Lenses for cooling atoms

Project ID: AA1

Primary Supervisor: Aidan Arnold **Email:** aidan.arnold@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gordon Robb

Project Background: Magnetic lenses for atoms have been around for over 20 years, but there has been a recent resurgence of interest in the area, now that drop tower and space experiments are available. As in most things, various approaches have pros and cons. Your - difficult - project is to find the most feasible path forward for future experiments.

Aim: To determine, in the new environment whereby cold and ultracold atoms are in space, if classical/quantum atoms and magnetic/optical lenses can yield the best atomic source for scientific experiments (and what does the best mean?)

Semester 1 Tasks: Your semester 1 work should cover the background of atomic lensing, with a literature review, and compare and contrast existing lensing strategies, establishing the basic principles and knowledge required.

Semester 2 Tasks: You need to write a ~30 page report in the form of an extended paper worth 50% of the final mark. This report should concentrate on and consolidate your findings regarding atomic lensing.

Key references:

[1] 10.1103/PhysRevA.65.031601
[2] 10.1038/s41586-020-2346-1
[3] http://web.stanford.edu/group/kasevich/cgi-bin/wordpress/wp-content/uploads/2014/10/sugarbakerThesis-augmented.pdf

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Mathematica/Matlab/Python skills useful.

Safety Training (if applicable): No special training required

Suitable for: MPhys only

Misc:

Use of ABCD matrices to design laser resonators and pump optics

Project ID: AJK1

Primary Supervisor: Alan Kemp **Email:** alan.kemp@strath.ac.uk **Division:** IoP

Secondary Supervisors: Niall Simpson

Project Background: ABCD matrix calculations use a conceptually very simple approach that associates a ray-transfer matrix with each resonator element, and by multiplication of these matrices builds up an overall matrix that describes the resonator as a whole. This approach is routinely used when designing a solid-state laser, since it allows the designer to work out the radius of the laser mode at all points in the resonator, and to assess how stable the laser resonator is against, for example, changes in the resonator length, or thermal lensing in the laser gain material. It can also be used to design the optics for the pump for a diode-laser pumped solid-state laser.

Aim: The resonator for a solid-state laser is typically designed using ABCD matrix software. This project will assess the effectiveness of freely-available software packages for ABCD matrix resonator design by applying them to some real-world laser design tasks. The project will first look at a simple two-mirror resonator, assessing the capability of the software to determine cavity stability and, in particular, stability against thermal lensing. Once the utility of the software has been proven, and if there is sufficient time, the project will then move on to assessing and improving the design of lasers currently being developed by the research team.

Semester 1 Tasks: The project will begin with a literature review on ABCD matrix approaches to ensure the underlying principles are understood. This will include doing ABCD calculations for some very simple resonators. However, doing ABCD matrix calculations for anything beyond the simplest resonator is laborious, and dedicated software is, therefore, usually used. This project will assess the effectiveness of freely available ABCD matrix software, comparing the software tools with each other, with the simple calculations done at the start of the project, and with 'test-case' laser cavity designs selected from literature. Modeling of optics for pump lasers will also be considered.

Semester 2 Tasks: Once the basic effectiveness of one or more of the software tools has been proven, the next step will be to examine the ability of these tools to assist the designer in assessing important considerations such as the tolerances on the resonator and pump system parameters and the stability of the resonator against thermal lensing. These tests will be used to select the most appropriate software tool. To conclude the project, the selected tool will be used for a real-world design task. The starting point will be a design for a laser currently being developed in the lab. The software tool will be used to assess this design, including important factors such as stability against thermal lensing or required positioning accuracy. Should there be sufficient time, the ABCD matrix software will then be used to suggest improvements and extensions to this design and other designs under development by the host research team.

Key references:

[1] H. Kogelnik and T. Li, "Laser Beams and Resonators," App. Optics, v. 5, pp. 1550-1566, 1966.
[2] W. A. Clarkson, "Thermal effects and their mitigation in end-pumped solid-state lasers," Journal of Physics D-Applied Physics, v. 34, pp. 2381-2395, 2001.
[3] O. Svelto, Principles of Lasers. New York: Plenum Press, 1998.

Theory: 0% **Comp:** 100% **Exp:** 0%

Recommended Background: No pre-requisites but student should be taking PH455 (Topics in Photonics). Student will require independent access to a PC and the internet, with permissions to install new software (the software can be downloaded for free).

Safety Training (if applicable): Laser safety training should be taken in case lab access become possible later in the project

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: We'd try to build in experimental aspects once covid regulations relax enough to allow lab access for a project student - as of Aug 2021 this isn't yet possible.

Laser specification and design for undersea LIDAR

Project ID: AJK2

Primary Supervisor: Alan Kemp **Email:** alan.kemp@strath.ac.uk **Division:** IoP

Secondary Supervisors: David McKee

Project Background: LIDAR – light detection and ranging – uses lasers, usually pulsed lasers, to perform imaging and assessment at range. At its simplest, it consists of firing a laser pulse at a distant object and working out the range to that object based on the time delay between the emitted and back-scattered pulses. More advanced implementations infer information about, for example windspeed (based on the Doppler shift of the return signal from aerosols in the atmosphere) and on the chemical composition of the atmosphere based on looking at the difference in the return signal at two or more wavelengths. While the environmental applications of LIDAR have been most widely exploited in atmospheric science, the technique also has potential in marine science, for example in sub-sea ranging.

Aim: To investigate the laser requirements for undersea LIDAR and to design a laser for such an application, in particular for measuring scattering layers in the water column

Semester 1 Tasks: This project would involve first collating the laser requirements for applications related to measuring scattering layers in the water column, where necessary back calculating properties of the laser output required to make a LIDAR system function in likely undersea conditions. Based on this laser requirement, a survey would be made of currently available laser types to identify the most promising laser designs to meet the application requirement.

Semester 2 Tasks: Based on the survey undertaken in semester one, further calculations would be made to draw up the outline of a laser design potentially capable of meeting the requirements identified. This is the likely end-point of the project. However, if time permits, a more enthusiastic student may wish to proceed to doing a full set of laser cavity design calculations.

Key references:

[1] M Massot-Campos, G Oliver-Codina, "Optical Sensors and Methods for Underwater 3D Reconstruction." Sensors, 15, 31525-31557, 2015.
[2] M. E. Zevallos et al., "Time-gated backscattered ballistic light imaging of objects in turbid water," Appl. Phys. Lett., 86, 011115, 2005.
[3] M. A. Montes, A. K. Vuorenkoski, F. R. Dalgleish, and B. Ouyang, "Characterization of underwater scattering layers based on variance components of LiDAR backscattering," Opt Express, vol. 27, pp. A1084-A1108, 2019.

Theory: 0% **Comp:** 100% **Exp:** 0%

Recommended Background: No pre-requisites but student should be taking PH455 (Topics in Photonics). Student will require independent access to a PC and the internet, with permissions to install new software (the software can be downloaded for free).

Safety Training (if applicable): No lab work is proposed on this project, but laser safety training should be taken since it is relevant to the project and would permit a lab visit should the project develop in such a way as to make that helpful and if covid-regulations allow.

