PH450 Project 2017-18

2nd Round Choices

Plasmas Division

Excitation of Heavy Atomic Species for ITER

(1) Prof Nigel Badnell, (2) Prof Bob Bingham (TBC)

Project Description:

The development of the ITER device for magnetic fusion requires the use of much heavier elements (Kr, Xe, W etc) than have traditionally been used, such as at the JET device.

Consequently, spectroscopic diagnostic modelling at ITER, which is already being simulated, requires atomic data where relativistic effects are likely much larger than have been seen before. The goal of the project is to assess the degree of importance of relativistic effects of relevance to ITER diagnostics. This will entail computational calculations of atomic data with varying degrees of treatments of relativistic effects viz. non-relativistic vs relativistic wavefunctions, the importance of the Breit interaction and the validity of its Pauli approximation at `low'-charge.

Key Reference: *http://www.iter.org/*

Ratio of Experiment/Theory/Computation:

Exp:	0 %
Theo:	30 %
Comp:	70 %

Suitable for: MPhys

Additional Comments: Familiarity with Unix (e.g. Linux) working environment and good computing skills in general.

Safety Training Requirements:

Simulation and measurement of two-dimensional periodic surface lattice

(1) Prof Adrian W. Cross, (2) Dr Craig W. Robertson

Project Description:

The main goal of the project is to study the interaction between two-dimensional (2D) periodic surface lattice (PSL) structures and electromagnetic waves. The primary objectives are: 1/ Theoretical study of electromagnetic wave propagation through a cylindrical 2D periodic surface lattice; 2/ Develop a CST Microwave Studio computer model of electromagnetic wave interaction with the 2D PSL; 3/ Experimental study of the transmission of electromagnetic radiation through the cylindrical 2D periodic surface lattice.

The properties of a periodic structure will be measured using a Vector Network Analyser. Experimental measurements will be compared with CST Microwave Studio simulations of the transmission of electromagnetic radiation through the structures**.**

Key Reference:

[1] I.V. Konoplev, A.J. MacLachlan, C.W. Robertson, A.W. Cross and A.D.R. Phelps, 'Cylindrical periodic surface lattice as a metadielectric: Concept of a surface-field Cherenkov source of coherent radiation' Phys. Review A., **84**, art. 022902, 2011.

[2] I.V. Konoplev, A.J. MacLachlan, C.W. Robertson, A.W. Cross and A.D.R. Phelps, "Cylindrical, periodic surface lattice-Theory, dispersion analysis, and experiment, Applied Physics Letters, **101**. 121111, 2012.

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	30%
Comp:	50%

Suitability: PH550 M.Phys.

Additional comments:

Safety Training Requirements:

Design and simulation of a millimetre wave source based on a pseudospark produced electron beam

(1) Prof Adrian W. Cross, (2) Dr Huabi Yin

Project Description:

A project is proposed to design, simulate and numerically model a Backward Wave Oscillator (BWO) driven by a pseudospark (PS) electron beam. The BWO is based on the interaction between an electron beam and the negative spatial harmonic of a corrugated slow wave structure. The energy velocity in the slow-wave structure moves opposite to the phase velocity of the negative spatial harmonic. If the electron beam is synchronised with the negative spatial harmonic then the energy of the electron beam transfers to the field in the backward (with respect to the direction of beam propagation) direction [1].

A pseudospark (PS) is an axially symmetric, self-sustained, transient, low pressure (typically 50-500 mTorr) gas discharge in a hollow cathode/planar anode configuration, which operates on the low pressure side of the hollow cathode analog to the Paschen curve [2]. A useful property of this type of discharge is the formation of an electron beam during the breakdown process. During a PS discharge, low temperature plasma is formed as a copious source of electrons and can be regarded as a low work function surface that facilitates electron extraction [3]. Because of the special geometry and discharge mechanism, the electron beam from a PS discharge can propagate without an external magnetic guiding field due to the existence of an ion-focusing channel. The ion-focusing channel is formed due to the background gas ionization by the front of the electron beam itself. For generation of high frequency radiation in millimetre wave and sub-millimetre wave region this beam is ideal due to its small beam size, compactness and long lifetime. The project will involve the design of a millimetre wave BWO using analytical theory with the beam/wave interaction modelled using the numerical simulation code MAGIC.

Key Reference:

[1] S. E. Tsimring “Electron Beams and Microwave Vacuum Electronics", Wiley Series in Microwave and Optical Engineering, John Wiley and Sons Inc, ISBN-13-978-0-470-04816-0, (2007).
[2] H. Yin, A. W. Cross, W. He, A. D. R. Phelps, K. Ronald, D. Bowes, C.W. Roberson “Millimeter wave generation from a pseudospark-sourced electron beam". Phys. Plasmas 16 (2009).
[2] D. Bowes, H. Yin, W. He, A.W. Cross, K. Ronald, A.D.R. Phelps, D. Chen, P. Zhang, X. Chen and D. Li, "Visualization of a Pseudospark-Sourced Electron Beam", IEEE Transaction on Plasma Science, 42, 10, pp2826-2827, (2014).

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	30%
Comp:	50%

Suitability: PH450 BSc

Additional comments:

Safety Training Requirements:

Simulations of magnetic turbulence in plasma

(1) Bengt Eliasson, (2) Kevin Ronald

Project Description:

Plasmas are ubiquitous in space and laboratory. The Earth is surrounded by a plasma layer, the so-called ionosphere, which shields us from radiation and energetic particles from the sun, and in the laboratory, plasmas are artificially created and studied with application to magnetic confinement fusion and basic research. A plasma is an ionised gas in which there are free electrons and ions so that the gas is electrically conducting. An outstanding problem in science is the generation of magnetic field in the Cosmos, and the generation of magnetic fields are also observed in laser-plasma interactions. Plasmas are inherently nonlinear systems, and often show unpredictable and turbulent behaviour.

