Physics Department Colloquia Speakers 2024/25

Prof Vahid Sandoghdar (Max Planck Institute for the Science of Light)

Exploring and exploiting light-matter interaction at the nanometer scale: from quantum optics to biophysics

Friday 18 October 2024

Light-matter interaction at the nanometer scale lies at the heart of elementary optical processes such as absorption, emission or scattering. Over the past two decades, we have realized a series of experiments to investigate the interaction of single photons, single molecules and single nanoparticles. In this presentation, I will report on recent studies, where we reach unity efficiency in the coupling of single photons to single molecules in a microcavity and exploit this system for the realization of complex hybrid states involving a controlled number of molecules and photons. Furthermore, I will show how the underlying mechanisms that play a central role in quantum optics, help detect, image, characterize, and track single biological nanoparticles such as viruses and small proteins with high spatial and temporal resolutions and in a label-free fashion.

Prof Amanda Wright (University of Nottingham)

Optical imaging deep into biological samples

Friday 1 November 2024

Aberrations, or wavefront distortions, present in optical microscopy systems degrade image quality and resolution. This problem is particularly apparent when imaging at depth in biological samples where changes in the local refractive index and structure of the sample can distort the beam producing a poor-quality focus and eventually making it impossible to image. Many techniques have been developed over the years to determine the aberrations present in a system and then subsequently correct for these aberrations by shaping the wavefront of the input beam with the equal but opposite distortion. Most of these approaches have been iterative, searching the wavefront space to optimise on a property of the image and determine the wavefront correction required. Such approaches typically require hundreds if not thousands of iterations to improve the quality of the image. This makes the correction processes slow; live, delicate, samples are exposed to an excessive amount of photons risking photo damage and it becomes impractical to make more than one correction across a field of view. I will present some of our recent work in the field of aberration correction, or wavefront shaping, for deep optical imaging, concentrating on approaches that are iteration free. The first method uses analytical approaches and more recently we have been employing AI and developing deep networks able to predict the aberrations present in an imaging system.

Prof David Alexander (Durham University)

I'm a quasar get me out of here

Friday 15 November 2024

Are quasars, the sites of the most rapidly growing black holes, buried in shrouds of dust? A quasar is the observed manifestation of a rapidly growing super-massive black hole. The majority of quasars discovered to date are blue in colour due to us having a direct view of the mass accretion onto the black hole. However, a minority of quasars are found to be optically red, almost always due to the presence of obscuring dust along the line of sight. The standard model postulates that these red quasars are more inclined towards our line of sight than blue quasars such that the accreting black holes are partially hidden from us. On the basis of this model red quasars would have essentially the same basic properties (on average) as blue quasars, when the effects of obscuration and orientation are taken into account.

I will report on a series of systematic and controlled multi-wavelength experiments where we identify fundamental differences between red and blue quasars, particularly in the radio waveband. I will show that these results suggest a connection between opacity and the production of radio emission, potentially due to shocks from winds and/or jets as the quasar tries to break free of a dusty shroud. These results appear in conflict with the standard model and I argue that they point towards red quasars representing a distinct phase in the evolution of quasars.

I will finish with our latest research which extends these results to even fully obscured quasars, where we also identify differences in the host galaxy and large scale properties. I will discuss plans to extend these results with our upcoming 4MOST survey and discuss our results in the context of the latest discoveries by the JWST telescope.

Dr Shuqiu Wang (University of Bristol)

Visualizing Intrinsic Topological Superconductivity

Friday 29 November 2024

Topological order represents a revolutionary framework in condensed matter physics that describes quantum states through their robust mathematical properties. This has led to the discovery of exotic quantum phases such as topological superconductivity and quantum spin liquids, with profound implications for new quantum matter physics and future technologies. A macroscopic quantum state emerges from the collective behaviour of electrons and spins. In correlated electronic systems, electrons or spins dance independently but follow identical patterns. In topological orders, electrons or spins interact through local quantum rules, creating coherent global patterns characterized by long-range entanglement. Intertwining electronic correlations and topology now stands at the frontier of modern quantum matter research. One of its most profound consequences is the intrinsic topological superconductivity (ITS), a unique and quite extraordinary type of macroscopic quantum matter. ITS promise both cutting-edge science and revolutionary quantum technology, such as quantum computing. Key signatures for an ITS include the existence of spin-triplet pairing, topological surface bands and persistent surface currents. None of these characteristics has ever been detected due to the lack of visualization techniques. I will present our quest to discover and visualize intrinsic topological superconductivity, starting with fundamental concepts and historical context. Using innovative scanning tunnelling microscopy (STM) imaging [1], we achieved a sequence of breakthroughs in the spin-triplet superconductor UTe2 [1], identifying key ITS signatures including distinctive surface bands and non-chiral pairing. These findings represent the first detection of three-dimensional ITS characteristics, which is an unprecedented quantum state.