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Analysis of Muon Ionisation Cooling Experiment

Project ID: ARY1

Primary Supervisor: Alan Young **Email:** a.r.young@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Kevin Ronald

Project Background: Due to their greater mass than electrons and their decay mechanism, muons are very appealing for the study of fundamental particle physics, either through a muon collider or a neutrino factory. An important step in realising this potential are the development of techniques to improve the quality of muon beams and ionisation cooling has been identified as an attractive method for achieving this.The international Muon Ionisation Cooling Experiment (MICE) aims to demonstrate this effect for the first time.

Aim: Carry out an analysis of data generated by the Muon Ionisation Cooling Experiment

Semester 1 Tasks: Review literature on moun physics, beam physics and ionisation cooling. Extract and present basic beam data from a MICE dataset.

Semester 2 Tasks: Characterise a Muon beam for a particular configuration of the MICE experiment.

Key references:

[1] Adams D. et al, 2013, 'Characterisation of the muon beams for the Muon Ionisation Cooling Experiment' Euro. Phys. J. C, 73, art. 2582

[2] Muon Ionisation Cooling Experiment http://mice.iit.edu

[3] Demonstration of Cooling by the MUON Ionization Cooling Experiment, Mice Collaboration https://doi.org/10.1038/s41586-020-1958-9

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Students should have a understanding of computer programming. Experience with C++ would be useful

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Nonlinear Propagation of Fully Structured Light

Project ID: AMY1

Primary Supervisor: Alison Yao **Email:** alison.yao@strath.ac.uk **Division:** Optics

Secondary Supervisors: Duncan McArthur

Project Background: Gaussian laser beams propagating in linear materials diverge during propagation. This diffraction can be compensated for by propagating through nonlinear materials that exhibit an intensity-dependent refractive index. Balancing the divergence and self-focusing results in a beam, known as a spatial soliton, that can propagate without changing shape. Laguerre-Gaussian (LG) modes are ring-like beams with an l-fold helical phase structure that carry an orbital angular momentum (OAM). These are of interest due to their potential to carry an increased information content. These are known to fragment during nonlinear propagation.

Aim: The aim of this project is to investigate the propagation of Laguerre-Gaussian beams in self-focusing nonlinear media and, in particular, to design superpositions of LG beams to prevent or control fragmentation.

Semester 1 Tasks: Reading and understanding the background literature; become familiar with using a linux system and learn how to run pre-written codes with different input parameters; learn how to display and analyse large sets of data; reproduce results in the literature.

Semester 2 Tasks: Use your understanding of results in current literature to design fully-structured light beams for particular propagation characteristics, such as control of fragmentation, polarisation structure etc.

Key references:

[1] W. J. Firth and D. Skryabin, Phys. Rev. Lett. 79, 2450 (1997)
[2] F. Bouchard et al., Phys. Rev. Lett. 117, 233903 (2016)
[3] CJ Gibson, P Bevington, GL Oppo, AM Yao, Phys. Rev A 97 (3), 033832 (2018)

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: No previous knowledge of programming is required, but an interest is highly recommended.

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc Maths and Phys

Misc:

Control of spatially rotating structures in diffractive Kerr cavities

Project ID: AMY2

Primary Supervisor: Alison Yao **Email:** alison.yao@strath.ac.uk **Division:** Optics

Secondary Supervisors: Duncan McArthur

Project Background: The interplay of diffraction and intensity-dependent nonlinearity is known to give rise to the formation of Turing patterns. Optical pumps carrying orbital angular momentum (OAM) have been shown to produce Turing patterns that rotate at particular speeds. Full control over the speed can be obtained by tuning the intensity and polarisation structure of the light and has potential applications in particle manipulation and stretching, atom trapping, and circular transport of cold atoms and BEC wavepackets.

Aim: The aim of this project is to investigate the formation of spatially rotation light patterns in nonlinear optical cavities.

Semester 1 Tasks: Reading and understanding the background literature; become familiar with using a linux system and learn how to run pre-written codes with different input parameters; learn how to display and analyse large sets of data; reproduce results in the literature.

Semester 2 Tasks: Use your understanding of results in current literature to investigate the speed of rotation. Extend the model to include saturating nonlinearities.

Key references:

[1] L. A. Lugiato and R. Lefever, Phys. Rev. Lett. 58, 2209 (1987).
[2] A. M. Yao, C. J. Gibson & G.-L. Oppo, Opt. Express 27, 31273 (2019).
[3] Q. Zhan, Adv. Opt. Photon. 1, 1 (2009).

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: No previous knowledge of programming is required, but an interest is highly recommended.

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc Maths and Phys

Misc:

Asymmetry and cavity solitons in nonlinear cavities

Project ID: AMY3

Primary Supervisor: Alison Yao **Email:** alison.yao@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gian-Luca Oppo

Project Background: The interplay of diffraction and intensity-dependent nonlinearity is known to give rise to the formation of Turing patterns. Optical pumps carrying orbital angular momentum (OAM) have been shown to produce Turing patterns that rotate at particular speeds. By adjusting the detuning between the pump and the cavity mode, it is possible to produce rotating cavity solitons and/or asymmetric patterns.

Aim: The aim of this project is to investigate asymmetric patterns and the formation of cavity solitons in nonlinear optical cavities pumped by beams carrying orbital angular momentum.

Semester 1 Tasks: Reading and understanding the background literature; become familiar with using a linux system and learn how to run pre-written codes with different input parameters; learn how to display and analyse large sets of data; reproduce results in the literature.

Semester 2 Tasks: Use your understanding of results in current literature to generate and investigate rotating cavity solitons. Investigate the - as yet unseen - potential for asymmetric patterns.

Key references:

[1] L. A. Lugiato and R. Lefever, Phys. Rev. Lett. 58, 2209 (1987).
[2] Woodley et al., Phys. Rev. A 98, 053863 (2018)
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: No previous knowledge of programming is required, but an interest is highly recommended.

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc Maths and Phys

Misc:

Useful entanglement in quantum devices through fast scrambling

Project ID: AD1

Primary Supervisor: Andrew Daley **Email:** andrew.daley@strath.ac.uk **Division:** Optics

Secondary Supervisors: Johannes Kombe

Project Background: Atoms trapped ion optical tweezers that form neutral atom arrays for quantum computing and simulation have been developed in a number of laboratories around the world, including ongoing work in the EQOP group at Strathclyde. Both in these systems and for cold atoms in optical cavities, we have recently shown that they can exhibit exponentially fast spreading of quantum information, known as fast scrambling, which was originally discussed in models of black holes. Here we will further explore such dynamics as realisable in near-term devices, to identify under which conditions it can be made useful for quantum technologies.

Aim: We aim to theoretically study dynamics attainable in near-term quantum computers and quantum simulators in which we can realise so-called fast scrambling dynamics, where quantum information is spread as quickly as is physically possible in any hardware. We will identify to which extent control over these dynamics allows us to build useful quantum entanglement that can be used either to demonstrate fundamental principles of quantum dynamics, or to build states that are useful for metrology and sensing

Semester 1 Tasks: Literature review on fast scrambling, dynamics in spin models, and measures of entanglement, especially the von Neumann Entropy and the Fisher information. Beginning of numerical studies (in Python/Matlab/Julia) of spin models that are realisable in near-term experiments, growth of entanglement in different degrees of freedom.

