SOILM13

Participant	Title	Abstract
Andrea Aiello	Surface spin angular momentum	
David Andrews	Multipole emission and multipole detection: spin and orbital selection rules	
Mohamed Babiker	Spin-orbit effects in optical and electron vortices	The spin-orbit coupling in the context of optical vortices and electron vortices is discussed, with particular reference to interaction of each type of vortex with matter. In the case of optical vortices, spin-orbit effects are manifest in the linear momentum density and require consideration of circularly polarised vortex modes. We show that the coupling between spin and orbit also arises in the interaction of such vortex with matter. In the context of electron vortices, we show that an electron vortex also possesses electric and magnetic fields in addition to its angular momentum properties and we emphasise that it is the radial nature of the electric field associated with the vortex which ensures the existence a spin-orbit interaction in this context. Order of magnitude estimates of the effect for electron vortices produced inside an electron microscope and in linear accelerators are discussed
Peter Banzer	Demonstration of a state of the light field with purely transverse angular momentum	
Stephen Barnett	Optical helicity and spin angular momentum	Stephen M. Barnett, Robert P. Cameron and Alison M. Yao Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK Helicity is a familiar concept in particle physics and in the physics of fluids and plasmas. It is less well known in classical and quantum optics. For the free field it takes the simple form [1] H_opt=(1/2)dV(AB-CE) where C is the 'electric potential'; the electric analogue of the familiar magnetic or vector potential A. Despite its strange appearance, the helicity is gauge-invariant and it is also a conserved quantity for the free field. The symmetry associated with this conservation law is the symmetry between the electric and magnetic fields , due to Heaviside and Larmor [2]. Helicity is quite distinct from the spin angular momentum: the first is a (pseudo) scalar and the other is a (pseudo) vector and they transform very differently on reflection, for example. They are also quite distinct from Lipkin's zilches and other quantities that have been used to analyse chiral interactions [3]. [1] S. M. Barnett, R. P. Cameron and A. M. Yao, Phys. Rev. A 86, 013845 (2012). [2] O. Heaviside, Phil. Trans. R. Soc. A 183, 423 (1892); J. Larmor, Phil. Trans. R. Soc. A 190, 205 (1897). [3] R. P. Cameron, S. M. Barentt and A. M. Yao, New J. Phys. 14, 053050 (2012).
Iwo Bialynicki-Birula	Geometry underlying the polarization-orbit coupling of photons	An uncertainty relation for photons will be deriveded in my talk that is close in spirit to the original Heisenberg uncertainty relation. It employs the analog of the position operator for the photon---the center of the energy operator. The noncommutativity of the components of the center of the energy operator results in the increase of the bound as compared to the standard Heisenberg uncertainty relation in three dimensions. This difference diminishes with the increase of the photon energy. In the infinite-momentum frame, the lower bound in the Heisenberg uncertainty relations for photons is the same as in nonrelativistic quantum mechanics. The relevance of the photon uncertainty relations for the photon spin/helicity problem will be pointed out.
Konstantin Bliokh	Dual electromagnetism: Helicity, spin, momentum, and angular momentum	The dual symmetry between electric and magnetic fields is an important intrinsic property of Maxwell equations in free space. This symmetry underlies the conservation of optical helicity (chirality), and, as we show here, is related to the separation of spin and orbital degrees of freedom of light. However, in the standard field-theory formulation of electromagnetism, the field Lagrangian is not dual symmetric. This leads to difficulties in the derivation of the helicity conservation and to problematic dual-asymmetric forms of the canonical energy-momentum, spin, and orbital angular momentum tensors. To resolve this discrepancy between the symmetries of the Lagrangian and Maxwell equations, we put forward a dual-symmetric Lagrangian formulation of electromagnetism. This preserves the form of Maxwell equations, all fundamental conservation laws of standard electromagnetism, and recovers the helicity conservation as the basic U(1) Noether current. We show that the dual-symmetric electromagnetism naturally yields meaningful canonical energy-momentum, spin, and orbital angular momentum tensors. This ensures a self-consistent separation of the spin and orbital degrees of freedom of light, which is in complete agreement with other recent results. Furthermore, only in the dual-symmetric electromagnetism, the helicity current naturally coincides with the spin density. We also discuss the observability of physical quantities in the dual electromagnetism, and relation to quantum weak measurements.
Etienne Brasselet	Interplay between material and optical topological defects	
Maarten DeKieviet	Exploring geometric phases	
Mark Dennis	The analogy between optical beam shifts and quantum weak measurements	
Aristide Dogariu	Optical Action in Complex Fields	We will review situations where the coherence and polarization properties of complex electromagnetic fields control the unique manifestations of mechanical action at mesoscales.
