used for lookup table generation [1]. While these nanopillar-based metalenses achieve high diffraction efficiency, Huygens sources promise nearly lossless performance by leveraging scatterers with balanced electric and magnetic dipole resonances that scatter light purely forward. Flat silicon cylinders have emerged as promising nanostructures for Huygens metasurfaces, enabling full 2π phase control through diameter tuning [2]. However, mutual coupling between neighboring structures disrupts dipole modes, degrading optical performance [1]. We demonstrate that holistic optimization, accounting for interactions with distant neighbors, significantly improves performance. Although the results remain below perfect transmission, this approach outperforms traditional lookup table methods and enables metalenses that focus light into arbitrary shapes, not just a single focal point.
To accelerate design, we developed an automatic differentiation framework integrated into torchGDM [3], a PyTorch-based implementation of the Green’s Dyadic Method. This toolkit models silicon discs using effective polarizability models and scales to large systems via moving windows with an effective interaction range. Fabricated samples, produced via electron-beam lithography and reactive ion etching, experimentally confirm the optimizations' validity.

[1] Gigli, C., et al., Laser & Photonics Reviews, Vol. 15, 2000448 (2021).
[2] Decker, M., et al., 2015 Advanced Optical Materials, Vol. 3, 813–820 (2015).
[3] Ponomareva, S., et al., SciPost Physics Codebases , 060 (2025).

Leandro Risso Venâncio

The University of Queensland, Australia, & University of Exeter, UK

A simple and controllable nonlinear optical encoding architecture via second-order Born interactions

with M. Mounaix, and J. Bertolotti

Nonlinear mappings lie at the core of modern machine learning models and underpin their success in highly complex tasks. In optical neural networks (ONNs), nonlinearities are traditionally generated through higher-order light–matter interactions in specific materials. However, nonlinear encoding of information can also be achieved through purely linear processes by exploiting the recurrence of the Born series in the multiple scattering regime.

This form of nonlinearity, referred to as structural nonlinearity, has previously been explored in the training of ONNs for image-based tasks using an Integrating Sphere and a Digital Micromirror Device (DMD). Nevertheless, such systems are highly sensitive to environmental conditions, which limit their scalability. In addition, precisely engineering a desired nonlinear transformation in these platforms remains a practical challenge.

In this work, we propose a controllable and experimentally simple optical arrangement capable of encoding information up to the second order of the Born series using a single DMD. In this configuration, linear and nonlinear optical encodings are generated simultaneously, enabling control over the degree of nonlinearity in the resulting transformation. We demonstrate the advantage of nonlinear over linear encoding by training optical reservoir models on chaotic systems (Mackey-Glass time series) for multi-step forecasting, significantly improving the average Normalized Mean Squared Error (NMSE) loss up to approximately 50% in short term predictions. This method contributes towards the development of stable and controllable optical nonlinear functions that are straightforward to implement.

Daria Panova

King's College London, UK

Hybrid conjugated polymer-metal nanostructures for plasmon-assisted photocatalysis

with Brian Tam, Anton Uzunoff, Miao Zhao, Diptiranjan Paital, Yoel Negrin-Montecelo, Andreas Kafizas, Aliaksandra Rakovich

Over the last few decades, conjugated polymers have proven to be a promising class of materials for various applications, including photocatalysis, owing to their non-toxic composition and excellent physicochemical properties. Likewise, plasmonic metal nanoparticles have attracted significant attention as light energy concentrators at the nanoscale. This study investigates hybrid conjugated polymer–metal nanoparticle systems designed to enhance photoelectrochemical water splitting by lowering photochemical energy barriers and maximizing the system's light-harvesting capabilities.

A systematic evaluation of thin-film photocathodes comprising the conjugated polymers PTB7, CN-PPV and F8BT was conducted. Donor-acceptor blends of PTB7 and F8BT were further formulated at various ratios in order to study charge-transfer interactions within bulk heterojunction architectures. To assess plasmon-driven efficiency gains, PTB7@Au photocathodes were engineered, incorporating spherical gold nanoparticles and gold nanorods. Furthermore, the role of dissolved oxygen was analysed to establish its impact on photocurrent generation, the oxygen reduction reaction contribution, and the formation of reactive oxygen species. By detailing the fundamental photophysical processes within these systems, this research provides valuable insights into the emerging field of plasmonic catalysis and directly supports the UK's drive towards environmental sustainability.

Leonardo Biancorosso

Imperial College, UK

Phonon contributions to plasmon decay and hot carrier generation in gold nanoparticles

with Damian Contant, Ivana Savic and Johannes Lischner

Plasmonic metal nanoparticles have driven advances in photocatalysis, sensing, and plasmon-enhanced spectroscopies over the past two decades. Realizing their full potential requires accurate theoretical frameworks capable of predicting optical and electronic response across diverse conditions. While computational methods have matured considerably in describing plasmonic behaviour, the microscopic mechanisms governing hot carrier generation remain incompletely understood.

Hot carriers emerge as a plasmonic excitation relaxes. Landau damping is the dominant and most studied relaxation channel. However, vibration-assisted intra-band transitions represent an equally important yet computationally neglected decay mechanism. Electron-phonon scattering on timescales of 100 fs to 1 ps critically shapes the final energy distribution of extractable carriers, and experimental evidence shows that increasing operating temperature enhances hot carrier generation through stronger phonon coupling — indicating that atomic vibrations actively participate in carrier generation rather than acting as a mere dissipation channel.

In this work, we present a workflow that explicitly incorporates structural disorder and thermal motion. Molecular dynamics simulations of gold nanoparticles using Machine Learning Interatomic Potentials accurately capture vibrational properties at finite temperature. Hot carrier generation rates are then computed directly on selected snapshots, allowing us to disentangle electron-electron and electron-phonon contributions to plasmon decay in a physically transparent and computationally tractable framework.

Jordan Edwards

Imperial College, UK

Ab initio theory of chemical interface damping of surface plasmons

with Johannes Lischner, Andrei Stefancu, Wenxuan Tang, Ming Fu, Ross Schofield, Toby Millard, Rupert Oulton, Pilar Carro, Naomi Halas, Peter Nordlander, and Emiliano Cortes

Metallic nanostructures exhibit fascinating optical properties made possible by surface plasmons, which are collective oscillations of the conduction electrons in the metal. The properties of surface plasmons can be modified by functionalising the nanostructure with molecular adsorbates. For example, a significant reduction in the surface plasmon propagation length after functionalisation has been experimentally observed [1]. This phenomenon is known as chemical interface damping (CID). However, the physical origin of CID remains unclear, with two proposed mechanisms being: (1) excitation of electron-hole pairs involving adsorbate orbitals [2], and (2) electronic scattering by adsorbate-induced dipoles [3].