Semester 2 Tasks: Use of the acquired background to explore useful entanglement for metrology in these systems.

Key references:

[1] T. Hashizume et al., Phys. Rev. Lett. 126, 200603 (2021)
[2] G. Bentsen et al., Phys. Rev. Lett. 123, 130601 (2019)
[3] L. Pezze et al., Phys. Rev. Lett., 102, 100401 (2009)

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: PH384, PH389. This project will involve mathematical derivations of the properties of entangled quantum states in spin systems, as well significant computational work

Safety Training (if applicable):

Suitable for:

Misc:

Photonic neurons with lasers for ultrafast brain-inspired computing

Project ID: AH1

Primary Supervisor: Antonio Hurtado **Email:** antonio.hurtado@strath.ac.uk **Division:** IoP

Secondary Supervisors: Dr Julian Bueno

Project Background: Neuromorphic photonics aims at emulating the brain's powerful computational capabilities for novel paradigms in ultrafast, energy efficient information processing. Biological neurons respond by firing spikes when stimulated. Semiconductor lasers, such as Vertical Cavity Surface Emitting Lasers (VCSELs) can also produce spiking responses similar to those observed in biological neurons but several orders of magnitude faster. This feature makes them ideal candidates for the use in novel brain-inspired systems for all-optical information processing.

Aim: This project will analyse in theory neuronal-like spiking regimes in Vertical-Cavity Surface Emitting Lasers (VCSELs). This project will thus explore numerically the spiking responses obtained in VCSELs and the potential of these devices for neuromorphic processing tasks (e.g. image feature detection, pattern recognition) for use in future light-enabled Artificial Intelligence (AI) systems.

Semester 1 Tasks: Background of the project, literature review on photonic spiking neuronal models with lasers including VCSELs. The student will be provided with simulation tools in Matlab modeling the fast spiking responses in VCSELs. The student will familiarise themselves with the simulations and will reproduce recent experimental/numerical result obtained by our group.

Semester 2 Tasks: Expand the simulation work to model the operation of VCSEL-based photonic neurons in tasks using spikes to process information. These will include image processing and pattern recognition among others.

Key references:

[1] J. Robertson et al, "Toward neuromorphic photonic networks of ultrafast spiking laser neurons", IEEE JSTQE, 26, 770715 (2020)
[2] J. Robertson et al, "Ultrafast optical integration and pattern classification for neuromorphic photonics based on spiking VCSELs", Scientific Reports, 10, 6098 (2020)
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Basic knowledge in photonics is desirable. Knowledge of Matlab. Attendance to PH455 is also recommended.

Safety Training (if applicable): No special training required

Suitable for: MPhys

Misc:

Spiking neurons with resonant tunneling diodes for high speed and energy efficient neuromorphic nanophotonic computing

Project ID: AH2

Primary Supervisor: Antonio Hurtado **Email:** antonio.hurtado@strath.ac.uk **Division:** IoP

Secondary Supervisors: Dr Juan Alanis

Project Background: Neuromorphic photonics aims at emulating the brain's powerful computational capabilities for novel paradigms in ultrafast, energy efficient information processing. Biological neurons respond by firing spikes when stimulated. Resonant Tunneling Diode devices can also produce spiking responses similar to those observed in biological neurons but several orders of magnitude faster and with very low energy requirements. This feature makes them ideal candidates for the use as nanoscale spiking neuronal models for novel brain-inspired computing systems for future optoelectronic neural network implementations for future low energy and high speed light-enabled Artificial Intelligence systems.

Aim: This project will analyse in theory neuronal-like spiking regimes in Resonant Tunneling Diode (RTD) devices for high-speed and energy efficient neuromorphic nanophotonic computing systems for Artificial Intelligence (AI).

Semester 1 Tasks: Background of the project, literature review on optoelectronic spiking neuronal models with RTD devices. The student will be provided with simulation tools modedling the fast and low energy responses in RTD devices. The student will familiarise themselves with the simulations and will reproduce recent experimental and numerical results produced by our group and our European colleagues as part of the EU FET Open project 'ChipAI' (www.chipai.eu).

Semester 2 Tasks: Expand the simulation work to simulate the operation of RTD-based artificial spiking neurons to investigate the potentials for very high operation speeds (GHz rates) and low energy requirements (<pJ/spike). Explore the use of RTD spiking neurons for neuromorphic processing tasks at high data rates.

Key references:

[1] B. Romeira et al, "NanoLEDs for energy-efficient and gigahertz-speed spike-based sub-λ neuromorphic nanophotonic computing", Nanophotonics, Ahead of Print (2020). DOI: https://doi.org/10.1515/nanoph-2020-0177

[2] B. Romeira et al, "Regenerative memory in time-delayed neuromorphic photonic resonators", Scientific Reports, 6, 19510 (2016)

[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Basic knowledge in optoelectronics is desirable. Knowledge of Matlab. Attendance to PH455 is also recommended.

Safety Training (if applicable): No special training required

Suitable for: MPhys

Misc:

Calculating the optical properties of Ga_2O_3

Project ID: BH1

Primary Supervisor: Ben Hourahine **Email:** benjamin.hourahine@strath.ac.uk **Division:** Nano

Secondary Supervisors: Fabien Massabuau

Project Background: Gallium oxide (Ga_2O_3) is an emerging wide bandgap semiconductor with potentially game-changing applications in ultraviolet optoelectronics and high-power electronics. This material can be produced in a number of crystal phases, labelled as α, β, ε, κ, and δ, each with their own structural, electronic, and optical properties. Semiconductor electronic and optical parameters, such as the effective mass, refractive index, absorption coefficients, and bandgap, are of paramount importance for designing semiconductor devices. These parameters are however not accurately established for new materials like Ga_2O_3.

Aim: In this project the student apply state of the art computational tools to (i) simulate the crystal structure of several phases of Ga_2O_3, and (ii) calculate their optical properties. The results will be compared to experimental data and existing literature.

Semester 1 Tasks: Literature survey on crystal structure and optical properties of Ga_2O_3. LINUX and high performance computing introduction. Work through the tutorials for the QUESTAAL code for single particle and many-body calculations. Initial construction and geometry optimisation of selected polytypes of Ga_2O_3.

Semester 2 Tasks: Compute the optical and electronic properties of Ga_2O_3 at increasingly accurate levels of theory, starting from the single particle density-functional level, GW many-body theory and quasi-particle self-consistent GW.

Key references:

[1] Zhang et al. APL Mater. 8, 020906 (2020) https://doi.org/10.1063/1.5142999
[2] Pashov et al. Comp. Phys. Comms. 249, 107065 (2020) https://doi.org/10.1016/j.cpc.2019.107065
[3] https://www.questaal.org

Theory: 0.4 **Comp:** 0.6 **Exp:** 0

Recommended Background: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386). Attendance of the module "Topics on Solid State Physics" (PH453) is strongly recommended.