Eric Eliel	Optical angular momentum conversion in a nanoslit	
Vladimir Fedoseyev	Transverse forces related to the transverse shifts of the reflected and transmitted light beams	The process of reflection and transmission of a paraxial wave packet at a plane interface of two isotropic transparent media is considered. The transverse force (TF), i.e., the force perpendicular to the plane of incidence, which is exerted by the medium on the field in the course of this process, is investigated. It is shown that the TF under investigation can be identified as the reverse Abraham TF. The relations between this force and the transverse shifts (TSs) of the centers of gravity of the reflected and transmitted light beams are established. It is argued that the detection of linear and angular TSs means the determination of the respective TFs. On the basis of the aforementioned relations, the analytical expression for the TF associated with the linear TSs has been obtained, which shows that this TF is a fundamental feature of the transformation of the beam's intrinsic angular momentum at the interface.
Ivan Fernandez-Corbaton	Spin to orbital angular momentum transfer: A revision based on symmetries	We propose a theoretical and practical framework for the study of light-matter interactions and the angular momentum of light. Our proposal is based on helicity, total angular momentum, and the use of symmetries. We compare the framework to the current treatment, which is based on separately considering spin angular momentum and orbital angular momentum and using the transfer between the two in physical explanations. In our proposal, the fundamental problem of spin and orbital angular momentum separability is avoided, predictions are made based on the symmetries of the systems, and the practical application of the concepts is straightforward. Finally, the framework is used to show that the concept of spin to orbit transfer applied to focusing and scattering is masking two completely different physical phenomena related to the breaking of different fundamental symmetries: transverse translational symmetry in focusing and electromagnetic duality symmetry in scattering.

Sonja Franke-Arnold	Trans-spectral quantum imaging	Spatial light modes allow to encode information as quantum images, and the orbital angular momentum modes provide a particularly accessible basis set. We use multi-photon processes in atomic cascades to transfer orbital angular momentum modes and their superpositions across the visible spectrum from IR pump light to blue output light.
Giulio Guzzinati	Observing Image Rotations induced by Larmor and Gouy phase in Electron Vortices	Electron vortex beams are created in a transmission electron microscope. The interaction between the OAM of the vortex beams and the magnetic fields of the microscope lenses lead to various rotational phenomena in mode superpositions. The Zeeman coupling is proportional on the OAM but produces the Larmor rotation, which is OAM-independent. The Gouy phase acquired by a beam passing through a focal point depends on the absolute value of the OAM, but causes a rotation that depends on the sign of the OAM. The superposition of the two effect results in the addition or subtraction of the rotations, depending on the OAM sign.
Erez Hasman	Spinoptical metamaterials: spin-controlled photonics	
Ebrahim Karimi	Generation of an electron spin-polarisiation filtering based on spin-to-orbit conversion	
Antonio Khoury	Quantum and nonquantum entanglement in spin-orbit optical modes	In this work we present a summary of our recent developments in the investigation of important coherence properties of optical vortices with potential applications to quantum information. Combination of orbital and spin angular momentum gives rise to interesting applications to quantum information tasks like the implementation of conditional quantum gates and quantum criptography. In the classical domain, spin-orbit modes can reveal important properties of entanglement with classical optical setups. For example, using spin-orbit nonquantum entanglement we discuss the topological phase associated with the SO(3) representation in terms of maximally entangled states. Bell's inequality can also be discussed in this framework. In the quantum domain, continuous variable hyperentanglement in an optical parametric oscillator and a spin-orbit teleportation protocol have been proposed.
Jan Korger	Direct measurement of a novel geometric spin Hall effect of light	Spin Hall effect of light (SHEL) is an amazing phenomenon occurring when a beam of light interacts with an oblique interface. It amounts to a polarization-dependent beam shift, which is a consequence of the coupling between spin and spatial degrees of freedom. Geometric SHEL is a particularly pure kind thereof, largely independent from the properties of the physical interface. We present an experimental study of a novel geometric spin Hall effect of light. Here, a tilted polarizer is used to break the symmetry of a circularly polarized light beam. As a result, the linearly polarized beam transmitted across the polarizing interface undergoes a shift of more than half the wavelength.