To resolve this issue, we perform first-principles density-functional theory calculations for different molecules adsorbed on Au (111) surfaces [4]. We evaluate both the contribution to CID from mechanism (1) and also determine the adsorbate-induced dipoles which contribute to mechanism (2). We find that mechanism (1) can explain the observed changes in plasmon propagation length, suggesting it is the dominant contributor to CID. These findings offer valuable insights for the design of metallic nanostructures for photocatalysis and plasmonic applications.

[1] M. Fu, et. al, Nat. Nanotechnology 17 (2022).
[2] B. Persson, Surf. Science 269 (1992).
[3] B. Foster, et. al, Sci. Advances, 5 (2019).
[4] A. Stefancu, et. al, Sci. Advances, 11 (2025).

Zeyu Kuang

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Adiabatic energy transfer in periodically modulated time-varying media

with Konstantin Y. Bliokh, and Stefan Rotter

Periodically modulated time-varying media can enable a wide range of functionalities such as frequency translation, amplification, and nonreciprocity by allowing energy to be injected into the light field through an external modulation. However, demonstrations of such energy transfer have so far relied almost exclusively on fast periodic modulations, which are experimentally demanding. In contrast, adiabatic periodic modulations are far easier to implement, but with only a single modulation parameter they cannot produce net energy exchange. For example, any energy transferred to the light during a slowly increasing refractive index in coherent scattering must be canceled when the index slowly returns to its original value.

Here, we show that this cancellation is not fundamental. When multiple parameters are modulated, even a slow closed loop in parameter space can yield nonzero net optical work in coherent scattering. This effect closely parallels the nonconservative optical force in optomechanics, where a closed spatial path produces net work determined by the curl of the force. We make this analogy precise by modeling adiabatic energy transfer for general time-varying media. Within our model, we show that the transferred energy depends solely on the shape of the modulation trajectory, not its traversal rate, giving it a geometric character analogous to a Berry curvature. We identify the optimal coherent input and the optimal modulation loop that maximize energy transfer per cycle. Furthermore, we show that, for mutually incoherent incident channels, the adiabatic energy transfer vanishes altogether. These results uncover new geometric features of adiabatic scattering and offer design principles for adiabatically modulated photonic devices.`

Jaime Echave-Sustaeta

Universidad Autónoma de Madrid, Spain

Fluctuational quantum electrodynamics of dispersive time-varying media

with Thomas F. Allard, Francisco J. García-Vidal, Paloma A. Huidobro

Time-varying media studies optical systems in which the constitutive parameters, such as the permittivity and the permeability, are varied in time by the action of an external pump mechanism. Crucially, the time-modulation breaks time-translational symmetry and thus, energy conservation, offering new and exciting possibilities for wave amplification and the modification of light-matter interactions. In regard to the latter, in *https://journals.aps.org/prl/abstract/10.1103/lfr1*-dwlv we study the interaction between a harmonic electric dipole and a periodically time-modulated plasmonic slab (i.e., a plasmonic time crystal slab). We show that the plasmonic time crystal slab enables near-field gain by the dipole, in which the energy flow between the time-varying slab and the emitter becomes inverted in the vicinity of the air-metal interface, with the dipolar source acting as an energy sink. Furthermore, we also report the possibility of controlling the emission properties of emitters in the far-field.

However, a missing piece in the field of time-varying media is a proper quantum mechanical theory of light in these time-modulated environments, one that accounts for dissipation and frequency-dispersion and crucially, that goes beyond conventional perturbative methods. In this work, we present a novel quantum formalism based on extending the fluctuation-dissipation theorem to time-modulated media. Importantly, our theory accounts for dissipation and dispersion and is non-perturbative, treating the time-modulation in an exact manner. We prove that the classical results discussed above can be derived within a Fermi Golden Rule and we show how the temporal modulation creates pairs of entangled surface-plasmon polaritons. Additionally, we demonstrate that gain and loss must both be accounted for in order to define a local density of states for these out-of-equilibrium systems.

Anna Roccaforte

University of Padua, Italy

Bottom up nanostructured multi-mode optical fibers using gold nanoparticles from low temperature plasma synthesis as SERS probes

with Ehsan Shakerinasab , Chiara Guidolin, Boris Kalinic, Riccardo Fiorotto, Claudia Longo, Alessandro Patelli, and Filippo Pisano

Detecting neurochemicals at physiological concentrations in the mouse brain remains a key challenge in neuroscience. While genetically encoded fluorescent reporters enable optical monitoring via imaging and fiber photometry [1], they still hinder future translational applications. In contrast, label-free surface enhanced Raman spectroscopy (SERS) through optical fibers with integrated plasmonic nanostructures has recently emerged as a promising alternative for neurochemical detection [2].

Current fabrication strategies, such as block-copolymer synthesis or solid-state dewetting, face limitations in achieving robust nanoparticle attachment and biocompatibility. In this work, we present a scalable approach for nanostructuring SERS fiber probes. Using an atmospheric pressure Argon plasma jet, we synthesize stable, size-controlled gold nanoparticles without reducing or capping agents, improving long-term biocompatibility [3]. The nanoparticles are immobilized on the fiber tip via APTES functionalization, ensuring stable attachment and homogeneous coverage. We evaluate probe performance using Rhodamine 6G, achieving a detection limit of 100 nM, consistent with the state of the art [4].

Looking forward, light propagation in optical fibers can be framed as a complex medium problem, where modal interference generates speckle patterns that affect the local field at the nanostructured interface. Wavefront shaping could enable improved matching between the input field and the plasmonic nanostructure, further enhancing SERS signals.

By combining scalable, biocompatible nanofabrication with the perspective of wavefront-controlled light delivery in complex media, this approach represents a promising strategy for the next generation of nanophotonic tools for in situ, label free neurochemicals detection.

[1] Simpson et al., Neuron (2024)
[2] Zheng et al., Adv. Mater. (2023)
[3] Nam et al., Plasma Process. Polym. (2024)
[4] Lei et al., J. Raman Spectrosc. (2025)

Esmaeel Zanganeh

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From circular Huygens dipoles to 3D chiral routing: Complex dipole interferences in achiral nanoparticles

with Antonio Lombardo

Simultaneous control over the directionality and spin of light at the nanoscale is a central goal in nanophotonics, with crucial applications in chiral quantum optics and topological photonics. Typically, coupling spin to directional momentum requires complex structurally chiral nanoparticles or structured vector beam illumination.

In this work, we present a unifying theoretical framework and numerical realization for deterministic spatial spin-control using a single, monolithic achiral silicon nanocuboid. Our framework relies on a progression of complex dipole interferences. First, we establish the baseline concept of the Circular Huygens Dipole (CHD). We demonstrate that under simple linearly polarized plane-wave illumination, the nanocuboid excites co-located circular electric and magnetic dipoles in phase quadrature, enabling deterministic switching of forward-scattered radiation between purely right- and left-circularly polarized states.