Safety Training (if applicable): N/A

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

Stochastic particle heating of charged particles by plasma waves

Project ID: BE1

Primary Supervisor: Bengt Eliasson **Email:** bengt.eliasson@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Kevin Ronald

Project Background: 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. The Earth's ionosphere is magnetized by the geomagnetic field, and in the laboratory, an external magnetic field is used to confine the plasma and prevent it from escaping to the walls. The acceleration of charged particles by plasma waves can lead to chaotic motion of the particles and a rapid heating of the magnetised plasma due to the complicated motion of the particles. This is important for heating of particles in the laboratory, in magnetic confinement fusion devices, in the solar corona, in the Earth's ionosphere, etc., where collisions between particles are relatively rare. Stochastic heating is therefore different from Ohmic heating which is due to collisions between particles.

Aim: To study rapid heating of an ionised gas (plasma) by the chaotic motion of particles in a plasma wave.

Semester 1 Tasks: Literature study of the topic. Initial simulations of stochastic heating using the code (in Matlab) provided by the supervisor

Semester 2 Tasks: Study stochastic heating and calculate statistical quantities such as temperature from a distribution of particles.

Key references:

[1] J. M. McChesney, R. A. Stern, and P. M. Bellan (1987) Observation of fast stochastic ion heating by drift waves, Phys. Rev. Lett. 59, 1436-1439.

[2] J. M. McChesney, R. A. Stern, and P. M. Bellan (1987) Observation of fast stochastic ion heating by drift waves, Phys. Rev. Lett. 59, 1436-1439.

[3] Najmi, A., B. Eliasson, X. Shao, G. M. Milikh, and K. Papadopoulos (2016), Simulations of ionospheric turbulence produced by HF heating near the upper hybrid layer, Radio Sci., 51, 704-717, doi:10.1002/2015RS005866.

Theory: 50% **Comp:** 50% **Exp:** 0%

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

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Ion Channel Laser with Large Oscillation Amplitude

Project ID: BEr1

Primary Supervisor: Bernhard Ersfeld **Email:** bernhard.ersfeld@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Dino Jaroszynski

Project Background: 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). An important difference is that an efficient ICL requires oscillation amplitudes in excess of the electron beam width, which reduces the overlap with the emitted radiation and leads to non-linear effects, which are the subject of this investigation.

Aim: The project aims to investigate, analytically and numerically, effects of large oscillation amplitudes in ion channel lasers, e.g., harmonic generation and correlations between longitudinal and transverse electron motion.

Semester 1 Tasks: Familiarise with Key Ref. 1 (below); literature review; familiarise with existing C code for numerical work

Semester 2 Tasks: Extend theory to include non-linear terms/ harmonics; implement corresponding terms in C code; produce and analyse numerical results; prepare presentation; write ~30-page report.

Key references:

[1] : B. Ersfeld et al., "The ion channel free-electron laser with varying betatron amplitude", New Journal of Physics 16 (9), 093025 (2014)
[2]
[3]

Theory: 50% **Comp:** 50% **Exp:** 0%

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

Safety Training (if applicable): No safety training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Beam-driven Plasma Wakefield Acceleration of electrons to highest energies

Project ID: BHi1

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Andrew Sutherland/Fahim Habib

Project Background: Plasma wakefield acceleration (PWFA) is a revolutionary method of production and acceleration of electron beams with highest energy and intensity, in compact, university laboratory-scale setups. Such beams are required to power modern brilliant x-ray light sources and high energy physics colliders. The understanding and modelling of plasma wakefield acceleration is required in order to develop and apply this technology. This project will investigate the physics of PWFA and model it based on a semi-analytical framework and simulations.

Aim: Describe and model the physics of particle-beam driven plasma wakefield acceleration

Semester 1 Tasks: Review electron beam-driven plasma wakefield acceleration, strategies and state-of-the-art. Literature review. Explore methods and tools to describe and simulate the process with modelling and particle-in-cell simulations.

Semester 2 Tasks: Model PWFA based on scalings laws and semi-analytically. Simulate PWFA with particle-in-cell codes such as VSim or via the Sirepo framework. Compare simulation results with modelling, with a focus on the plasma photocathode injection approach.

Key references:

[1] Manahan, Habib .. Hidding, Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams, G.G. Manahan, F.A. Habib et al., Nature Communications 8, 15705 (2017)
[2] Deng .. Hidding, Generation and acceleration of electron bunches from a plasma photocathode, Nature Physics 15, pages 1156–1160(2019)
[3] http://nexource.phys.strath.ac.uk/

Theory: 40% **Comp:** 40-60% **Exp:** 0-20%

Recommended Background: Student should ideally have had contact with Matlab, and/or Python, or similar scientific programming language for developing simulations. Previous knowledge in accelerator, laser or plasma physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for:

Misc: This project is open to more than one student.

Free-electron-laser x-ray beams from ultrabright plasma-accelerator based electron beams

Project ID: BHi2

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Fahim Habib

Project Background: Free-electron-lasers (FEL) are the radiation sources of the 21st century, capable to illuminate the ultrasmall and ultrafast. They require high quality and high energy electron beams. The plasma photocathode wakefield approach promises ultrabright electron beams, which in turn may beget ultrabright, coherent x-ray pulses from the FEL process. The STFC PWFA-FEL programme explores these prospects. The project aims at an understanding and estimation of x-ray photon pulse generation in this constellation, and exploration of the parameter space using scaling laws.

Aim: Investigate and model Free-Electron-Laser radiation generation capabilities of ultrabright beams from plasma accelerators

Semester 1 Tasks: Review central elements and scalings of free-electon-laser physics and plasma photocathode wakefield acceleration. Familiarize with estimation approaches to model FEL radiation output such as the 1D M. Xie approach.

Semester 2 Tasks: Use scaling laws and the scripts based on the M. Xie radiation generation estimation approach to explore the parameter space of x-ray output from ultrabright, plasma-generated electron beams, and compare it with 3D simulation and experimental data.

Key references:

[1] Manahan, Habib .. Hidding, Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams, G.G. Manahan, F.A. Habib et al., Nature Communications 8, 15705 (2017)
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, 4, 814, 2010
[3] http://pwfa-fel.phys.strath.ac.uk/

Theory: 60% **Comp:** 30-40% **Exp:** 0-10%

Recommended Background: Previous knowledge in accelerator, laser, plasma and light source physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for:

Misc: This project is open to more than one student.

Electron beam transport modelling and machine learning in particle accelerators

Project ID: BHi3

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Fahib Habib/Andrew Sutherland

Project Background: Particle beams such as electrons are accelerated, transported and focused by various building blocks such as quadrupole magnet triplets, chicanes to manipulate the beam duration and energy spread, and dipole magnets. The individual trajectories of individual electrons vary around the design orbit. It is crucial to transport electron beams loss-free, and to preserve beam quality along the accelerator and transport beamline towards the application. This project will examine the description of particle beam phase space, its modeling and beam behaviour in view of beam and beamline parameter variations.

Aim: Describe and model the transport of particle beams in accelerators and transport beamlines

Semester 1 Tasks: Review electron beam dynamics and become familiar with concepts such as Twiss parameters, Hill's equation, and phase space, and familarize with computational tools such as elegant and SDDS and/or Astra.

Semester 2 Tasks: Characterize and describe electrron beams and their transport within beamline elements. Model a beamline suited for high-brightness electron beam transport, and carry out parameter studies. Explore the use of machine learning e.g. with Python to optimize the beamline.