References:

[1] Gu, Carroll, Wang et al., Nature 618, 921 (2023).

[2] Gu, Wang, Carroll, Zhussupbekov et al., Science (2024).

Prof Sir Michael Berry (University of Bristol)

https://michaelberryphysics.wordpress.com/

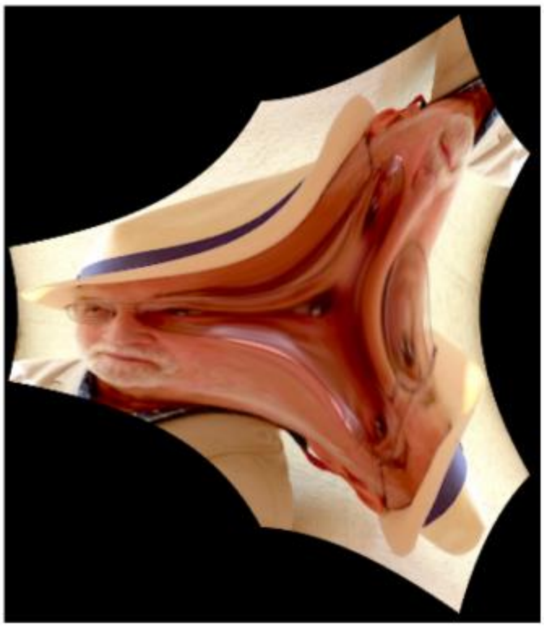
Four geometrical-optics illusions

Friday 13 December 2024

Centuries after the laws of geometrical optics were established, they still have nontrivial and varied applications. Illustrating this are some illusions:

Mirages, and Raman's error. Understanding why he denied the applicability of geometrical optics requires careful exploration of the continuum limit of a discretely-stratified medium, to reveal its nonuniform convergence.

Oriental magic mirrors and the Laplacian image. The optics of these several-millenniaold objects involves the unfamiliar regime of pre-focal brightening. The transmission analogue ('Magic windows') raises a challenge for freeform optics.



The squint moon and the witch ball. The moon sometimes appears to point the wrong way because we perceive the sphere of directions as a distorted 'skyview', on which geodesics appear curved. This can be conveniently viewed and analysed by viewing the sky in a reflecting sphere.

Distorted and topologically disrupted reflections in curved mirrors. Mirror-reflected rays from each point of a continuous object form caustic surfaces in the air. Images are organised by those points whose caustics intersect our eyes and can be systematically understood in terms of the elementary catastrophes of singularity theory.

Prof Sonja Franke-Arnold (University of Glasgow)

Polarisation textures of light and atoms

Friday 21 February 2025

Polarisation - while invisible to the eye - has been recognized as an important feature of light since the days of Ptolemy. Over the last decades we have gained unprecedented control over light, allowing us to generate polarisation structures in 2D and 3D, explore its topologies and its interaction with matter. In this talk I will present how we generate and analyse arbitrary polarization textures and introduce you to some of its curious properties, including new insights into knife-edge diffraction, and optical skyrmions. I will explain how we can transfer optical polarisation textures to polariton structures in atomic gasses. Unlike optical polarizations, atomic spin alignments react to external fields and forces, promising applications in magnetometry and inertial sensing - and vice versa allowing us insights into optical properties that can not be detected directly with photodiodes or cameras.

Prof Francesca Santoro (RWTH Aachen and Forschungszentrum Juelich)

Neuromorphic Materials and Biointerfaces for Neuroelectronics

Friday 7 March 2025

The replication of neural information processing in electrical devices has been exten-sively explored, particularly in the context of brain-computer interfaces. Neuromorphic materials, particularly organic electrochemical transistors (OECTs) based on PE-DOT:PSS, exhibit mixed ionic-electronic conduction, biocompatibility, and synaptic plasticity, making them ideal for biointerfacing applications. These devices emulate neural plasticity mechanisms such as short-term facilitation and long-term potentiation, with neurotransmitter-dependent modulation playing a crucial role in the establishment of biohybrid synapses. The electrolyte composition, particularly the role of bio-gels, significantly influences synaptic behavior and long-term memory effects.