Building upon this, we introduce orthogonal circular-linear dipole interferences. We show that under linear polarization, this mechanism generates a "spin-split Huygens source." This acts as a robust spatial spin-splitter, deterministically segregating right- and left-circularly polarized scattered light into opposite hemispheres.

Finally, we demonstrate true 3D off-axis chiral routing via planar circular-linear interferences. Under circularly polarized excitation, the nanocuboid inherently excites spatially orthogonal sets of these composite dipoles. Their coherent superposition completely extinguishes on-axis radiation and deterministically steers spin states into entirely distinct 3D off-axis spatial quadrants.

Our findings establish a robust, passive method for reconfigurable spin-directional control. By bridging fundamental complex dipole theory with practical monolithic nanostructures, this work opens new avenues for chip-scale spin-optics, chiral quantum interfaces, and advanced sensing platforms.

Karoline Becker

University of Rostock, Germany

3D nanoscale tomography of laser-written integrated photonics

with Jonas Himmel, William Chèvremont, Yasser Pordeli, Marco S. Kirsch, Matthias Heinrich, Alexander Szameit, Dmitry Karpov, Pepijn W. H. Pinkse, and Tom A. W. Wolterink

We performed near-field x-ray tomography on nanophotonic structures at the European Synchrotron Radiation Facility. Specifically, we for the first time recorded full 3D nanoscale resolution density profiles of laser-written photonic structures in glass.
Femtosecond laser direct writing is a manufacturing method for photonic structures in arbitrary three-dimensional geometries. It works by inducing permanent refractive index changes in glass wafers via intense focused laser pulses, enabling e.g. 3D photonic integrated circuits.
Using x-ray tomography, we are able to resolve laser-induced filamentation as well as self-organized nanogratings in remarkable detail, as well as the internal structural details of larger complex photonic media. Even waveguides with an extremely low refractive index contrast of 1e-3 in the visible range (and associated X-ray contrast of 1e-9) are clearly visible. This is key for deeper understanding of the writing process, optimization of laser-written photonics, and testing the limits of x-ray metrology. Our results show how modern synchrotron x-ray microscopy is very suitable to probe minute density variations, enabling unprecedented volumetric imaging inside nanophotonic structures.

Evgenia Klironomou

ICFO, Spain

Thermal Radiation for Infrared Light sources

with Mitradeep Sarkar, Georgia T. Papadakis

All objects at non-zero temperatures emit photons via a process known as thermal radiation. This radiation is by nature incoherent and unpolarized. At near room temperatures the absorption spectrum reaches its maximum predominantly at mid-infrared (mid-IR) frequencies. Additionally, according to Kirchhoff's law of thermal radiation, the emissivity of a blackbody at a given wavelength and angle of incidence is equal to its absorptivity. As a result, by leveraging the intrinsic material properties in lithography free thin films, the spectrum, polarization and direction of thermally emitted light can be controlled. This poster is based on two recent projects of our group; during the first one, we managed to tame and to succesfully measure the circularly polarized light emitted from microscopic samples, whose surfaces were almost a million times smaller than those typically measured in conventional FTIR experiments and during the second one, we controlled the direction of thermal emission without the need of any complex lithographic schemes, just by exploiting the simple wokring principle of a Salisbury screen.

Themistoklis Deloudis

University of Birmingham, UK

Enhancement of Spontaneous Decay Rate in Hybrid Photonic Nanocavities

with Angus Crookes, Angela Demetriadou

Optical nanocavities constitute environments that enhance the spontaneous decay rate of emitters placed inside them. Nonetheless, the intrinsic disadvantages that stem from the material of the cavity prevent the emission rate from reaching ultra high values. Recently, high finesse hybrid structures have been proposed to overcome these restrictions. However, the majority of these cavities operate at telecommunication wavelengths. We design a hybrid nanocavity with dielectric and plasmonic parts, which yields a three fold enhancement of the spontaneous emission decay rate compared with its isolated constituents while operating in the optical spectrum. Furthermore, the size and shape of our hybrid nanocavity are such that a quantum network is easily formable by fabricating a sequence of these cavities that spans a large distance.

Zijia Wu

University of Cambridge, UK

Single Atom-thick Redox Optical Switches from Plasmonic Nanocavities

with Eric S A Goerlitzer, Angus Crookes, Shu Hu, Rakesh Arul, Sarah May Sibug-Torres, Bart de Nijs, Reshma R Rao, Mary P Ryan, Angela Demetriadou, Jeremy J Baumberg

Controlling redox reactions at the atomic scale is key to enabling next-generation low-power memristive and neuromorphic devices. Ultrathin metallic layers, such as atomic monolayer palladium (Pd), offer tunable redox behavior well suited for switchable components in nanoscale electronics. Here, we present an in-situ plasmonic-electrochemical platform that probes redox processes within sub-nanometer gaps using a nanoparticle-on-mirror (NPoM) geometry. Atomically thin Pd layers are grown by underpotential deposition and their redox is monitored via surface enhanced Raman spectroscopy (SERS), revealing reversible transformations between metallic and dielectric Pd redox states. This confined plasmonic cavity enhances sensitivity to vibrational and electronic changes, allowing non-destructive optical readout of redox switching behaviors. By reducing the active switching volume to the monolayer limit while maintaining precise geometric control, this work establishes a powerful platform for probing redox dynamics at the atomic scale and points toward highly energy-efficient nanoswitches based on redox-active ultrathin materials.

Yacine El Ghazi

Université Côte d'Azur, France

Light transport in optical fibers and reciprocity breaking

with Geoffroy Aubrey, Matthieu Bellec

Reciprocity in optics is often seen as a property responsible for the fact that "if Ican see you, you can see me". In multiple scattering coherent wave transport, i.e., if interferences within the scattering region are taken into account, reciprocity is known to reduce the transmission of the medium with respect to a situation where interferences are absent. This phenomenon is known as localization. It is possible to break reciprocity for instance in the presence of materials showing some magneto-optical Faraday effect. There are situations where reciprocity breaking might be desirable: For instance in radiative-energy harvesting devices, one might want to increase the absorption without increasing the emissivity. In laser systems, Faraday-isolators are commonly used to reduce noise. On top of the potential applications of non-reciprocal optical systems, breaking of reciprocity gives new insight to the fundamental understanding of coherent wave transport.

Callum Cook

University of Birmingham, UK

Quantum emitters in a plasmonic lattice

with *Angela Demitriadou*

Plasmonic effects enhanced by the Nanoparticle on Mirror (NPoM) system are ideal for observing strong light-matter coupling with quantum emitters (QEs), due to high field enhancement from subwavelength light confinement. In an array of multiple NPoM structures, cooperative field effects are observed, caused by propagating Surface Plasmon Polariton (SPPs) excited on the mirror. We plan to build a description for a series of NPoM cavities, accounting for the long range coupling between the cavities via the SPP. We will eventually build a lattice of NPoMs, where Bloch modes are created via the propagating SPPs. Such structures will allow for enormous control on the cavity modes and their coupling the QEs or arrays of QEs for future applications in quantum technologies and quantum plasmonics.