Key references:

[1] Fundamentals of Beam Physics, J.B. Rosenzweig, Oxford University Press
[2] Overview of elegant and SDDS:
http://www.aps.anl.gov/Accelerator_Systems_Division/Accelerator_Operations_Physics/elegant.html
[3] ASTRA http://www.desy.de/~mpyflo/

Theory: 60% **Comp:** 30-40% **Exp:** 0-10%

Recommended Background: Previous knowledge in accelerator physics and computational physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for:

Misc: This project is open to more than one student.

Laser pulse based ionization of matter

Project ID: BHi4

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Paul Scherkl

Project Background: Electrons can be released from atoms if they experience intense electromagnetic fields that distort the atomic Coulomb potential. Focused laser pulses can provide such fields when interacting with matter, and provoke ionization into plasma. The physics of multiphoton ionization, tunneling ionization and barrier suppression ionization will be explored. Tunneling ionization will be simulated with a Mathlab/Python script, and compared with analytical estimation. Laser-matter ionization is a fundamental effect that is exploited in the laboratory.

Aim: Describe and model the ionization of matter in the electromagnetic field of intense laser pulses

Semester 1 Tasks: Review (Gaussian) laser optics, concepts such as Rayleigh length, ionization mechanisms such tunneling ionization, barrier suppression ionization, multi-photon-ionization, Keldysh parameter. Review applications e.g. for plasma-based beam generation and diagnostics.

Semester 2 Tasks: Model and visualize laser pulse ionization yields for various laser pulse parameters in various gases, examine ionization profiles and compare to estimations and experiments in plasma wakfield acceleration.

Key references:

[1] Bruhwiler et al., Particle-in-cell simulations of tunneling ionization effects in plasma-based accelerators, Physics of Plasmas 10, 2022 (2003)

[2] Chen et al., Numerical modeling of laser tunneling ionization in explicit particle-in-cell codes, Journal of Computational Physics 236, 220-228 (2013)

[3] P. Scherkl .. Hidding, Plasma-photonic spatiotemporal synchronization of relativistic electron and laser beams, https://arxiv.org/abs/1908.09263, 2019

Theory: 40% **Comp:** 50-60% **Exp:** 0-10%

Recommended Background: Previous knowledge in accelerator, laser, plasma and computational physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for:

Misc: This project is open to more than one student.

Particle-in-cell modelling of laser-plasma acceleration with kHz lasers

Project ID: BHi5

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Thomas Heinemann

Project Background: Intense, focused laser pulses can ionize matter, expel electrons and excite plasma oscillations. The transient separation of plasma electrons and ions generates huge fields that can be used to accelerate electrons to high energies. The physics of such interaction can be modelled with particle-in-cell codes, whereby electrons are represented by so called macroparticles, each representing a large number of real electrons. The interaction of laser pulses, exploiting effects such as relativistic self-focusing shall be modeled by particle-in-cell codes.

Aim: Simulate laser-plasma wakefield acceleration with laser pulse parameters accessible by state-of-the-art kHz repetition rate laser pulses

Semester 1 Tasks: Review physics of laser plasma acceleration, particle-in-cell-codes and (Ti:Sapphire) kHz laser system capabilities. Familarize with existing modelling techniques of interactions of these laser systems with intensities up to moderately relativistic levels with matter.

Semester 2 Tasks: Use a particle-in-cell code such as FBPIC, VSim or WARP (potentially via the Sirepo web interface) to explore laser-matter interaction and electron acceleration up to a few MeV energies.

Key references:

[1] Gustas et al., High-charge relativistic electron bunches from a kHz laser-plasma accelerator, PRAB 21, 013401 (2018)
[2] Wilson et al., Laser pulse compression towards collapse and beyond in plasma, J. Phys. B: At. Mol. Opt. Phys. 52 (2019) 055403
[3] https://www.sirepo.com/ https://github.com/fbpic

Theory: 40% **Comp:** 50-60% **Exp:** 0-10%

Recommended Background: Previous knowledge in accelerator, laser, plasma and computational physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for:

Misc: This project is open to more than one student.

Space radiation reproduction with laser-plasma-accelerators and Monte Carlo codes

Project ID: BHi6

Primary Supervisor: Bernhard Hidding **Email:** bernhard.hidding@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Andrew Sutherland/Paul Scherkl

Project Background: Space radiation is a great danger to electronics and astronauts onboard space vessels. The spectral flux of space electrons, protons and ions for example in the van-Allen radiation belts is inherently broadband, which is a feature difficult to mimic with conventional radiation sources. Using laser-plasma-accelerators such as those developed at the Scottish Centre of the Application of Plasma-based Accelerators (SCAPA), however, has the potential to reproduce important kinds of space radiation exactly. Thus could have transformative impact for space exploration, because better testing may lead to better performance of space missions.

Aim: Investigate reproduction and modelling of space radiation in the laboratory

Semester 1 Tasks: Review radiation effects of charged particle radiation on matter in general, and on space electronics (such as spaceraft charging, single event effects etc.) and biomatter in particular. Explore methods of radiation hardness assurance testing and modelling.

Semester 2 Tasks: Investigate radiation effects on simple and more complex objects, modelled by RSim or other codes based on the Geant4 modelling framwework. Compare the flux and dosage levels with theoretical estimations based on stopping power.

Key references:

[1] RSim https://www.txcorp.com/products/rsim
[2] T. Königstein .. Hidding, Design considerations for the use of laser-plasma accelerators for advanced space radiation studies, Journal of Plasma Physics, Volume 78, Issue 4, pp. 383-391 (2012)
[3] B. Hidding et al., Laser-plasma-based Space Radiation Reproduction in the Laboratory, Scientific Reports 7, Article number: 42354 (2017)

Theory: 40% **Comp:** 40-60% **Exp:** 0-20%

Recommended Background: Previous knowledge in accelerator, laser, space or plasma physics useful, but not mandatory.

Safety Training (if applicable):

Suitable for:

Misc: This project is open to more than one student.

Computational Modelling of X-ray Free Electron Lasers

Project ID: BWJM1

Primary Supervisor: Brian McNeil **Email:** b.w.j.mcneil@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gordon Robb

Project Background: X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2]. The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level. The supervisor of this project Dr Brian McNeil works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Aim: Predict new effects that can enhance or extend current XFEL performance.

Semester 1 Tasks: Starting from the basic working equations that describe the FEL process, the student will gain an understanding of how an XFEL works. You will then use numerical methods to solve the simplest case. This will involve solving equations describing the electron trajectories through the combined undulator and light fields, while simultaneously solving the equation that describes how the light field is driven by the electrons. Initially a code like MATLAB can be used.

Semester 2 Tasks: The student may wish to then use a lower-level language like Fortran, C or Java (your choice), to solve the same or extended equations describing further effects (e.g. harmonic light generation) and then present the solutions in a meaningful way using available plotting packages. The skills that you will learn are generic to a working theoretical/computational physicist and will prepare you well for a future career in this field. A good student should be able to take the analysis further and begin looking at more advanced topics. This will be like performing 'numerical experiments'.