Beyond their biochemical functionality, neuromorphic interfaces also benefit from bio-mimetic structural features. We have engineered 2.5D and 3D microstructures that resemble dendritic spines and neuronal morphologies using two-photon polymeriza-tion and PEDOT-based blends. These structures include thin, contact-initiating spines, dynamically reshaping mushroom-like spines, and stubby forms, all of which contribute to the remodeling of neural circuits. Our findings indicate that microelectrodes and sur-face topography influence neural network behavior, affecting growth cone dynamics and directing neuronal outgrowth. Importantly, we demonstrate that growth cone rates change in response to different surface pitches, suggesting that topographical cues impact membrane adhesion proteins and enhance electrical coupling.

Furthermore, optoelectronic materials, such as conjugated polymers engineered with azopolymers, enable light-induced short- and long-term plasticity. The integration of these biomimetic materials into bioelectronic devices opens new possibilities for seam-less neural interfaces, with implications for implantable probes and artificial neuronal networks. This research advances the development of biohybrid neuromorphic sys-tems, paving the way for enhanced bidirectional communication between artificial and biological neuronal networks in vitro and in vivo.

Prof Yulin Chen (University of Oxford)

Visualization of Electronic Structures of Quantum Materials

Friday 25 April 2025

The discovery of materials with novel properties is one of the most captivating aspects of physics, playing a pivotal role in advancing science and improving human life.

The electronic structure of a material is critical information that determines its electrical, magnetic, and optical properties. A precise understanding of this information not only provides insights into the diverse properties and phenomena of quantum materials but also guides the design of their potential applications.

Angle-resolved photoemission spectroscopy (ARPES) is a powerful technique for determining the electronic structures of materials. With its energy and momentum resolution, ARPES can directly visualize the dispersions of electronic bands in reciprocal space, providing critical parameters for understanding material behaviour.

In this talk, I will begin with a brief introduction to ARPES, including its basic principles and the wealth of information it offers. I will then highlight its application on the study of topological quantum materials, low-dimensional systems, and exotic superconductors. Finally, I will discuss recent advancements in ARPES technology and share perspectives on its future directions and applications.

Prof Debora Sijacki (University of Cambridge)

Unveiling the emergence of first galaxies and supermassive black holes with cosmological simulations in the JWST era

Friday 23 May 2025

The James Webb Space Telescope (JWST) is a stunning technological achievement. It is the largest and most powerful space telescope ever built and has sensitivity up to three orders of magnitude higher in parts of the infrared than its predecessors. JWST promises to be a formidable cosmic time machine' allowing us to peer back in time to only a few hundred million years after the Big Bang, when the very first stars, galaxies and supermassive black holes emerged from theDark Ages'. The first results have already stirred the observational and theoretical communities, with spectacular discoveries bound to come in the next few years.

In this talk I will review the state-of-the-art in our theoretical efforts to understand the physics governing the evolution of the very first cosmic structures from the time of the ` Dark Ages'. I will discuss the complex interplay of galaxies and supermassive black holes in the early Universe, from the formation of dwarf galaxies hosting perhaps the elusive intermediate mass black holes, to the most massive proto-clusters harbouring 'gargantuan' black holes. I will emphasize what we can learn from the latest cosmological simulations of these objects in conjunction with the incoming JWST data. Finally, I will also discuss synergies of JWST with other upcoming space missions, such as Athena and LISA, which will fully unlock the multi-messenger view of our Universe.

Dr Mohammad Saeed Bahramy (University of Manchester)

Modelling Emergence and Complexity in Quantum Materials

Friday 6 June 2025

The rich landscape of quantum materials arises from the subtle interplay among charge, spin, orbital, and lattice degrees of freedom—an interplay that gives rise to phenomena far greater than the sum of their parts. Understanding these emergent effects, from topological phase transitions to unconventional superconductivity, requires theoretical tools capable of bridging microscopic interactions and macroscopic behaviour. In this talk, I will present a series of recent studies exploring emergent quantum phenomena using multi-scale modelling approaches. Focusing on systems with intrinsic disorder and magnetic anisotropies, I will discuss topics such as disorder-induced multifractality in superconductors, quantum coherence in low-dimensional systems, and topological phase transitions in 2D materials. I will also highlight how local magnetic moments coupled with itinerant carriers can drive novel valley-spin locking mechanisms and enable nontrivial topological phases in 2D van der Waals materials. By connecting atomistic interactions to emergent quantum behaviour, these studies pave the way for the rational design of materials with tailored quantum functionalities.