Xinyi Yuan

Aalto University, Finland

Breakdown of Bulk-Radiation Correspondence in Radiative Photonic Lattices

with Loïc Malgrey, Helgi Sigurðsson, Hai Son Nguyen, Grazia Salerno

We develop a non-Hermitian model to describe the guided and leaky modes of photonic crystal slabs with non-local responses. Within this framework, we investigate the concept of bulk-radiation correspondence in the vicinity of the gamma point of the square lattice and the K point of the honeycomb lattice. The results show that the comparability between bulk topology and radiation topology is not universal and completely breaks down in the presence of bound states in the continuum.

Hal Gee

University of St Andrews, UK

Correlation Revival Eigenmodes for Differential Sensitivity in Speckle Metrology

with Morgan Facchin, Graham D. Bruce

Speckle metrology exploits the high sensitivity of complex scattering in order to map macroscopic changes in scattered fields to microscopic changes in a measurand. Shifts of attometers in wavelength, picometers in displacement, and parts-per-billion in refractive index can be quantified with simple, cost-effective systems that do not require precise alignment or specialised equipment. However, it is precisely this sensitivity which presents a challenge. Scattering systems often react just as strongly to environmental fluctuations, leading to noise and measurement degradation. This problem is typically treated by physical isolation or analytical techniques, while the root cause, the scatterer's response to unwanted variation, remains. By using transmission matrix formalism, it has previously been shown that specific input modes can be applied to a scatterer to reduce sensitivity to a given parameter. Recently, we have been able to experimentally verify a wide-range eigenmode approach to desensitisation, in contrast to localised techniques used thus far. This method of desensitisation does not substantially affect measurements in other parameters, and therefore represents a path to robust, controlled sensitivity in metrological applications.

Zoltan Sztranyovszky

University of Birmingham, UK

Extreme field enhancement through anapoles in high-index metamaterials

with N. Spiesshofer, C. Todd, R. Arul, J. J. Baumberg, A. Demetriadou

Metamaterials allow us to engineer devices with unique and extreme optical properties, often not found in nature. In recent years, bottom-up fabrication methods, in particular, self-assembly of nanoparticles became popular, as this provides a way to control both the meta-atom shape, lattice constant and arrangement with great precision, allowing the creation of even sub-nanometer gaps [1]. Here we consider a metasurface made by self-assembled spherical gold nanopraticles (meta-atom), which form an effective dielectric in the mid-IR, with high dispersionless refractive index and minimal losses (n=4.1+0.1i). Additionally, the gaps between the nanoparticles provide strong localised field enhancement (EF=90). By shaping the nanoparticle aggregate layer into a disk, we engineer a resonator that supports an anapole, which are non-radiative states that appear as pronounced dips in the scattering spectrum [2]. They also provide strong field localization in the center of the disk resonator and further boost the field enhancement inside the nanogaps (EF=300). By changing the size of the resonator, or the morphology of the meta-atom, the anapole can be tuned across a wide spectral range. The extreme field enhancement in these gaps can be exploited, for example, by the placement of quantum dots or gain media within them, making the effective dielectric an excellent candidate for sensing, enhancing non-linearities and light-matter interactions [3].

[1] R. Arul, D. B. Grys, R. Chikkaraddy, et al. "Giant mid-IR resonant coupling to molecular vibrations in sub-nm gaps of plasmonic multilayer metafilms", Light: Science and Applications, Vol. 11, 281 (2022).
[2] A. E. Miroshnichenko, A. B. Evlyukhin, Y. F. Yu, et al. "Nonradiating anapole modes in dielectric nanoparticles", Nature Communications, Vol. 6, 8069 (2015).
[3] N. Spiesshofer, E. Wyatt, Z. Sztranyovszky, et al. "Tailoring ultrahigh index plasmonic combinatorial metamaterials for SEIRA and SERS by tuning the fill fraction", Optica, Vol. 12, 1357 (2025).

Luke Hands

University of Birmingham, UK

Free-space propagation in the quantization of radiative nanophotonic systems

with Ben Yuen, Angela Demetriaudou

Recent advances have shown that it is possible to achieve strong coupling between quantum light sources and a range of radiative nanoplasmonic systems, showing promise for designing miniaturized quantum technologies operating at ambient conditions. However, a full description of the quantum mechanical processes that govern these systems is not easily obtainable as radiative systems suffer from complexities in defining a set of normal photonic modes, an essential step in their second quantization. Currently, most descriptions of these systems rely on phenomenological closed-cavity analogues that often omit crucial non-Markovian dynamics which play an important role in the coupling of light to molecules under the strong coupling regime.

Recently, we presented work that describes the nanophotonic system through a set of discrete pseudomodes, obtained from transforming the continuous classical normal modes for a system with an infinite boundary to the complex plane. This was originally done for a quantum emitter positioned on the surface of a resonator; however, for a quantum emitter at an arbitrary position outside the nanophotonic geometry, new, additional terms must be included in this transformation to fully explain all the quantum dynamics present. These additional terms correspond to free space propagation and decay and reduce, under certain assumptions, to known values as expected by other quantum theories.

We demonstrate the complete quantum dynamics for a quantum emitter at an arbitrary position coupled to a spherical dielectric nanoparticle to illustrate these additional terms. By applying our quantization framework to a spherical nanoparticle coupled to an arbitrarily position quantum emitter, we will demonstrate quantum dynamics that preserve both Markovian and non-Markovian contributions.

As these findings provide a full picture of the dynamics, they are essential for accurately designing the aforementioned radiative quantum nanophotonic devices.

Henry Putley

University of Birmingham, UK

State-insensitive optical conveyor belts on integrated nanophotonic waveguides

with P.F. Griffin, D.J. Paul, A. Demetriadou

Integrated atom-nanophotonic platforms offer a promising route towards on-chip quantum technologies by enabling strong light–matter interactions in compact geometries. Here, we demonstrate a state-insensitive optical conveyor belt for cold cesium (Cs) atoms along an integrated nanophotonic waveguide. Using a magic compensation scheme and appropriate frequency ramping, we achieve deep confinement and simultaneous transport of atoms in both their ground and excited states pertaining to their D2 transition. This conveyor effect allows for the coherence-preserving transport of atomic ensembles over micrometer-scale distances, as well as the acceleration and injection of atoms into a flat, atom guide potential, which is independent of their internal state. This work paves the way for controlled atom transport and state-insensitive manipulations in integrated nanophotonic architectures, for on-chip quantum information processing and matter wave inertial sensing.