Byoungho Lee	Plasmonic vortex generation and its characteristics	With appropriately designed metallic slit structures, plasmonic vortex patterns can be generated on metallic surfaces. The total vortex charge is determined by the geometrical cahrge, orbital angular momentum and spin of incident light. The location of vortex can be adjusted by the use of spatial light modulator with phase modulation of incident light. Further extention of plasmonic pattern shaping will also be discussed.
Daniel Leykam	Nonlinear wave dynamics in photonic Lieb lattices: The role of pseudospin	Some periodic structures with more then one site in a unit cell have intersections between two or more Bloch bands, and the wave excitations around these intersection points are described by relativistic wave equations. The amplitude of the waves on the different sites in the unit cell is usually called pseudospin. Surprisingly, there are some indications that the pseudospin is connected to real angular momentum. We study analytically and numerically the effect of the pseudospin on wave propagation in the Lieb lattice, which has 3 sites in each unit cell, and is associated with pseudospin 1. We find that the effective wave equation describing the excitations is a spin 1 version of the nonlinear Dirac equation, incorporating intrinsic spin-orbit coupling. In the presence of long range disorder, the pseudospin enhances wave transport by suppressing backscattering.
Chunfang Li	On the angular momentum of photons: Canonical quantization of radiation fields at the inner reference frame	A new representation, called Jones representation, is introduced to canonically quantize the radiation field. Being different from the Maxwell wavefunction that is defined in the laboratory reference frame and is constrained by the transversality condition, the Jones wavefunction is defined in the so-called inner reference frame. It is the position vector with respect to the inner reference frame that is canonically conjugate to the momentum. Nevertheless, the inner reference frame is not associated with the laboratory reference frame simply by a spatial translation. Instead, the origin of the inner reference frame with respect to the laboratory reference frame is described by an operator in the Jones representation. A new degree of freedom is also identified to determine this operator. The notion of inner reference frame can be regarded as a natural generalization of the classical concept of center of mass in the quantum theory. As a matter of fact, for the eigen excitations such as the plane-wave modes and the diffraction-free modes, the origins of their inner reference frames become their centers of mass with respect to the laboratory reference frame. Based on these observations, the angular momentum of photon is shown to satisfy the commutation relations that were obtained by van Enk and Nienhuis [J. Mod. Opt. 41, 963 (1994)] from a consideration of the second quantization.
Natalia Litchinitser	Strcutured Light in Linear and Nonlinear Nanostructures	We discuss linear and nonlinear optical interactions of structured light with magnetic, negative index, and indefinite metamaterials. Our studies predict that many light-matter interactions that involve structured light, including second harmonic generation and parametric amplification that rely on phase matching, will be strongly modified in negative index materials. This is due to the fact that for structured light the Poynting vector is not collinear with the direction of the beam as it has an azimuthal component while phase and energy velocities are antiparallel in negative index materials.
Sophia Lloyd	Mechanical and electromagnetic properties and interactions of electron vortices	Recent advances have led to the creation in the laboratory of electron vortices, which are akin in some respects to optical vortices. However, in addition to orbital angular momentum as a major feature, an electron vortex is endowed with electric charge, mass and spin. These attributes imply, respectively, associated electromagnetic fields due to the electric charge and current density sources, mechanical properties due to electron mass flux and magnetic properties associated with the spin magnetic moment and spin orbit coupling. This presentation outlines research at York on the consequences of the charge, spin and mass of electron vortices. In particular it evaluates the fields, their electromagnetic-mechanical torque, and the spin and spin-orbit interactions. It also evaluates the mass flux and its mechanical linear and orbital angular momenta. The influence of the vortex on the motion of matter, either in the form of atoms or matter in the bulk is also discussed.
Lorenzo Marrucci	Orbital angular momentum from a spin rotation: the optical and electron-beam cases	The angular momentum of photons and of most material particles can be split into spin and orbital components. In the optical case, processes involving a controlled conversion of angular momentum from one form to another in suitable media were conceived and experimentally demonstrated, both in the classical [1] and quantum regimes [2]. These processes allow for the generation of a nonzero orbital angular momentum from an imposed rotation of the spin. We will briefly review some of these processes, and survey their applications in classical and quantum optics [3,4]. A similar process can be theoretically proposed for the case of material particles, such as electrons, that are freely propagating in suitable electric and magnetic fields [5]. The latter effect might lead, among other possible applications, to designing a relatively high-efficiency electron-beam spin filter, a device for which there is no current existing technology. [1] L. Marrucci, C. Manzo, D. Paparo, Phys. Rev. Lett. 96, 163905 (2006). [2] E. Nagali, F. Sciarrino, F. De Martini, L. Marrucci, B. Piccirillo, E. Karimi, E. Santamato, Phys. Rev. Lett. 103, 013601 (2009). [3] L. Marrucci, E. Karimi, S. Slussarenko, B. Piccirillo, E. Santamato, E. Nagali, F. Sciarrino, J. Opt. 13, 064001 (2011). [4] V. D'Ambrosio, E. Nagali, S. P. Walborn, L. Aolita, S. Slussarenko, L. Marrucci, F. Sciarrino, Nature Communications 3, 961 (2012). [5] E. Karimi, L. Marrucci, V. Grillo, E. Santamato, Phys. Rev. Lett. 108, 044801 (2012).