The project involves at building a numerical model for fluid turbulence of electrons in plasmas and magnetic field generation due to temperature and density gradients. A theoretical derivation and understanding of the mathematical models is also part of the project.

Key Reference: B. Eliasson, P. K. Shukla, and V. P. Pavlenko (2009), Dynamics of nonlinearly interacting magnetic electron drift vortex modes in a nonuniform plasma, Physics of Plasmas 16, 042306, doi:10.1063/1.3103785.

Ratio of effort: Exp/Theo/Comp	Exp:	0%
	Theo:	50%
	Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: Experience in simulations using Matlab (or any other programming language) and good theoretical skills are beneficial.

Safety Training Requirements:

Design of a Brewster Window for a W-band Gyro-TWA

(1) Dr Wenlong He, (2) Dr Liang Zhang

Project Description:

A W-band gyrotron-travelling wave amplifier (gyro-TWA) based on a helically corrugated waveguide and a cusp electron gun is currently being studied. It is predicted to achieve an output power of 5 kW over a wide frequency band of 90 - 100 GHz. For an amplifier the microwave window, which separates the high vacuum side from the atmospheric pressure outside must couple in or out the microwave power with minimum absorption or reflection, and is one of the critical components for the successful operation of the gyro-TWA.

In this project, a Brewster-type microwave window will be studied using analytical theory. Numerical simulations Brewster-type microwave window will be carried out using CST Microwave Studio. A corrugated waveguide that maintains the Gaussian-like HE mode required for the Brewster window will also be designed and simulated. The design goals of the Brewster window are 10% bandwidth at a centre frequency of 95 GHz, small insertion loss and a reflection of less than -20 dB for the operating band. If the design meets the requirement, the Brewster window will be manufactured and measured using a Vector Network Analyser (VNA).

Key References:

[1] Wenlong He, Craig R. Donaldson, Liang Zhang, Kevin Ronald, Paul McElhinney and Adrian W. Cross, "High Power Wideband Gyrotron Backward Wave Oscillator Operating towards the Terahertz Region", Physical Review Letters, 110(16):165101, 04, 2013.

[2] Paul McElhinney, Craig R. Donaldson, Liang Zhang and Wenlong He, "A High Directivity Broadband Corrugated Horn for W-band Gyro-devices", IEEE Transactions on Antennas and Propagation, vol. 61, no. 3, pp. 1453-1456, 2013.

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	30%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments:

Safety Training Requirements: *High voltages will **not** be used and X-ray emission will **not** be generated during this project although a risk assessment will need to be completed in semester 1.*

Design and Measurement of a Mode Converter for a Microwave Amplifier

(1) Dr Wenlong He, (2) Dr Craig Donaldson

Project Description:

A microwave amplifier in the form of a gyrotron traveling wave amplifier is being studied at the University of Strathclyde. The amplifier uses the interaction between a rotating electron beam and a low power microwave signal to amplify the microwaves to high power over a wide bandwidth. In order to have the correct interaction a low power microwave signal needs to go through a mode converter to change from a $TE_{1,1}$ mode to a $TE_{3,1}$ mode.

In this project, a mode converter will be studied using analytical theory. Numerical simulations will be carried out using CST Microwave Studio. This converter is a four-fold helical corrugated waveguide. Initially this will be studied and measured using a vector network analyser (VNA), at X-band frequencies ~9 GHz.

In year 2 of the project the converter will be scaled down in size to operate at a much higher frequency in the W-band, at ~ 94 GHz. In both applications the converter will have to operate over the amplifiers bandwidth range of 10GHz and have a high conversion efficiency whilst maintaining a low reflection coefficient.

Key Reference: *He W., Donaldson C.R, Zhang L., Ronald K., McElhinney P., and Cross A.W., "High power wideband gyrotron backward wave oscillator towards the terahertz region", Phys. Rev. Letts, 110, art 165101, (2013).*

Ratio of effort: Exp/Theo/Comp

Exp:	25%
Theo:	25%
Comp:	50%

Suitability: MPhys

Additional comments:

Safety Training Requirements: *High voltages and X-ray emission will **<u>not</u>** be required for this project although a risk assessment will need to be completed in semester 1.*

Numerical simulation of cyclotron maser amplifiers

(1) Dr Kevin Ronald, (2) Dr Alan Young

Project Description:

Applications including communications, RaDAR, industrial heating, fundamental physics research (both particle and plasma physics) and medicine require the amplification of electromagnetic wave signals to levels far in excess of that possible with solid state electronics. Free electron techniques are vital to addressing these needs. Typically an electron beam is accelerated to a high level of kinetic energy, and microwave signals are amplified as they induce a deceleration of the particles. Using the interaction of an EM wave with a gyrating particle beam having a large component of perpendicular velocity has been shown to offer some two orders of magnitude improvement in peak and average power capacity. This project will investigate cyclotron maser amplifiers using a multi-dimensional Finite-Difference Time-Domain method to self consistently model the evolution of the EM fields and particles.

Key References:

He W. et al, 2013, Phys. Rev. Lett., **110**, art 165101
Bratman V.L. et al, 2000, Phys. Rev. Lett., **84**, pp2746-2749
Denisov G.G. et al, 1998, Phys. Rev. Lett., **81**, pp5680-5683
Denisov G.G. et al, 1998, IEEE Trans. Plasma Science, **26**, pp508-518
Cooke S.J. et al, 1996, Phys. Rev. Lett., **77**, pp2320-2323
Lawson W., 2005, IEEE Trans. Plasma Science, **33**, pp858-865
Blank M., 2000, IEEE Trans. Plasma Science, 28, pp706-711

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	10-20 %
Comp:	80-90 %

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: prerequisite PH352, recommended PH452

Additional comments:

Safety Training Requirements: Review and adherence to guidelines for use of computer workstations/VDUs.