William Parfitt

University of Birmingham, UK

Molecular Optomechanics in Nanophotonic Cavities

Quantum emitters within nanoplasmonic cavities - such as the commonly used NanoParticle-on-Mirror (NPoM) cavity - offer an effective method of achieving strong light-matter coupling through extreme electromagnetic field confinement. Using dual-wavelength nanoantennae and the IR-active molecular vibrational modes of quantum emitters allows us to couple to the molecule at both visible and infra-red frequencies, enabling simultaneous excitation and mixing of both excitonic and phononic polariton modes. Understanding this regime will allow for a host of applications in quantum technologies including enhanced sensitivity in SERS and SERRS, mid-IR upconversion, and IR lasing.

Oscar Jackson

University of Southampton, UK

Data-driven inverse design of infrared phonon-polariton 4H-SiC metasurfaces

with Emmanuele Cannavo, Simone De Liberato and Alessandro Tredicucci

Nanophotonics has shown great promise in utilizing Surface Phonon Polaritons (SPhPs) for sub-wavelength light confinement within polar dielectrics, offering low optical losses across the Terahertz to mid-infrared spectrum. In this regime, SPhPs serve as a robust alternative to plasmonic systems. These modes are excited within the Reststrahlen band (the spectral region between longitudinal and transverse optical phonon frequencies), which for 4H silicon carbide (4H-SiC) spans the 25 to 29 THz. In this work, we employ both one-shot and iterative deep learning approaches to tune the absorption spectra of 4H-SiC SPhP metasurfaces to match the spectral signatures of specific gaseous or liquid chemical substances. By maximising the spectral overlap between the metasurface absorption and the target chemical species, one can enable high-sensitivity detection. The metasurface comprises periodic rectangular arrays with feature sizes ranging from 0.5 to 2.0 μm.

While deep learning has gained significant use for inverse design in nanophotonics, its application to SPhP resonators remains relatively unexplored. Our approach utilises probabilistic deep learning models to map the physical design space into a continuous latent representation. By sampling from this learned manifold, we aim to mitigate the challenges of out-of-distribution (OOD) inference. Our model leverages the underlying distribution of the latent space to generate viable spectral targets for inverse design via a conditional variational autoencoder. Pillar width, depth, height, separation, and rotation are varied to generate the training dataset via COMSOL, running in parallel on the University of Southampton's High-Performance Computing (HPC) cluster. This work has paved the way for the inverse design of more complex SPhP resonator structures, with direct applications in radiative cooling and high-sensitivity gas sensing.

Sarah Muzard

ESPCI Paris, France

Wavefront control in nonlinear disordered resonators

with Lola Guengard-Morineau, Samuel Grésillon, Sébastien Bidault

Conventional approaches to nonlinear conversion often rely on bulky devices or resonant nanostructures fabricated using complex techniques. Although these systems perform well, they are generally optimized for a single wavelength and offer limited adaptability. A promising alternative involves introducing disorder into resonant systems: random couplings between resonators enable broadband optical properties while simplifying fabrication processes. Furthermore, a disordered medium that effectively scatters light offers numerous degrees of freedom for controlling wave propagation through far-field wavefront shaping. It therefore appears possible to compensate for the apparent complexity of disorder to optimize nonlinear optical responses.
We aim to propose a novel optical nanoresonator platform in the form of colloidal gallium phosphide (GaP) nanospheres, which combine high-quality resonances and negligible absorption in the visible and near infrared. We want to demonstrate the potential of this new resonator platform for nonlinear optics at the single particle level, but we also plan to use wavefront shaping in disordered assemblies of these nanospheres in order to maximize broadband three-wave mixing (TWM) phenomena such as spontaneous parametric down conversion (SPDC) or sum-frequency generation (SFG).

Tim Ehret

University of Freiburg, Germany

A Lindblad master equation for twisted photons in a turbulent atmosphere

with Vyacheslav Shatokhin, Andreas Buchleitner

Propagation of photonic spatial modes carrying orbital angular momentum (OAM) through a turbulent atmosphere is an active research area that is important from the fundamental point of view, as well as for applications. A standard approach to account for atmospheric effects on spatial modes is based on the stochastic parabolic equation and the numerical multiple phase screens method derived therefrom. Notwithstanding the success of these approaches, a fully quantum treatment of the propagation of photons through turbulence taking full advantage of the open quantum system toolbox would be highly desirable. However, until now this problem has remained essentially unsolved. In the present contribution, we derive a quantum master equation for the ensemble-averaged density operator of twisted photons that are phase-distorted by turbulence and present some numerical results.

Sean Mitchell

University of Birmingham, UK

Accelerated T-Matrix Model for Simulating Light Transport in Large Complex Media

with Jake Bewick, Dylan Marques, Jonathan Watkins, and James Guggenheim

Many optical technologies are impeded by light scattering and absorption in complex media, including biomedical imaging in tissue and transporting light through multimode fibre. These effects may be negated via techniques such as wavefront shaping, or by exploiting phenomena such as the memory effect. Methods like these are most essential when light traverses multiple mean free paths, which for biological tissue means depths on the order of thousands of wavelengths. However, simulating light transport on such scales is infeasible using conventional simulation tools such as finite difference time domain (FDTD) and pseudo-spectral time domain (PSTD) methods. Recently, an alternative method involving coupling an angular spectrum decomposition (ASD) of the incident field with a T-matrix method was explored. By modelling materials using simplified collections of spherical particles, this enabled simulating larger media. However, speed was still limited by the need to run the whole model many times – once for each wave in the ASD – rendering large scale simulations still challenging. To address this challenge, we present a new T-matrix model which simulates the transport of wavefronts specified using ASDs in single simulation runs, reducing the overall run time by three orders of magnitude (for ASDs containing thousands of waves). In addition, the slowest parts of the code were designed to utilise single instruction, multiple data (SIMD) – a CPU feature for further parallelising code, granting a further five times speedup. By enabling simulations of structured light transport through thick, e.g. millimetre-scale tissue-like, materials, the model could aid the development of techniques such as dynamic wavefront shaping and phase conjugation in deep complex media, paving the way to the development of a whole host of next-generation optical imaging, sensing and manipulation techniques.