Key references:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, 4, 814, 2010
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background:

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc (Maths Physics)

Misc:

The theory of X-ray Free electron Lasers

Project ID: BWJM2

Primary Supervisor: Brian McNeil **Email:** b.w.j.mcneil@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gordon Robb

Project Background: X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2]. The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level. The supervisor of this project Dr Brian McNeil works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Aim: Predict new effects that can enhance or extend current XFEL performance.

Semester 1 Tasks: This project will involve the derivation of the working equations that describe the FEL process from the coupled Maxwell and Lorentz force equations. This will involve deriving equations that describe the trajectories of the relativistic electrons as they propagate through the undulating magnetic fields, how they consequently radiate light, how they then couple to this light, and how this coupling feeds back onto the electrons.

Semester 2 Tasks: Once derived, these non-linear equations can be analysed and simplified to obtain a set of coupled linear differential equations that can be solved analytically to obtain a solution. The skills that you will learn are generic to a working theoretical physicist and will prepare you well for a future career in any theoretical field. A good student may be able to take this theoretical analysis further and begin looking at more advanced topics involving a degree of research into areas that have previously not been well explored, and perhaps even predicting new and useful practical ideas.

Key references:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, 4, 814, 2010
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background:

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc (Maths Physics)

Misc:

Adaptive noise reduction for sCMOS cameras

Project ID: BP1

Primary Supervisor: Brian Patton **Email:** brian.patton@strath.ac.uk **Division:** Nano

Secondary Supervisors: David McKee

Project Background: The camera devices used widely for scientific imaging are now typically based on sCMOS technology. Each pixel has its own amplification and readout electronics which allows for high framerate imaging among other advantages. However, for quantitative imaging, this also means that each pixel will have its own characteristic noise, which means that it can be difficult to process noisy images. This project aims to test a new method which claims to produce significant image quality enhancement when denoising sCMOS images.

Aim: Test the effectiveness of new noise-reduction algorithms on the image quality of cameras used for our microscopy

Semester 1 Tasks: Review physics of semiconductor imaging devices and the typical processing done on microscopy images (denoising, deconvolution). Get the algorithm code working on the test images supplied with the authors' code. Decide what images are needed for testing on Strathclyde-based cameras.

Semester 2 Tasks: Use the knowledge gained from semester 1 to calibrate one or more cameras in use in the department and test the quality of image improvement that is obtained by using the adaptive noise removal algorithm,

Key references:

[1] "Fast and accurate sCMOS noise correction for fluorescence microscopy", B. Mandracchia et al., https://doi.org/10.1038/s41467-019-13841-8

[2] "Video-rate nanoscopy using sCMOS camera–specific single-molecule localization algorithms", F. Huang et al., https://doi.org/10.1038/nmeth.2488

[3] Diekmann, R., Till, K., Müller, M. et al. Characterization of an industry-grade CMOS camera well suited for single molecule localization microscopy – high performance super-resolution at low cost. Sci Rep 7, 14425 (2017). https://doi.org/10.1038/s41598-017-14762-6

Theory: 40% **Comp:** 40% **Exp:** 20%

Recommended Background: Student must have good experience of Matlab. Python programming is also very useful. Image processing experience is helpful but not essential

Safety Training (if applicable): It is unlikely that we will be able to provide direct access to experimental facilities in semester 1. We will provide training in case there is the possibility of access in semester 2.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Will need to be able to use Matlab on Windows (there are code compatibility problems for Apple computers)

Constructing and testing a portable holographic microscope

Project ID: BP2

Primary Supervisor: Brian Patton **Email:** brian.patton@strath.ac.uk **Division:** Nano

Secondary Supervisors: David McKee

Project Background: Holographic microscopy takes advantage of computational techniques to enhance the performance of comparatively low cost optical components. This project will aim to test a recently reported modular holographic microscope; by using low cost cameras and portable computers such as the NVidia Jetson or Raspbedrry Pi 4, high quality scientific data can be obtained at low cost.

Aim: To test a compact holographic microscope using either a Nvidia Jetson compact computer or a Raspberry Pi to allow a high degree of portability,

Semester 1 Tasks: Review of holographic microscopy and modular/low cost microscopy. Decide on the best version of the microscope to construct based on the literature review. Test the microscope code on the portable computer device. Desing and arrange for the printing of the microscope body.

Semester 2 Tasks: Construct and test the microscope, obtaining images demonstrating the holographic imaging capabilities of the microscope.

Key references:

[1] Compact off-axis holographic slide microscope: design guidelines, https://doi.org/10.1364/BOE.11.002511

[2] Amardeep S.G. Singh, Arun Anand, Rainer A. Leitgeb, and Bahram Javidi, "Lateral shearing digital holographic imaging of small biological specimens," Opt. Express 20, 23617-23622 (2012)

[3] Timothy O'Connor, Jian-Bing Shen, Bruce T. Liang, and Bahram Javidi, "Digital holographic deep learning of red blood cells for field-portable, rapid COVID-19 screening," Opt. Lett. 46, 2344-2347 (2021)

Theory: 40% **Comp:** 40% **Exp:** 20%

Recommended Background: Student must have good experience Python programming. Image processing experience is helpful but not essential. Experience in CAD or 3D printing would also be helpful. Expereinece of Linux is very helpful.

Safety Training (if applicable): It is unlikely that we will be able to provide direct access to experimental facilities in semester 1, although we will need to come to a sutiable arrangement to allow printing of test pieces for the microscope. We will provide training in case there is the possibility of access in semester 2.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Characterisation of Digital Cameras

Project ID: DO1

Primary Supervisor: Daniel Oi **Email:** daniel.oi@strath.ac.uk **Division:** Optics

Secondary Supervisors: TBA

Project Background: Electro-optic sensors are important components, from photography, machine vision, autonomous vehicle guidance, and scientific data gathering. In this project, the student will characterise the electro-optical performance of a consumer digital camera. Parameters of interest include sensitivity, noise, dark-current, spectral response, and full-well capacity. The student will learn the basic operating principles of CCDs and CMOS imagers and the physics of digital camera sensors.

Aim: Determine the Electro-Optical properties of a digital camera

Semester 1 Tasks: Review physics of semiconductor imaging devices. Survey literature on Photon Transfer Curve (PTC). Derive sensor noise model.

Semester 2 Tasks: Collect image data from camera at home. Use PTC method to characterise sensor.

Key references:

[1] Photon Transfer, James R. Janesick, https://doi.org/10.1117/3.725073
[2] Photons to Photos https://www.photonstophotos.net/
[3] Photon Transfer Curve Characterization Method https://www.couriertronics.com/docs/notes/cameras_application_notes/

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background: Student should have access to a suitable camera, DSLR or mirrorless. Strongly advised to contact supervisor to check camera suitability. Students should be comfortable with using Matlab, Python, or similar scientific programming language for the processing of data.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

Scheduling in Quantum Key Distribution Networks

Project ID: DO2

Primary Supervisor: Daniel Oi **Email:** daniel.oi@strath.ac.uk **Division:** Optics

Secondary Supervisors: TBA

Project Background: Quantum key distribution provides secure communication links even in the presence of unlimited quantum computational powert that can crack existing public-key cryptosystems. The most practical current method of building large-scale QKD networks is by using trusted-nodes. However, end-end connectivity through intermediate trusted-nodes incurs overheads in secret key generation as well as latency between client requests and the establishment of a secure link. This project will investigate network optimisation of QKD trusted-node networks to maximise efficient key use whilst retaining low-latency access.