Michele Merano	Role of spatial coherence in the Goos-Hänchen shift	We investigate experimentally the role of spatial coherence on optical beam shifts. This topic has been the subject of recent theoretical debate. We consider Gaussian Schell-model beams, with different spatial degrees of coherence, reflected at an air-glass interface. We prove that the angular Goos-Hänchen and the angular Imbert-Fedorov effects are affected by the spatial degree of coherence of the incident beam, whereas the spatial Goos-Hänchen effect does not depend on incoherence. Our data unambiguously resolve the theoretical debate in favour of one specific theory.

Gabriel Molina-Terriza	Electromagnetic duality and optical helicity	In this talk I will present our latest results on the connection between electromagnetic duality and optical helicity. Helicity is the projection of the total angular momentum onto the linear momentum and has been used in particle physics to describe the quantum state of particles. In the case of the photon it is a conserved quantity in free space and its related symmetry is the electromagnetic duality (the symmetry between electric and magnetic fields). I will explain the advantages of using helicity in experiments and in particular in the field of nanooptics.
Klaus Morawetz	Quantum transport and response to electric fields in non-Abelian systems with spin-orbit coupling and magnetic fields	Electronic transport in spin-polarized systems with impurity and electron-electron interactions as well as spin-dependent meanfields are discussed. The appropriate quantum kinetic equation for SU2 are derived with special consideration of spin-orbit coupling and magnetic fields. With the help of this the spin and density dynamical response to electric fields (polarized light) is calculated and several effects are described: spin-Hall, anomalous Hall and optical Hall effect, spin-heat coupling, extended quasiparticle picture and polarization effect from correlated density. Clarifying the relative importance of meanfield and scattering correlations, new modes due to magnetic fields and spin-orbit coupling are found.
Gerard Nienhuis	Linear operators and conserved quantities in classical and quantum optics	
Marco Ornigotti	Goos–Hänchen and Imbert–Fedorov shifts for bounded wavepackets of light	The spin of a circularly polarized beam of light in vacuo is calculated and compared with the value of the spin of a wave packet of light. While the latter has a finite longitudinal and transverse extent, the beam virtually extends indefinitely along the direction of propagation. This fact introduces a flaw in the textbook derivation of the spin part and of the orbital part of the angular momentum of the wave. Such a derivation assumes that some surface terms vanishes at infinity or, equivalently, that the light wave has a finite extent along any direction. This condition is clearly not satisfied by a beam-like wave. Remarkably, accounting for these surface terms yields to an extra observable spin-like part of the angular momentum of the beam. We report an explicit calculation of this novel “surface spin angular momentum” term for a Gaussian and Bessel beams, and discuss diverse fundamental facets of this issue.
Miles Padgett	The orbital angular momentum of light scattered from a spinning object	ht caries both a spin and an orbital angular momentum. Whereas the spin angular momentum is associated with circular polarisation, the orbital component is linked to helical phase-fronts. If there is a relative rotation between the source and the observer then the light undergoes a frequency shift proportional to its angular momentum; the rotational Doppler shift. Here we show, not restricted to specially prepared beams, that light scattered from a spinning object experiences a similar effect. We demonstrate that by analysing the orbital angular momentum of the scattered light the rotational speed of the object can be inferred. This ability to remotely detect the rotation of a body with an angular momentum directed along the observation direction has applications in both terrestrial and astronomical settings.