Ion Channel Laser with Large Oscillation Amplitude

(1) Dr Bernhard Ersfeld, (2) Prof Dino Jaroszynski

Project Description:

The ion channel laser (ICL) is a proposed device for generating coherent radiation, similar to the free-electron laser (FEL), but much more compact. In the FEL, a relativistic electron beam radiates due to periodic deflection by the magnetic field of an undulator, whereas in the ICL electrons oscillate in the electrostatic field of a channel in plasma from which background electrons have been expelled (by an intense laser pulse or a relativistic particle beam). As an important difference, an efficient ICL requires oscillation amplitudes in excess of the electron beam width, which reduces the overlap with the emitted radiation.

The project offers the opportunity to investigate, analytically and numerically, effects of such large oscillation amplitudes, like harmonic generation and correlations between longitudinal and transverse electron motion.

Key References: B. Ersfeld et al., "The ion channel free-electron laser with varying betatron amplitude", New Journal of Physics **16** (9), 093025 (2014), and literature on free-electron lasers

Ratio of effort: Exp/Theo/Comp	Exp:	0 %
	Theo:	50 %
	Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Knowledge in the following areas would be advantageous: wave propagation, Fourier theory; computer programming (C or similar).

Additional comments: Anyone interested in taking up this project should contact the supervisors beforehand.

Safety Training Requirements: None

Plasma optical modulators for intense lasers

(1) Prof Zhengming Sheng, (2) Dr Feiyu Li

Project Description:

Optical modulators are key components for manipulating optical signals, which are widely used in scientific and industrial applications. For example, high-speed compact electro-optic modulators (EOMs) are essential for data communications. EOMs can alter the fundamental characteristics (that is, amplitude, frequency, phase and polarization) of a light beam in a controllable manner, by making use of electro-optic effects to change the refractive index of a material when an external radio-frequency electric field driver is applied. Normal EOMS can only apply for low light intensity due to the low optical damage threshold. Recently, we have proposed a plasma-based optical modulator [1], which can directly modulate high power lasers with intensity to produce an extremely broad spectrum with ultra-broad bandwidth.

The main task of this project is to investigate the effect of plasma density inhomogeneity along the laser propagation on frequency modulation. The student may also explore the effect of a plasma channel on frequency modulation to see the modulation limit. The student will use a one-dimensional and/or two-dimensional particle-in-cell (PIC) code to study this problem.

Key References:

[1] L.L. Yu, Y. Zhao, L.J. Qian, M. Chen, S.M. Weng, Z.M. Sheng, D.A. Jaroszynski, W.B. Mori, and J. Zhang, "Plasma optical modulators for intense lasers", Nature Comm. 7,11893 (2016).

Ratio of effort: Exp/Theo/Comp			
	Exp:	0	%
	Theo:	20	%
	Comp:	80	%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Laser and Optics, Classical Electrodynamics, some basic knowledge on computer programming such as C, C++, or Fortran and software for visualisation such as MATLAB would be helpful, but not essential.

Additional comments: No

Safety Training Requirements: No

Compact X-ray sources from nonlinear Thomson scattering with intense lasers

(1) Prof Zhengming Sheng , (2) Dr Feiyu Li

Project Description:

X-ray sources are widely used in scientific research, industry, and medicine. Well-known X-ray sources include X-ray tube, synchrotron radiation, X-ray free electron lasers, etc. With the advent of ultrashort high power, one can obtain compact X-ray sources in various new ways.

This project aims to develop a theory model together with corresponding numerical simulation to study the production of ultrashort X-ray sources from nonlinear Thomson scattering. In particular, an all-optical scheme will be considered, in which electrons will be first accelerated by an intense laser pulse and subsequently they are used to scatter the second intense laser pulse (or two intense lasers) for X-ray generation. In this project, the student will focus on the scattering processes. By the end of the project, the student will become familiar with the laser acceleration of a test electron in vacuum and familiar with the calculation of temporal and angular distributions of the X-ray radiations from the scattering of an energetic electron from intense laser pulses.

Key References:

1. W.-M. Wang, Z.M. Sheng et al., Phys. Rev. ST-AB 13, 071301 (2010).
2. S. Corde et al., Rev. Mod. Phys. 85, 1-48 (2013).
3. K. Ta Phuoca et al., Eur. Phys. J. D 33, 301–306 (2005).
4. S. P. Goreslavskii et al., Laser Physics 9, 1039–1044 (1999).
5. Y. Y. Lau et al., Phys. Plasmas 10, 2155-2162 (2003).
6. W. Yan et al., Nature Photonics 11, 514–520 (2017).

Ratio of effort: Exp/Theo/Comp

Exp:	0	%
Theo:	20	%
Comp:	80	%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Classical Electrodynamics, some basic knowledge on computer programming either with C, C++, or Fortran, or MATLAB for simulation and visualisation is essential.

Additional comments: No.

Safety Training Requirements: No.

High harmonics and attosecond radiation from laser interaction with a solid target

(1) Prof Zhengming Sheng, (2) Dr Feiyu Li

Project Description:

Recently with the development of chirped pulse amplification (CPA) technology, one can produce ultrashort and high intensity laser pulses. Such laser pulses can push electrons to relativistic quiver motion, and thereby produce X-ray sources via various schemes.