Isobel Henderson

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Developing Highly Sensitive Fused Silica Fabry Perot Ultrasound Sensors for High Resolution Deep Tissue Photoacoustic Imaging

with Benjamin Keenlyside, Dylan Marques, Edward Zhang, James Guggenheim

Photoacoustic imaging (PAI) is a rapidly advancing biomedical imaging technique in which pulsed light is used to excite ultrasound waves inside living tissue. One promising method of detecting ultrasound for PAI is with Fabry-Perot ultrasound sensors (FPUSs); optical ultrasound sensors formed of an optical cavity with an ultrasonically compressible spacer layer. FPUSs can simultaneously provide high sensitivity, small ultrasonic element size and broad ultrasonic detection bandwidth, enabling high-fidelity PAI systems with 50-100μm spatial resolution and penetration depths of 10-15mm. This allows for detailed, non-invasive imaging of small blood vessels and other structures, making the technique well suited for applications such as monitoring skin cancers and assessing superficial vasculature morphology. Increasing imaging depth could significantly broaden the applicability, which requires increasing the sensitivity of the FPUS. A limiting factor in sensitivity is optical losses within the spacer layer, which is typically made of a polymer. In this work, we investigate replacing the spacer layer with one made from fused silica which could enable higher Q-factor cavities; while less compressible than polymer, optical losses in fused silica are significantly lower. Additionally, the ability to polish fused silica to a highly uniform flatness creates the potential for sensor readouts based on the delivery of structured light through a multimode optical fibre at a single wavelength. To test this design concept, we fabricated and characterised several fused silica FPUSs and used them to acquire photoacoustic images. Preliminary results suggest sensitivity values could far exceed those of polymer FPUSs. This indicates fused silica FPUSs could offer a promising alternative to polymer FPUSs that could pave the way to new PAI applications such as deep tissue imaging.

Samuel Donachie

Heriot Watt University, Edinburgh, UK

Neural network optimization of MPLC masks for high-dimensional quantum gates

with Bohnishika Ghosh, Suraj Goel, Callum Jones, David B Phillips, Mehul Malik

Multi-plane light conversion (MPLC) is a powerful technique for implementing high-dimensional spatial mode transformations, with applications in quantum optics and optical communications. However, achieving robust and efficient mode conversion remains challenging due to sensitivity to experimental imperfections and limitations in mask optimization strategies.

In this work, we propose a neural network-based optimization framework for MPLC mask design, leveraging a multi-objective loss function combining mode fidelity, spatial frequency regularization, and efficiency-related constraints. In particular, we introduce k-space filtering within the optimization process to enforce smoother phase profiles, leading to masks that are more compatible with experimental implementation. We target the specific application of high-dimensional quantum gates in 64 dimensions, designed for integration with a 64-pixel SNSPD array. The MPLC implements a basis change between generalized input bases such as HG, LG or pixel bases and a square macro-pixel output basis matched to the detector geometry, enabling flexible measurement settings for high-dimensional quantum information protocols.

This approach enables the native integration of physical constraints into the optimization through differentiable regularization terms, in contrast to traditional wavefront matching techniques where such constraints are typically enforced via hard filtering steps. Preliminary results suggest that the obtained solutions achieve performance comparable to standard methods, while offering improved control over mask regularity and power distribution.

Angus Crookes

University of Birmingham, UK

Tunable band structures for cavity-embedded bilayer dipole lattices

with Angela Demetriadou

The ability to engineer band structures through controllable long-range interactions is central to the design of modern photonic and quantum materials. In this work, we demonstrate how the band structures of layered dipole lattices can be manipulated through embedding them within a cavity waveguide. In particular, we calculate the band structures of cavity-coupled bilayer lattices using a Greens function formalism, in which the coulomb and photon-mediated dipole-dipole interactions are encoded within the longitudinal and transverse Greens functions respectively. By varying the cavity width, we tune the relative strength of these interactions, enabling control over the dominant coupling mechanism. This in turn, allows the effective mass at high-symmetry points, and positions of type-II Dirac points to be engineered. Importantly, this approach provides a means of controlling the band structure of bilayer dipole lattices, without changing their underlying lattice structure. Moreover, the ability to switch long-range interactions on and off in a controlled manner, also offers a unique platform for band structure engineering within Moire materials.

Milcent Simon

Lyon University, France

Modeling of light transport in very heterogeneous media : application to the contemporary stained-glasses windows of Pierre Soulages

with Kevin Vynck, Jean-Jacques Greffet, Mathieu Hebert, Jialin Hu

The physics of wave propagation in complex media is a highly active research topic across several scientific communities ranging from seismology to acoustic and optical imaging systems, as well as atmospheric optics. The understanding of light transport in media such as suspensions of randomly and uniformly distributed particles (milk, fogs) is now well established [1,2]. The stained-glass windows of the abbey church of Conques [3], created by Pierre Soulages (1919–2022), stand out from conventional disordered media due to their remarkable optical properties: they are both highly diffusive and luminous, whereas turbid scattering media are generally dark in transmission. This peculiarity may result from the strong heterogeneity of the glass, composed of grains of very diverse sizes and shapes.
Our objective in this study is to understand - by theory, numerical simulations and experiments - how light transport is affected by the strong heterogeneity of a material and eventually provide a physical interpretation of Soulages' artwork. In this presentation, we will discuss results of light transport Monte Carlo simulations in strongly heterogeneous media constructed from Voronoi diagrams. We will also provide a theoretical background of light transport in statistically homogeneous and very heterogeneous media by presenting the radiative transfer equation and its generalized forms [4,5], which are not always well-connected to the Maxwell's equations. Finally, we will present our first experimental results which we can put in perspective with our numerical predictions.

[1] Vynck, K et al., Light in correlated disordered media, Rev. Mod. Phys., vol. 95, pp. 045003, 2023.
[2] Carminati R and Schotland JC, Principles of Scattering and Transport of Light, Cambridge University Press, 2021.
[3] Soulages, P. Verre, carton des vitraux de Conques, Paris : Actes Sud et Musée Fabre, 2010
[4] Larsen, E. W. and Vasques, R., A generalized linear Boltzmann equation for non-classical particle transport, Transport Theory Stat. Phys., vol. 40, pp. 623–654, 2011.
[5] Pierrat, R., Jayamanne, et al., A diffusion model for light scattering in strongly scattering media beyond the radiative transfer equation, arXiv:2507.04972, 2025.

Priya Deoli

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Physics of Low-loss Phase Change Material Enabled Nanophotonic Metasurfaces

with K.Sun, I. Zeimpeki, O.L.Muskens

This project focuses on developing an active, dynamically reconfigurable metasurface by integrating low-loss chalcogenide phase-change material Antimony Selenide (Sb2Se3) with a silicon-based dielectric metasurface. The goal is to achieve precise control over light modulation, specifically targeting amplitude modulation and eventually attaining of full 2π phase control, thereby enabling fully reprogrammable optical functionalities. Chalcogenide materials, particularly Sb2Se3, are well-suited for these applications owing to their reversible phase transitions between amorphous and crystalline states, coupled with minimal optical loss at the telecom wavelength of 1550 nm.
A silicon-based metasurface consisting of square pillars (900 nm height & period, width varying from 260–540 nm) was fabricated using Deep UV lithography, followed by Sb_2Se_3 deposition and thermal annealing to facilitate crystallisation.
Fourier-transform infrared (FTIR) spectroscopy revealed the metasurface's optical response, including its characteristic Mie resonances. Subsequently, targeted, localised laser-induced switching performed on a crystalline background using a 488 nm laser achieved reversible modulation of the transmission response.
The results demonstrate controlled, reversible tuning of optical transmission, confirming the feasibility of active, reconfigurable metasurfaces. These findings lay the foundation for future exploration of dynamic amplitude and phase control, paving the way for fully reprogrammable optical devices such as metalenses.