Aim: Analyse how trusted-node QKD networks should allocate key-pairs to to reduce key-swapping overheads.

Semester 1 Tasks: Review QKD theory, literature, and background work. Define network optimisation problem. Set up numerical tools to evaluate network performance.

Semester 2 Tasks: Develop optimisation tools. Investigate different topologies and client demand models.

Key references:

[1] Chen YA, Zhang Q, Chen TY, Cai WQ, Liao SK, Zhang J, Chen K, Yin J, Ren JG, Chen Z, Han SL. An integrated space-to-ground quantum communication network over 4,600 kilometres. Nature. 2021 Jan;589(7841):214-9.
[2] Newell RT, Peterson CG, Evans PA, Alshowkan M, Earl D, Mulkey D, Peters N, Safi CL, Tripp JL. Trusted Node QKD at an Electrical Utility. Los Alamos National Lab.(LANL), Los Alamos, NM (United States); 2021 Apr 15.
[3] Polnik M, Mazzarella L, Di Carlo M, Oi DK, Riccardi A, Arulselvan A. Scheduling of space to ground quantum key distribution. EPJ Quantum Technology. 2020 Dec 1;7(1):3.

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Student should have strong numerical modelling skills including proficiency in Matlab, Python, or similar.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths with Physics

Misc: Student should have access to their own computer to run code

Why do ocean colour chlorophyll products fail in coastal waters?

Project ID: DMcK1

Primary Supervisor: David McKee **Email:** david.mckee@strath.ac.uk **Division:** Nano

Secondary Supervisors: Oliver Henrich

Project Background: Ocean colour remote sensing provides a unique view of global oceanic biogeochemistry in surface waters. However, standard ocean colour chlorophyll algorithms are optimised for deep oceanic waters where the influence of non-algal materials is negligible. In coastal waters, the presence of variable concentrations of non-algal materials can disrupt the performance of both Chlorophyll algorithms and the atmospheric corrections that support them. We will use radiative transfer simulations to test the sensitivity of remote sensing Chlorophyll products to both of these confounding problems.

Aim: Establish the impact of non-algal materials and incomplete atmospheric correction on performance of ocean colour algorithms.

Semester 1 Tasks: 1. Literature review. 2. Familiarisation with Hydrolight radiative transfer model. 3. Production of modelled data set for coastal waters.

Semester 2 Tasks: 1. Systematically test impact of non-algal materials on multiple Chl algorithms 2. Systematically test impact of modelled atmospheric correction error on Chl products.

Key references:

[1] https://doi.org/10.1016/j.ecss.2007.03.028
[2] https://doi.org/10.1016/j.pocean.2016.10.007
[3]

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background: Competent programming ability in either Matlab or Python.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Could run with more than one student, but would be running in parallel towards same goal.

Modelling scattering from natural particle populations in the marine environment.

Project ID: DMcK2

Primary Supervisor: David McKee **Email:** david.mckee@strath.ac.uk **Division:** Nano

Secondary Supervisors: Brian Patton

Project Background: Scattering of light by particles plays an imprtant role in determining the reflectance signal measured by ocean colour satellites. The volume scattering function (VSF) describes the angular distribution of light scattering. Simplistic modelling of the particle size distribution (PSD) suggests that the VSF is wavelength independent. However, fiedl observations suggest the VSF is wavelength dependent. This project will use Mie theory to model particulate light scattering and assess the sensitivity of the VSF to deviations from assumed power law PSDs.

Aim: Test the sensitivity of particle scattering properties to changes in particle size distribution.

Semester 1 Tasks: 1. Literature review. 2. Familiarisation with Mie Theory. 3. Development of integrated optical mode (PSD - VSF).

Semester 2 Tasks: 1. Validate optical model against literature. 2. Systematically test deviations from power law PSD on VSF. 3. Assess impact of optically complex particles.

Key references:

[1] https://doi.org/10.1364/AO.53.001067
[2] https://doi.org/10.1364/AO.57.001777
[3] https://doi.org/10.1016/j.jqsrt.2019.106730

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background: Competent programming ability in either Matlab or Python.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Could run with more than one student, but would be running in parallel towards same goal.

A coherent synchrotron source based on a laser-plasma wakefield accelerator

Project ID: DAJ1

Primary Supervisor: Dino Jaroszynski **Email:** d.a.jaroszynski@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Dr. Antoine Maitrallain, Dr. Enrico Brunetti

Project Background: Laser wakefield acceleration in plasma (1) is a new scheme to accelerate particles, which enables bunch properties hitherto not achievable with conventional accelerators. Moreover, this type of accelerator can sustain accelerating fields 3-4 orders of magnitude higher than in a conventional RF accelerator, hence reducing the footprint of facilities substantially, which provides a unique source of electrons and electromagnetic radiation. Beams from laser wakefield accelerators have mono-energetic energy spectra at relatively high-energy and durations of approximately one femtosecond (10^-15s). Taking advantage of these extremely short bunches it is possible to directly produce coherent radiation using an undulator (2,3), which provides a unique compact femtosecond source of XUV coherent radiation.

Aim: The project will involve theoretical and numerical calculations (using software packages and purpose written routines) to study the evolution of the electron bunch properties during its propagation through the undulator and the characteristics of the radiation emitted.

Semester 1 Tasks: Literature review and in depth understanding of the field, familiarise with the codes used in the group, compare results with theory and potentially explain differences obtained

Semester 2 Tasks: Study bunch duration effects, space charge and energy effects on the radiation emitted after the undulator

Key references:

[1] Esarey E, Schroeder CB, Leemans WP. Physics of laser-driven plasma-based electron accelerators. Rev Mod Phys. 2009 Aug 27;81(3):1229–85.
[2] Schlenvoigt H-P, et al. A compact synchrotron radiation source driven by a laser-plasma wakefield accelerator. Nat Phys. 2008 Feb;4(2):130–3.
[3] D. A. Jaroszynski, et al., Coherent startup of an infrared free-electron laser, Phys. Rev. Lett. 71, 3798, 1993

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Knowledge of Fortran or C++, PYTHON, MATLAB etc., good marks in a theoretical course and/or numerical simulation.

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc: 1 Student for this project

Dislocations in Ga_2O_3: analysis of atomic resolution images

Project ID: FM1

Primary Supervisor: Fabien Massabuau **Email:** f.massabuau@strath.ac.uk **Division:** Nano

Secondary Supervisors: Ben Hourahine

Project Background: Owing to a wide bandgap of about 5 eV, Gallium Oxide (Ga_2O_3) has recently positioned itself as one of the most promising semiconductor materials for future applications as ultraviolet light emitters and detectors as well as high power transistors.

This material is however at the early stage of development, and while it is generally agreed that defects in semiconductors have adverse effects on the device properties, little is known about such defects in Ga_2O_3. In particular, dislocations are amongst the most common defects in such materials, yet they have been overlooked until now.