One scheme is based upon intense laser solid interaction. It is found that free electrons at the solid surface can be driven into relativistic oscillations in the incident laser fields. As a result, high harmonics of the laser pulse will be produced. When the solid target is very thin such as a few nano-meters, the high harmonics generation enters a new regime called coherent synchrotron radiation, where attosecond (1 attosecond=10-15s) light pulses may be produced.

In this project, the student will use some well-developed numerical simulation tool---a particle-in-cell code, to investigate high harmonics generation in different regimes or conditions.

Key References:

1. R. Lichters, J. Meyer-ter-Vehn, & A. Pukhov, Phys. Plasmas 3, 3425 (1996).
2. H.-C. Wu, Z.-M. Sheng et al., Phys. Rev. E 75, 016407 (2007).
3. S. Cousens, B. Reville, B. Dromey, and M. Zepf, Phys. Rev. Lett. 116, 083901 (2016).
3. U. Wagner et al., Phys. Rev. E 70, 026401 (2004).
4. M. Tatarakis et al., Nature (London) 398, 489 (2002).

Ratio of effort: Exp/Theo/Comp	Exp:	0	%
	Theo:	20	%
	Comp:	80	%

Suitability: BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Laser and Optics, Classical Electrodynamics, some basic knowledge on computer programming such as C, C++, or Fortran and software for visualisation such as MATLAB would be helpful, but not essential.

Additional comments: No.

Safety Training Requirements: No.

Nanoscience Division

Calibration of Spatial Light Modulators for Adaptive Optics Microscopy

(1) Dr Brian Patton , (2) TBC

Project Description:

Super-resolution microscopy won the Nobel prize in Chemistry in 2014 for allowing imaging of objects beyond the classical diffraction limit. We are performing research into adaptive optical technologies to improve the performance of planned super-resolution microscopes that will be contrasted and operated within the department.

Adaptive optics uses dynamically controlled components to correct for optical aberrations in an imaging system, restoring near-perfect performance. In the context of microscopy, it allows imaging deep into tissue, where the imhomogeneous refractive index causes problems for standard microscopes. The liquid-crystal spatial light modulator (SLM) is one class of device that finds widespread use in adaptive optics enhanced microscopy. However, in order to correctly incorporate the SLM into the design of the microscope, it is necessary to know its optical performance parameters such as the optical flatness of the device and the magnitude of optical-phase change induced by each pixel of the device. This project involves setting up an interferometric characterisation apparatus to evaluate the performance of a low-cost, but useful, SLM. The project will entail optics design, programming of some software to drive the SLM and analysis of the data derived from the setup.

Key References:

"Optimisation of a low cost SLM for diffraction efficiency and ghost order suppression", R. Bowman et al., DOI: 10.1140/epjst/e2011-01510-4
M. J. Booth, "Adaptive optical microscopy: the ongoing quest for a perfect image," Light Sci. Appl. 3, 165 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	40%
Theo:	20%
Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: Experience of programming is strongly advised, experience of optical design would be helpful but not essential. Some experience of data analysis with Matlab would also be beneficial.

Safety Training Requirements: Low power laser diodes will be required, so Laser Safety Training is essential.

Digital Light Projectors for Dynamically Reconfigurable Microscopy

(1) Dr Brian Patton, (2) TBC

Project Description:

This project will contribute to the development of next generation super-resolution and dynamic optical microscopes within the department. Traditional wide-field microscopes use simple illumination configurations with their design being fixed by the imaging mode (brightfield, darkfield, phase contrast) to be performed. Switching imaging modes is typically not a trivial task and may even be impossible in some designs. Adaptive optics enhancement of the widefield microscope using dynamically reconfigurable devices such as deformable mirrors or spatial light modulators has typically only addressed the detection path of the microscope and has left the illumination path untouched. A recent paper has shown how the incorporation of a low-resolution liquid crystal display (LCD) into the illumination path greatly expands the usefulness of a given wide-field microscope.

This project aims to develop a testbed for these dynamically reconfigurable illumination systems. Instead of using an LCD, the project will use a digital light projector (DLP). The combination of higher pixel count and variable colour illumination will add to the possible parameter space in which improvements to the performance over a traditional microscope design can occur.

The project will initially involve some simple optical design and construction to build the testbed. The majority of the project will involve programming the DLP to generate the test patterns used in the different imaging modes and analysing the data generated by the imaging system.

Key References:

"Microscopy illumination engineering using a low-cost liquid crystal display", Kaikai Guo et al., DOI: 10.1364/BOE.6.000574
M. J. Booth, "Adaptive optical microscopy: the ongoing quest for a perfect image," Light Sci. Appl. 3, 165 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	40%
Theo:	20%
Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: Experience of programming is strongly advised, experience of optical design would be helpful but not essential. Some experience of data analysis with Matlab would also be beneficial.

Safety Training Requirements: Laser Safety Training is required due to the nature of the other work performed in the group.

Characterisation and implementation of computational super-resolution algorithms

(1) Dr Brian Patton, (2) Dr Sebastian Van de Linde

Project Description:

Super-resolution microscopy won the Nobel prize in Chemistry in 2014 for allowing imaging of objects beyond the classical diffraction limit. We are performing research into multiple versions of super-resolution microscopy, including Stimulated Emission Depletion (STED) and Single Molecule Localisation techniques.

The realisation that the diffraction limit can be overcome by appropriate imaging methods has led to a wide variety of super-resolution techniques that vary in their experimental and analytical complexity.

One approach that appears to produce excellent results is known as Super-Resolution Radial Fluctuation (SRRF) imaging and involves an algorithm that can be applied to multiple-image stacks acquired by a wide range of microscopes.