Lilian de Thevenot Oubaha

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Probing plasmonic antenna matrices design for infrared emission control

with Baptiste Fix, Patrick Bouchon, Yannick de Wilde

The antennas under study use a metal–insulator–metal (MIM) architecture and were designed through previous work conducted jointly by the Langevin Institute and ONERA. Nevertheless, there are still open questions regarding the behavior of a single MIM antenna and, more importantly, the behavior of arrays of MIM antennas.

To investigate this, numerical simulations of our systems are performed to explore different array configurations, simulating the enhancement of the electric field and the scattering and absorption cross sections. We also aim to control the excitation of a single antenna within an array using precise thermal excitation. The goal is to use local thermal excitation to create a reconfigurable antenna array, in the spirit of a RIS.

Using near-field spectroscopy techniques (TRSTM, s-SNOM, IR-SMS), we are able to map the local enhancement of the electric field and perform spectroscopy on our antennas. These techniques will be used to quantify the effectiveness of the design and the thermal excitation.

Hugo Dawson

University of Exeter, UK

Development of a multimode fibre-based endoscope for remote imaging in extreme environments

with Hugo Dawson, Jérôme A. Don Jayamanne, Unė G. Būtaitė, Euan Hendry, Ozan Tokatli, David Phillips

Multimode fibres (MMFs) offer a versatile way to perform remote minimally invasive optical imaging into confined, clinical [1,2] or industrial [3,4] environments. Such imaging requires a method to reverse the spatial scattering of optical signals transmitted through MMFs, which scrambles images into unrecognisable speckle patterns [5]. Over the last decade, significant progress in MMF imaging has been made via measurement of the MMFs Transmission Matrix (TM) [6,7], which fully describes the mapping of light from the input (proximal) to the output (distal) end of the fibre. Knowledge of the TM enables high resolution scanning imaging through a thin strand of MMF with no active electronic components required at the distal end [8]. This capability opens up the possibility of using cheap and disposable lengths of MMF to image into extreme environments, such as those that are highly radioactive, where conventional electronic cameras can be rapidly damaged and fail.

The aim of this project is to develop an MMF-based imaging system to explore the feasibility of such an approach. We are at the start of the project, and our initial work has focussed on building a prototype MMF imaging system and programming the experimental control interface using python. We use a high-speed Digital Micromirror Device (DMD), synchronised with a high-speed camera, to rapidly measure the TM of a step-index MMF in a few seconds [9]. The MMF supports 750 spatial modes at a wavelength of 633nm. Once the TM is measured, we generate a set of input fields that evolve into focussed points of light across the output end, allowing all-optical scanning imaging through the MMF. Calculating this set of input fields is a computationally demanding process. We optimise this operation to exploit sparse matrices and parallel processing, reducing the computation time from hours (prior to computational optimization) to a few minutes, with potential for further reductions in processing time in the future. Here we present the first results of this MMF-based imaging system, and discuss future work towards imaging within extreme environments.

1) Stibůrek, M., Ondráčková, P., Tučková, T., Turtaev, S., Šiler, M., Pikálek, T., ... & Čižmár, T. (2023). 110 μm thin endo-microscope for deep-brain in vivo observations of neuronal connectivity, activity and blood flow dynamics. Nature Communications, 14(1), 1897.

2) Ohayon, S., Caravaca-Aguirre, A., Piestun, R., & DiCarlo, J. J. (2018). Minimally invasive

multimode optical fiber microendoscope for deep brain fluorescence imaging. Biomedical optics express, 9(4), 1492-1509.
3) Stellinga, D., Phillips, D. B., Mekhail, S. P., Selyem, A., Turtaev, S., Čižmár, T., & Padgett, M. J. (2021). Time-of-flight 3D imaging through multimode optical fibers. Science, 374(6573), 1395-1399.
4) Leite, I. T., Turtaev, S., Boonzajer Flaes, D. E., & Čižmár, T. (2021). Observing distant objects with a multimode fiber-based holographic endoscope. APL Photonics, 6(3).
5) Cao, H., Čižmár, T., Turtaev, S., Tyc, T., & Rotter, S. (2023). Controlling light propagation in multimode fibers for imaging, spectroscopy, and beyond. Advances in Optics and Photonics, 15(2), 524-612.
6) Popoff, S. M., Lerosey, G., Carminati, R., Fink, M., Boccara, A. C., & Gigan, S. (2010). Measuring the Transmission Matrix in Optics: An Approach to the Study and Control of Light Propagation in Disordered Media. Physical review letters, 104(10), 100601.
7) Čižmár, T., Mazilu, M., & Dholakia, K. (2010). In situ wavefront correction and its application to micromanipulation. Nature Photonics, 4(6), 388-394.
8) Čižmár, T., & Dholakia, K. (2012). Exploiting multimode waveguides for pure fibre-based imaging. Nature communications, 3(1), 1027.
9) Li, S., Saunders, C., Lum, D. J., Murray-Bruce, J., Goyal, V. K., Čižmár, T., & Phillips, D. B. (2021). Compressively sampling the optical transmission matrix of a multimode fibre. Light: science & applications, 10(1), 88.

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Low-resolution Multi-plane Light Conversion

with Jérôme A. Don Jayamanne, David B. Phillips

Multi-plane light converters (MPLCs), also known as linear diffractive optical networks, enable arbitrary manipulation of the spatial distribution of optical fields via successive phase modulations [1-3]. MPLCs are constructed from a cascade of phase masks, each separated by free-space propagation, allowing conversion of an orthogonal set of optical fields into any other orthogonal set via a unitary transformation. This approach is beginning to find broad applications in mode multiplexing, beam shaping, and optical signal processing. However, as MPLCs are based on cascading planes, they are extremely sensitive to fabrication errors, which accumulate as light propagates through the device. This means that even a minor mismatch between the digital model used in the design phase and the physically realised optical system leads to a severe drop off in real-world MPLC performance. To tackle this problem, we recently introduced a high-speed self-configuring MPLC architecture, capable of automatically optimizing itself to achieve a specified optical transformation [4]. In this system, the optimization time scaling linearly with the number of pixels. Here we investigate the class of light transformations that can be achieved using MPLCs operating in a low-resolution regime with a limited number of pixels, offering a path towards substantially reducing the time needed for these optical systems to self-configure. We present programmable transformations between spatial mode bases, together with reconfigurable spatial routing of the output modes, showing that these operations remain feasible in low-resolution MPLC systems with reduced spatial degrees of freedom. Our results highlight the potential for deploying self-configuring MPLCs in compact, high-speed optical systems.