Pepijn Pinkse	Spin-Orbit coupling in a Fabry-Perot resonator	The appearance of a Berry's geometric phase is a universal phenomenon when dealing with 3D rotations. A consequence for simple Fabry-Perot resonators, however, is quite unexpected. Using analytical solutions to Maxwell's equations in spheroidal coordinates [1], the first-order corrections to eigenmodes and eigenfrequencies in a Fabry-Perot resonator are calculated in the short-wavelength limit [2]. Analogous to atomic spectra, these analytical expressions show the “fine structure” of the spectrum of an optical resonator [2]. An important and unexpected feature of this theoretical result is the lifting of the degeneracy of Fabry-Perot cavity resonances by spin-orbit coupling of light. Moreover, the spin-orbit coupling can be shown to be entirely due to a Berry's geometric phase being picked up by the resonating light. Precision measurements on a high-finesse optical resonator revealing intricate mode patterns demonstrate these surprising effects. Modes which are degenerate within the paraxial approximation are split according to their total angular momentum. Quantitative agreement between the theoretical and experimental resonator spectrum is obtained. [1] Solutions to Maxwell's Equations using Spheroidal Coordinates, M. Zeppenfeld, New J. Phys. 11, 073007 (2009). [2] Calculating the Fine Structure of a Fabry-Perot Resonator using Spheroidal Wave Functions, M. Zeppenfeld and P.W.H. Pinkse, Opt. Expr. 18, 9580-9591 (2010).
Graciana Puentes	Weak Measurements with Orbital-Angular-Momentum Pointer States	Weak measurements are a unique tool for accessing information about weakly interacting quantum systems with minimal back action. Joint weak measurements of single-particle operators with pointer states characterized by a two-dimensional Gaussian distribution can provide, in turn, key information about quantum correlations that can be relevant for quantum information applications. Here we demonstrate that by employing two-dimensional pointer states endowed with orbital angular momentum (OAM), it is possible to extract weak values of the higher order moments of single-particle operators, an inaccessible quantity with Gaussian pointer states only. We provide a specific example that illustrates the advantages of our method both in terms of signal enhancement and information retrieval [1]. [1] G. Puentes, N. Hermosa, J. P. Torres, Phys. Rev. Lett. 109, 040401 (2012).
Llorens Serra	Spin-orbit interation and Majorana modes in semiconductor wires	I discuss the formation of zero-energy Majorana modes in semiconductor wires due to the combined action of Rashba SO interaction, induced superconductivity and Zeeman splitting. In particular, I will focus on the role of finite size effects and Rashba mixing on the formation of Majorana states. Motivated by recent transport experiments, I will present a coupled channel model allowing the calculation of the linear and differential conductance in Majorana nanowires. Finally, I will discuss the description of Majorana modes using the complex-band structure formalism. In this approach the wave function of a Majorana state is described as the superposition of multiple evanescent waves.
Manuel Valiente	Effective single-branch theory for interacting ultracold Fermi gases with artificial spin-orbit coupling	I will present our recent results concerning interacting Fermi gases at ultra low temperatures. After showing how artificial spin-orbit coupling arises in ultracold gases of Fermionic atoms, I will show how to construct a single-branch (negative helicity) theory for interacting fermions that is free of the extra undesired ultraviolet divergence. In this way, perturbation theory reduces to that for spin-polarized (in this case, helicity-polarized) fermions, which allows for a simple, systematic treatment of the system.
Johan Verbeeck	Electron vortices interacting with matter	Orbital angular momentum in electron waves provides an interesting addition to the family of singular optics phenomena. This talk will give an overview of the state of the art in producing elecron vortices with special attention to their interaction with matter. Both elastic and inelastic interaction will be discussed and preliminary experiments will be shown.
Zachary Walters	Quantum Dynamics of the Avian Compass	Recent experiments involving migratory birds suggest that their ability to orient themselves relative to the Earth's magnetic field may involve a coherent superposition of the $m_=0$ singlet and triplet states of a radical electron pair. However, such a mechanism demands that the coherent dynamics necessary to generate a useful signal must somehow survive the decoherence induced by hyperfine interactions between the radical pair and the surrounding nuclear spins. I show how the dynamics of a radical pair interacting with a bath of spin 1/2 particles may yield long coherence times, and propose a simple and robust mechanism for generating a useful biological signal.
Jun Yuan	Recent experimental progress on Electron Vortex Beams in York	Research into physics and applications of electron vortex beam has emerged as a hot topic in science in recent years, as it potentially offers many exciting and possibly game-changing opportunities in electron spectroscopy and electron microscopy. In this talk, our recent experimental results in this area will be summarized. This consists of work in the generation of electron vortex beams inside an aberration corrected electron microscope, the characterization of their physical properties as well as their interaction with nanostructures. In particular, we will present direct evidence of nanomanipulation of gold nanoparticles driven by electron vortex beams and our effort in the understanding of the microscopic physical processes involved, in conjunction with theoretical simulation. The application of electron vortex beams in chiral specific energy-loss spectroscopy will also be presented.