This project is an investigation of the practicalities of implementing SRRF on super-resolution microscopes being constructed in the department. In order to generate some initial test data, a simple microscope will be constructed and images captured by it will be analysed with the SRRF algorithm. If successful, the student will also be able to request images from our research microscopes to test the effectiveness of SRRF on data-sets from super-resolution microscopes.

Key References: “Fast live-cell conventional fluorophore nanoscopy with ImageJ through super-resolution radial fluctuations”, N. Gustafsson et al., DOI: 10.1038/ncomms12471M

“Super-resolution microscopy at a glance”, C. G. Galbraith and J.A. Galbraith, DOI:10.1242/jcs.080085

Ratio of effort: Exp/Theo/Comp

Exp:	30%
Theo:	30%
Comp:	40%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: Experience of programming is strongly advised, experience of optical design would be helpful but not essential. Some experience of data analysis with Matlab would also be beneficial.

Safety Training Requirements: Low power laser diodes may be required, so Laser Safety Training is essential.

Automated Image Analysis in Single-Molecule Localization Microscopy

(1) Dr Sebastian van de Linde, (2) Dr Oliver Henrich

Project Description:

Recently, different super-resolution microscopy have methods emerged that overcome the diffraction limit of light microscopy as evidenced by the Nobel Prize awarded for this work in 2014. A very powerful variant is single-molecule localization microscopy (SMLM) that achieves a lateral resolution down to 20 nm.

SMLM is a wide-field based imaging technique utilizing photoswitchable fluorophores, i.e. molecules that exhibit a transition between non-fluorescent off- and fluorescent on-states. Image generation is based on the acquisition and processing of a series of images, each of them containing different subsets of stochastically activated fluorophores.

With the aid of sensitive cameras, fluorophores are detected as diffraction limited spots as they are convolved with the point spread function (PSF) of the microscope. By fitting a two-dimensional Gaussian function to its emission profile, the centre of the molecule can be determined with nanometre precision. Finally, a super-resolution image is generated by merging all single-molecule coordinates into a single image.

Objectives of this project are an introduction to state-of-the-art SMLM software packages and image processing. Depending on progress and interest of the student software routines for (i) correcting experimental stage drift during image acquisition and/or (ii) averaging emission patterns of single molecules in order to characterize the experimental PSF of the super-resolution microscope will be developed.

Key References:

[1] C. G. Galbraith and J. A. Galbraith. *Super-resolution microscopy at a glance*. J. Cell Sci., 124, 1607 (2011).
[2] S. Wolter, M. Schuettpelz, M. Tscherepanow, S. van de Linde, M. Heilemann, M. Sauer. *Real-time computation of subdiffraction-resolution fluorescence images*. J. Microsc., 237, 12 (2010).
[3] A. Small and S. Stahlheber. *Fluorophore localization algorithms for super-resolution microscopy*. Nat. Methods, 11, 267 (2014).

Ratio of effort: Exp/Theo/Comp

Exp:	20 %
Theo:	20 %
Comp:	60 %

Suitability: MPhys, BSc, BSc Maths and Physics

Additional comments: Experience of programming is strongly advised. Experience of data analysis would also be beneficial.

Safety Training Requirements: Low power laser diodes will be required, so Laser Safety Training is essential.

Hysteretic Photochromic Switching (HPS) of europium-magnesium (Eu-Mg) defects in GaN.

(1) Prof K.P. O'Donnell, (2) Dr P.R. Edwards

Project Description:

Rare earth ions in semiconductors have been studied for several decades [1] with the aim of extending the range of emission wavelengths of optoelectronic devices [2]. Optical spectra of tri-positive rare earth (RE3+) ions in crystalline solids feature sharp lines at characteristic wavelengths that depend rather weakly on the host material. At the same time, the spectral patterns of such transitions are sensitive to the symmetry of the RE local environment in a way that can be described by simple crystal-field theory. Double-doping of epitaxial GaN samples with Mg and Eu introduces both metastable and quasistable defects associated with an extrinsic hysteretic photochromism, which may form the basis of a novel solid-state qubit.

In this project, we will utilize RE spectroscopy as a probe to monitor Eu3+ photochromism and photo-induced migration of Mg acceptors in GaN.

Key papers):

[1] P.N. Favennec, H. L'Haridon, M. Salvi, D. Moutonnet and Y. Le Gillou, Electronics Letts. **25**, 718 (1989); see also K.P.O'Donnell, P hys. Status Solidi C, 1–3 (2015) / DOI 10.1002/pssc.201400133
*[2] K.P. O'Donnell and V. Dierolf (eds.), Topics in Applied Physics **124** (Springer, Dordrecht, 2010)*

Ratio of effort: Exp/Theo/Comp	Exp:	60%
	Theo:	10%
	Comp:	30%

Suitability: M.Phys, B.Sc. Nano, Optics

Additional comments: Requires working knowledge of semiconductors/solid state physics and understanding of atomic term notation in the Russell-Saunders approximation. Involves advanced data handling skills or access to a Mac.

Safety Training Requirements: Laser Safety. High Intensity light sources.

Optics Division

Beam Quality of Broad-area Diode Lasers

(1) Prof Thorsten Ackemann, (2) Dr Michael Strain

Project Description:

Power scaling of semiconductor laser diodes and maintaining at the same time a high beam quality is a notoriously difficult challenge, since increasing the emission aperture leads to numerous instabilities limiting the brightness of a broad-area laser (BAL) [2].

Recently, a novel approach to control the beam quality of edge-emitting BALs maintaining their attractive monolithic compactness was proposed [1]. The suggestion is to implement a two-dimensional spatial modulation- *simultaneously transverse and parallel to the cavity axis* – of the gain characteristics, i.e. of the imaginary part of the susceptibility, by a modulation of the current injection. Similar to the case of photonic crystals (relying on a modulation of the real part of the susceptibility), the modulation is predicted to lead to a modification of spatial dispersion curves, in particular to a spatial filtering and a highly directional gain along the optical axis. As a result, *noise triggered by inhomogeneities or dynamically generated via instabilities* is quenched.