[1] Morizur, J. F., Nicholls, L., Jian, P., Armstrong, S., Treps, N., Hage, B., ... & Bachor, H. A. (2010). Programmable unitary spatial mode manipulation. Journal of the Optical Society of America A, 27(11), 2524-2531.
[2] Fontaine, N. K., Ryf, R., Chen, H., Neilson, D. T., Kim, K., & Carpenter, J. (2019). Laguerre-Gaussian mode sorter. Nature communications, 10(1), 1865.
[3] Kupianskyi, H., Horsley, S. A., & Phillips, D. B. (2023). High-dimensional spatial mode sorting and optical circuit design using multi-plane light conversion. Apl Photonics, 8(2).

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Optimising transmission of spatially entangled photons through complex media

with Callum Jones, Simon A.R. Horsley, David B. Phillips

The transmission of entangled photon states through complex scattering media is a problem that arises in multiple quantum technologies [1]. For example: quantum communication via free-space optical links or multi-mode fibres, quantum imaging through complex media, and quantum information processing using spatially encoded qudits.

Precise control over the propagation of classical optical fields through complex media has received much attention over the last decade, relying on a now well-established technique known as wavefront shaping [2,3]. Yet wavefront shaping with entangled photon states is still a technique in its infancy. Entangled photons introduce the additional challenges of weak optical power, stringent requirements on optical losses and potentially long measurement times for optimisation algorithms. Existing strategies for optimising the transmission of a two-photon state through complex media often first run an optimisation algorithm using a classical input state [4,5]. Intriguingly, it has also been demonstrated that optimisation using the two-photon state itself allows alternative solutions to be found which maximise photon correlations but produce a speckle pattern for a classical input state [6].

In this work, we simulate optimisation strategies to steer two-photon states through complex media and maximise the detected photon coincidence rate between a given pair of output modes. Input spatial modes from a photon pair source using spontaneous parametric down-conversion are modelled by a double-Gaussian wavefunction. We compare optimisation strategies and discuss their practicality for wavefront shaping in experimentally realistic scenarios.

[1] O. Lib & Y. Bromberg. Nature Physics 18.9 (2022): 986-993
[2] I. M. Vellekoop & A. P. Mosk. Optics letters 32.16 (2007): 2309-2311
[3] Popoff, S. M., Lerosey, G., Carminati, R., Fink, M., Boccara, A. C., & Gigan, S. (2010). Physical review letters, 104(10), 100601
[4] O. Lib, G. Hasson, Y. Bromberg, Sci. Adv. 6, eabb6298 (2020)
[5] B. Courme, P. Cameron, D. Faccio, S. Gigan, H. Defienne, PRX Quantum 4, 010308 (2023)
[6] B. Courme, C. Vernière, M. Joly, D. Faccio, S. Gigan, H. Defienne, arXiv:2503.24283 (2025)

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Phase-Change Metasurfaces for Reconfigurable Optical Mode Conversion and Orbital Angular Momentum Generation

with Guoce Yang, Carlota Ruiz de Galarreta, Mengyun Wang, Stuart Kendall, Joe Pady, Nikolaos Farmakidis, David B. Phillips, Jacopo Bertolotti, Harish Bhaskaran, C. David Wright

We present two actively reconfigurable metasurfaces based on phase-change materials (PCMs) for optical beam shaping and orbital angular momentum (OAM) generation. Reconfigurable control of optical modes and OAM is of growing importance in applications spanning optical communications, integrated photonic systems, and quantum information processing, where compact, low-power, and non-volatile switching are highly desirable device characteristics [1]. Our approach leverages PCMs and the large refractive index contrast between the amorphous and crystalline phases to realise distinct metasurface functionalities in a single device with switching achieved in a non-volatile manner with the potential for low-power, fast switching applications [2].
The first device (Sb2Se3 cylinders on SiO2) performs switchable TEM_{00} to HG_{10} mode conversion. In the amorphous state, the metasurface acts as a high-transmission window. Upon crystallisation, a π phase shift is imparted to one half of the incident beam, driving conversion to the HG_{10} mode, as confirmed by experimental measurements. The second device enables switchable OAM generation. Metasurface resonators with different radii and periods sizes are arranged across twelve sectors. In the crystalline state, the design provides a stepped 2π phase ramp around the aperture, converting a TEM_{00} input to an LG_{01} mode. In the amorphous state, unperturbed beam transmission is recovered. These devices show a proof-of-concept PCM metasurfaces for tuneable mode conversion and OAM control. We further demonstrate the applicability of this platform to image processing tasks such as edge detection and extension of the concept to fractionally tuneable PCMs.

[1] Yao, A. M., et. al. (2011). Orbital angular momentum: origins, behaviour and applications. Advances in Optics and Photonics.
[2] Siegel, J., et. al. (2004) Rewritable phase-change optical recording in Ge2Sb2Te5 films induced by picosecond laser pulses. Applied Physics Letters.

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Laser-written birefringent nanogratings for miniature multi-plane light converters

with Martynas Beresna, David B. Phillips

Multi-plane light converters (MPLCs) are promising three-dimensional beam shaping devices that enable controlled transformations between sets of spatial light modes. These high-dimensional mode conversion operations are of growing interest for applications across classical and quantum photonics, including optical communication systems, computational photonics, and advanced imaging. MPLCs consist of a series of diffractive elements separated by free space. They have so far been realised through a few different means, for example, using multiple reflections from spatial light modulators or lithographically etched phase masks, and metasurfaces. Here we explore how millimetre-scale MPLCs can be fabricated inside a single block of glass using single-step direct laser writing. The method exploits self-organised birefringent nanogratings induced by femtosecond-pulsed laser irradiation. The optical axis of these nanogratings can be locally controlled, allowing spatially varying geometric phase profiles to be embedded within the glass. By stacking multiple patterned layers within a single substrate, we create transmissive multi-plane optical systems capable of performing complex spatial mode manipulations. As a proof-of-concept demonstration here we present MPLCs that perform Hermite-Gaussian beam sorting. Our work plots a path towards the rapid prototyping of robust monolithic MPLC technology.

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Influence of structural correlations on optical extinction in colloïdal suspensions

with Yihui Cai, Nicolas lequeux, François-Genès Tournilhac, Rémi Carminati, Romain Pierrat, Jean Baudry

We investigate the influence of structural correlations on the optical absorbance of silica particle suspensions in water. The absorbance is directly related to the extinction mean free path and is therefore sensitive to scattering effects. Experimental measurements are compared with numerical simulations for suspensions ranging from highly dilute systems to denser suspensions exhibiting significant spatial correlations.

Uncorrelated systems are compared with correlated ones, including hard-sphere and charged-sphere interactions. Attention is given to the roles of concentration, effective refractive index, and inter-particle interactions in the determination of the extinction mean-free path. This study provides insight into the optical response of complex colloÏdal media and highlights the importance of structural correlations and multiple scattering effects in dense systems.