The project will set up a probe station to measure beam quality of BALs and perform measurements of samples processed at the University of Glasgow.

Key Reference:

[1] R. Herrero et al., Beam shaping in spatially modulated broad-areasemiconductor amplifiers, Opt Lett. 37, 5253 (2012);

[2] Crump et al., Experimental and theoretical analysis of the dominant lateral waveguiding mechanism in 975 nm high power broad area diode lasers. Semicond. Sci. Technol. ***27*** *(2012) 045001*

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	10%
Comp:	20%

Suitability: MPhys, BSc

Additional comments: *The student is required to attend PH445 and PH453 to obtain the necessary background.*

Safety Training Requirements: *laser*

Characterization of optically pumped quantum well and quantum dot vertical-cavity structures

(1) Prof Thorsten Ackemann, (2) Dr Antonio Hurtado

Project Description:

The research field of spintronics aims at utilizing the carrier spin for applications in addition to the number of carriers as usual in electronics and semiconductor photonics. However, electrical injection of spin polarized carriers is still limited to cryogenic temperatures or low temperatures in combination with a large magnetic field. At room temperature, optical pumping provides a convenient alternative to electrical injection since carrier spin and photon spin are coupled by angular momentum selection rules. III-V semiconductor gain media in vertical-cavity structures possess the necessary isotropy in the plane of the gain medium to investigate spin dependent effects. Most work centred on relatively low gain structures in vertical-cavity surface-emitting lasers (VCSEL) with quantum well gain media.

This project will look at high gain quantum well samples for external-cavity use (VECSELs) and VCSEL structures containing quantum dots, zero dimensional semiconductors with quantum confinement in all directions. The measurements will start with analyzing the polarization properties of the photoluminescence in dependence on the polarization ellipticity of the optical pump field. Polarization dependent gain will be measured afterwards via a tunable laser. The final aim of the project is to achieve lasing.

Key Reference:

[1] Bhattacharya et al., Quantum dot polarized light sources, Semicond. Sci. Technol. 26 (2011) 014002
[2] Hoevel et al., Appl. Phys. Lett. 92, 041118 (2008)

Ratio of effort: Exp/Theo/Comp

Exp:	70%
Theo:	15%
Comp:	15%

Suitability: MPhys, BSc

Additional comments: The student is required to attend PH445 and PH453 to obtain the necessary background. The project demands the engagement with tedious and careful optical alignment.

Safety Training Requirements: laser

Grating magneto-optical trap modelling

(1) Dr Aidan Arnold, (2) Dr Paul Griffin

Project Description:

Magneto-optical traps are ubiquitous in many atomic physics experiments, providing a dense source of ultracold atoms which can be utilised to obtain ultra-precise measurements [1]. However, such traps require six input laser beams and thereby suffer from optical complexity which can inhibit portable applications. We have pioneered the use of grating magneto-optical traps to circumvent this problem [2-5].

In this project you will model the acceleration in both forms of magneto-optical trap to see how the atom number collected scales with laser input power. An ideal extension of this project will be to compare your theoretical results to the lab experiments.

Key References:

[1] E. L. Raab, M. Prentiss, A. Cable, S. Chu, and D. E. Pritchard, *Trapping of Neutral Sodium Atoms with Radiation Pressure*, Phys. Rev. Lett. 59, 2631 (1987).

[2] M. Vangeleyn, P.F. Griffin, E. Riis and A.S. Arnold, *Single-laser, one beam, tetrahedral magneto-optical trap*, Opt. Express **17**, 13601 (2009).

[3] M. Vangeleyn, P.F. Griffin, E. Riis, and A.S. Arnold, *Laser cooling with a single laser beam and a planar diffractor*, Opt. Lett. **35**, 3453 (2010).

[4] C.C. Nshii *et al.*, *A surface-patterned chip as a strong source of ultracold atoms for quantum technologies*, Nature Nanotech. **8**, 321 (2013).

[5] J.P. McGilligan, P.F. Griffin, E. Riis, A.S. Arnold, *Phase-space properties of magneto-optical traps utilising micro-fabricated gratings*, Opt. Express **23**, 8948 (2015).

Ratio of effort: Exp/Theo/Comp

Exp:	20%
Theo:	20%
Comp:	60%

Suitability: MPhys only

Recommended Classes/Pre-requisites: PH355 Physics Skills

Additional comments:

Safety Training Requirements: Laser safety training will be provided.

Domain Walls in Optical Fibre Resonators

(1) Prof Gian-Luca Oppo, (2) Dr Alison Yao

Project Description:

Domain walls (also known as kinks) separate regions of different physical behaviours in magnetic systems, in chains of coupled pendula and in collision-less plasmas. In the optical domain, domain walls have been described in the plane perpendicular to the propagation of laser beam for coupled waves with orthogonal polarization and in optical parametric oscillators [1]. Recent developments have shown that nonlinear features in the transverse plane have one-to-one counterparts in optical fibres in resonators [2].

This project aims at investigating domain walls between left and right circular polarizations in an optical fibre resonator. In particular, we study and compare the formation of periodic structures, locked domain walls and solitons in theoretical and computational models of polarized light propagating in fibres with or without an optical resonator. The project is done in collaboration with experiments carried out at the University of Auckland (New Zealand).

Key References:

[1] R. Gallego et al., "Self-similar domain growth, localized structures, and labyrinthine patterns in vectorial Kerr resonators", Phys. Rev. E **61**, 2241 (2000); G.-L. Oppo et al, "Characterization, dynamics and stabilization of diffractive domain walls and dark ring cavity solitons in parametric oscillators"**,** Phys. Rev. E **63**, 066209 (2001)
[2] J.K. Jang et al., "Controlled merging and annihilation of localised dissipative structures in a driven damped nonlinear Schrödinger system" New Journal of Phys. **18**, 033034 (2016)

Ratio of effort: Exp/Theo/Comp		
	Exp:	0 %
	Theo:	40 %
	Comp:	60 %

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Soliton Glass

(1) Prof Gian-Luca Oppo, (2) Dr Francesco Papoff

Project Description:

Spatial optical solitons are beams of light in which nonlinearity counter-balances diffraction, leading to robust single-hump structures that propagate without change of form. In the case of light propagating through a medium, the simplest spatial soliton is due to self-focusing and Kerr nonlinearity, that is, a refractive index which changes in proportion to the intensity of the light. More general schemes where dissipation and driving are included can also support stable soliton-like solutions with lots of intriguing and new properties. Among these, localized bright spots in driven-optical cavities have received a great deal of attention because of their applications in information processing [1].

This project aims at investigating a new physical state for spatial optical solitons: a glass. Normal spatial solitons in random positions are susceptible to background noise fluctuations and can be described as a soliton gas. Above certain thresholds, however, spatial solitons in media pumped by two laser beams [2] can freeze at certain distances and form conglomerates similar to those observed in amorphous media such as glass. Characterization of the soliton glass phase, its origin and possible melting are among the objectives of the project. Please note that numerical codes are already in operation.

Key References:

[1] T. Ackemann, W. J. Firth and G-L Oppo, "Fundamentals and Applications of Spatial Dissipative Solitons", Adv. At. Mol. Opt. Phys. **57**, 323 (2009)

[2] M. Esalmi et al., "Complex structures in media displaying electromagnetically induced transparency: Pattern multistability and competition", Phys. Rev. A **90**, 023840 (2014)

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	40 %
Comp:	60 %

Suitability: MPhys, BSc Maths and Physics

Recommended Classes/Pre-requisites:

Additional comments: The project requires skills in mathematical and computational techniques.

Safety Training Requirements: None.

Optimisation of secure imaging

(1) Prof John Jeffers, (2) Dr Wojciech Roga

Project Description:

This project concerns security against jamming in imaging based on quantum mechanics. Due to indistinguishability of quantum states of photons' polarisation legitimate imagers who prepare the states have an informational advantage over an intruder. Our aim is to recognise optimal strategies of the imagers to detect the intrusion. We will analyse the scenario with two non-orthogonal polarisation states. In this case, the optimal scenario of the intruder is related to the Helstrom formula for the probability of correct discrimination between the states. Knowing this, we can recognise the best strategy of the imagers to detect the intrusion and deliver analytical formulas for the detection probability. The project can be extended on more complicated situations.

Key References:

1. W. Roga, J. Jeffers, Security against jamming and noise exclusion in imaging Phys. Rev. A (2016).
2. M. Malik, O. S. Magana-Loaiza, and R. W. Boyd, Quantum-secured imaging, Appl. Phys. Lett. 101, 241103 (2012).

Ratio of effort: Exp/Theo/Comp		
	Exp: 0	%
	Theo: 50	%
	Comp: 50	%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: Computational Physics, Quantum Mechanics

Candidate must have taken and passed well (>=65%) the following courses:

- Quantum Physics and Electromagnetism (year 3)
- Computational Physics (year 2)
- Linear Algebra and Differential Equations (year 2)

Additional comments: The numerical simulations using MATLAB and Mathematica will be essential.

Safety Training Requirements: None

Coherent Perfect Amplification of Light

(1) Prof John Jeffers, (2) Dr Daniel Oi

Project Description:

Absorption and emission of light are governed fundamentally by the rules of both quantum and classical physics. Classical physics provides the optical mode structure and quantum provides the absorption/emission probabilities and hence the light intensities.

In the most striking form of coherent perfect absorption [1] an absorbing medium of subwavelength thickness is rendered transparent or perhaps fully absorbing, merely by changing the mode of the incoming radiation. Precursors to this effect were suggested nearly 20 years ago in quantum optics in a body of work that examined the quantum properties of lossy beam splitters [2-4].

The optical mode structure of amplifying subwavelength films is similar to that of absorbers [5-6]. This project will model such devices and find the spectral and perhaps the quantum properties of the light that they can emit.

The project will begin with a study of the mode structure of slab devices, investigating the thin limit for both attenuating and amplifying media. The output light modes will be calculated and the possibility of basing a laser light source on such structures will be investigated.

Key References:

[1] J. Zhang, K.F. MacDonald and N.I. Zheludev, *Controlling light-with-light without nonlinearity*, Light: Science & Applications (2012) **1**, e18; doi:10.1038/lsa.2012.18, and references therein.
[2] R. Matloob et al., *Electromagnetic Field Quantisation in Absorbing Dielectrics*, Phys. Rev. A **52**, 4823 (1995).
[3] S.M. Barnett et al., *Quantum Optics of Lossy Beam Splitters*, Phys. Rev. A **57**, 2134 (1998).
[4] J. Jeffers, *Interference and the Lossless Lossy Beam Splitter*, J. Mod. Opt. **47**, 1819-1824 (2000).
[5] R. Matloob et al., *Electromagnetic Field Quantisation in Amplifying Dielectrics*, Phys. Rev. A **55**, 1623 (1997).
[6] J. Jeffers et al., *Canonical Quantum Theory of Light Propagation in Amplifying Media*, Optics Communications **131**, 66-71 (1996).

Ratio of effort: Exp/Theo/Comp

Exp:	0%
Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: High marks in 3rd Year Quantum Physics, Electromagnetism. Computational Physics.

Additional comments: A good level of mathematics will be required. Matlab programming.

Safety Training Requirements . N/A

Matrix product state representation of quantum states

(1) Dr Luca Tagliacozzo, (2) Dr Daniel Oi

Project Description

Many body quantum systems, systems made by several identical constituents, like materials, quantum gases, nuclei etc., are exponentially hard to describe. This means that we can at most describe exactly few tens of interacting particles but all interesting collective phenomena tend to appear when several thousand of particles interact strongly. This is at the origin of our incomplete understanding of several interesting effects, such as i.e. high temperature superconductivity.

In some cases, manly for systems organized in one dimensional structures such as wires and spin chains, however, people have been able to find extremely compact descriptions of specific states that allow to study very large systems and observe interesting emerging phenomena.

In this project we will discover one of these descriptions, the matrix product state representation of quantum states [2]. Originally introduced in the context of exactly solvable models [1] it is at the core of the Density Matrix Renormalization Group [3], the current standard tool to perform numerical simulations of 1D strongly correlated quantum systems. We will use this description to perform some simple out of equilibrium dynamics for 1D spin chains.

Key References:

[1] I. Affleck, T. Kennedy, E. H. Lieb, H. Tasaki, Comm. Mat. Phys. 115 477 (1998)
[2] D. Perez-Garcia, F. Verstraete, M.M. Wolf, J.I. Cirac, Quantum Inf. Comput. 7, 401 (2007)
[3] White S. PRL 69, 2863 (1992)

Ratio of effort: Exp/Theo/Comp	Exp:	0 %
	Theo:	50 %
	Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites: *Topics in Quantum Theory (PH458) to be taken in 4th year*

Additional comments: The student should be interested in working with numerical techniques and comfortable working with computers. Specific numerical methods will be covered over the course of the project as required. The student should also be comfortable with basic concepts of quantum mechanics.

Safety Training Requirements: No special safety training requirements.

Resonances in Clouds of Cold Atoms

(1) Dr Francesco Papoff, (2) Dr Gordon Robb, Dr Ben Hourahine

Project Description:

Spherical clouds of cold atoms and Bose-Einstein condensate have electromagnetic resonances that are similar to the Mie resonances of spherical dielectric particles. In most experiments, however, the atomic clouds are more similar to elongated cigars than to spheres. In this project we will develop a theory for bodies with axially symmetric density that will apply to these experiments and we will consider whether the scattering of light from these clouds can become an effective diagnostic tool to measure the density of the cloud.

Ratio of Experiment/Theory/Computation:		
	Exp:	0%
	Theo:	50%
	Comp:	50%

Suitability: MPhys, BSc

Modelling scanning near-field microscopy

(1) Dr F. Papoff, (2) Dr B. Hourahine

Project Description:

Scanning Near Field Optical Microscopes have been essential to investigate the optical properties of nano particles and nano cavities with a resolution higher than the diffraction lengths typical of conventional microscopes. One of the most remarkable recent developments has been the detection of the magnetic component of light at visible frequencies. This impressing ability has however highlighted the fact that the response of these microscopes depends crucially on the coupling between the metallic tip of the microscope and the nano structure investigated. In this project we aim to model this important effect and this will enable us to disentangle the properties of the nano structure investigated from those of the metallic tip.

Key References:

M. Burresi et al.,Magnetic Light-Matter Interactions in a Photonic Crystal Nanocavity, Phys. Rev. Lett. 105, 123901 (2010)
N. Caselli et al., Deep-subwavelength imaging of both electric and magnetic localized optical fields by plasmonic campanile nanoantenna, Sci. Rep. 5, 9606 (2015)
K. Imura et al., Plasmon modes in single gold nanodiscs, Opt. Exp. 22, 12189 (2014)

Ratio of effort: Exp/Theo/Comp

Theo:	50%
Comp:	50%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Parametric difference resonance in lasers

(1) Dr F. Papoff, (2) Dr Gordon Robb

Project Description:

It has been recently discovered that two oscillators appropriately coupled can be excited by a external force oscillating at a frequency equal to the difference between the resonance frequencies of the two oscillators. This has been proposed as a new mechanism to achieve lasing at frequencies much higher than the driving frequency used to pump energy into the lasers. In this project, we will instead look at using parametric difference resonances to synchronize lasers over a wide band of frequency, which can be useful in many applications, from metrology to to imaging of very fast processes.

Key References:

A. A. Svidzinsky et al., Quantum Amplification by Superradiant Emission of Radiation, PHYSICAL REVIEW X 3, 041001 (2013)

Ratio of effort: Exp/Theo/Comp		
	Exp:	0%
	Theo:	40%
	Comp:	60%

Suitability: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Recommended Classes/Pre-requisites:

Additional comments:

Safety Training Requirements:

Hybrid Atom-Superconductor Quantum System TBA

(1) Dr Jonathan Pritchard, (2) Dr Daniel Oi

Project Description:
TBC See Dr Pritchard for details

Key References: *Henschel et al,"Cavtiy QED with an ultracold ensemble on a chip: Prospects for strong magnetic coupling at finite temperatures" Phys Rev A* ***82,*** *033810 (2010)*

Ratio of effort: Exp/Theo/Comp

Exp:	0 %
Theo:	50 %
Comp:	50 %

Suitability: MPhys, BSc, BSc Maths and Physics

Recommended Classes/Pre-requisites: *Experience using Python would be beneficial but not essential.*

Additional comments:

Safety Training Requirements:

List of Projects