To fill this gap in knowledge, we have acquired atomic resolution data of Ga_2O_3 using transmission electron microscopy. The data indicate that the Ga_2O_3 film contains a high density of dislocations and stacking faults.

In the project, the student will (i) identify and analyse the defects present in atomic resolution images of Ga_2O_3 films, and (ii) use the available literature on defects in related material systems to inform its discussion. The results from this analysis will be insightful to future simulations of the optoelectronic properties of dislocations in Ga_2O_3 materials.

Aim: Identify the nature of dislocations in Ga_2O_3

Semester 1 Tasks: Literature survey on Ga_2O_3 materials, defects in Ga_2O_3, and on dislocations and stacking faults in corundum materials. Introduction with the dataset and analysis software. Commence data analysis.

Semester 2 Tasks: Determine the structure of dislocations and stacking faults in the available dataset. If applicable, compare the experimental results to simulated structures in collaboration with Ben Hourahine.

Key references:

[1] Roberts et al., J. Cryst. Growth 487 23 (2018) https://doi.org/10.1016/j.jcrysgro.2018.02.014
[2] Heuer et al., Phil. Mag. A 78 747 (1998) https://doi.org/10.1080/01418619808241934
[3]

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386).

Attendance to "Topics on Solid State Physics" module (PH453) is strongly recommended.

Safety Training (if applicable):

Suitable for: Mphys, BSc, BSc Maths and Physics, BSc Physics and Teaching

Misc:

Luminescence properties of Ti-alloyed Ga2O3 semiconductors

Project ID: FM2

Primary Supervisor: Fabien Massabuau **Email:** f.massabuau@strath.ac.uk **Division:** Nano

Secondary Supervisors: Naresh Gunasekar

Project Background: With a bandgap of ca. 5eV, gallium oxide (Ga2O3) is an ultra wide bandgap semiconductor that finds applications in ultraviolet detectors as well as high power devices. This material can be produced under several crystal forms labelled as α, β, ε, κ, and δ. The α-phase of Ga2O3 is of particular interest as it shares a common crystal structure with several other M2O¬3 semiconductors (M: metal), which opens much promise for engineering the bandgap through alloying.

Recently, our group has successfully deposited films of α-Ga2O3 alloyed with Ti2O3 [Ref. 1]. While we have been able to confirm that bandgap engineering could be achieved, little is known about the full spectrum of electronic transitions in the material. It is however important to identify these transitions as they can reveal essential structural or electronic properties (e.g. the presence of specific defects) critical for future device operation.

Photoluminescence is a technique that allows to probe electronic transitions of the material when excited using a light source (laser). Here films of (TixGa1-x)2O3 with different Ti:Ga ratios will be analysed by temperature-dependent photoluminescence in order to attain the electronic transitions in the materials. The student will (i) review the state-of-the-art in terms of luminescence of Ga2O3 and the impact of Ti, (ii) acquire and analyse the photoluminescence dataset, and (iii) attempt to identify the luminescence mechanisms at play.

Aim: Identify the nature of electronic transitions in Ti:Ga2O3

Semester 1 Tasks: Literature survey on Ga2O3 semiconductors, defects in Ga2O3, alloying with TixOy, and associated luminescence. Introduction to the photoluminescence setup and data analysis. Commence data acquisition.

Semester 2 Tasks: Complete the data acquisition, analysis and interpretation.

Key references:

[1] Barthel et al., Micromachines 11, 1128 (2020) https://doi.org/10.3390/mi11121128
[2] McCluskey, J. Appl. Phys. 127 101101 (2020) https://doi.org/10.1063/1.5142195
[3] Zhang et al. APL Mater. 8, 020906 (2020) https://doi.org/10.1063/1.5142999

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background: The student should be comfortable with the content of the “Condensed Matter Physics” module (PH386).

Attendance to “Topics on Solid State Physics” module (PH453) is strongly recommended.

Safety Training (if applicable): Laser safety training

Suitable for: Mphys, BSc, BSc Maths and Physics, BSc Physics and Teaching

Misc:

How to measure the bandgap energy of wide bandgap semiconductors?

Project ID: FM3

Primary Supervisor: Fabien Massabuau **Email:** f.massabuau@strath.ac.uk **Division:** Nano

Secondary Supervisors: Rob Martin

Project Background: The bandgap energy of a semiconductor is commonly defined as the difference in energy between the bottom of the conduction band and the top of the valence band. Experimental manifestations of the bandgap can be seen across a range of techniques, including in UV-vis spectrophotometry where the absorption spectrum displays a clear edge at the bandgap energy. However, putting a number on the bandgap energy can be a challenging task, in part due to different ways to interpret the above definition of the bandgap.

In the context of UV-vis spectrophotometry, several data analysis methods have been suggested to extract the bandgap energy from the absorption spectrum, with perhaps the most widespread of them tracing back to Tauc's work in the 1960s [Ref. 1]. Since then, the "Tauc method" has been generalised and employed across a range of semiconductors, but its validity and applicability remains controversial. More generally, the question of determining the bandgap energy of semiconductors is still an open debate.

In this project, we aim to investigate the definition of bandgap and how it applies to UV-vis spectrophotometry of wide bandgap semiconductors. The student will (i) review and critically assess the methods to determine the bandgap, (ii) acquire UV-vis spectrophotometry dataset for a range of wide bandgap semiconductors (e.g. Ga2O3, BN, AlGaN), and (iii) analyse the dataset in light of the literature search.

Aim: Investigate experimental determination of bandgap in semiconductors

Semester 1 Tasks: Literature survey on bandgap and determination methods. Begin data acquisition, and introduction to analysis software and methods.

Semester 2 Tasks: Complete data acquisition and analysis.

Key references:

[1] Tauc et al., Phys. Stat. Solidi B 15, 627 (1966) https://doi.org/10.1002/pssb.19660150224
[2] Zanatta, Sci. Rep. 9, 11225 (2019) https://doi.org/10.1038/s41598-019-47670-y
[3]

Theory: 40% **Comp:** 40% **Exp:** 20%

Recommended Background: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386).

Attendance to "Topics on Solid State Physics" module (PH453) is strongly recommended.

Safety Training (if applicable): Technology and Innovation Centre building induction training

Suitable for: Mphys, BSc, BSc Maths and Physics, BSc Physics and Teaching

Misc:

Microanalysis of epitaxial Hexagonal BN

Project ID: FM4

Primary Supervisor: Fabien Massabuau **Email:** f.massabuau@strath.ac.uk **Division:** Nano

Secondary Supervisors: Rob Martin

Project Background: Hexagonal boron nitride (h-BN) is a wide bandgap semiconductor of strong interest for applications such as ultraviolet light emitting diodes (LEDs), neutron detectors, or single photon sources. Research so far has mainly been performed on exfoliated h-BN flakes, which are a non-ideal source of material for industrial applications. In comparison, h-BN produced by scalable and industry-viable methods is at its infancy, and the materials properties have received less attention so far.

Here we propose an investigation of h-BN films produced by metalorganic chemical vapour deposition (MOCVD). The technique allows the deposition of h-BN on 2-inch sapphire substrates, and the project will focus on analysing the film's structural, chemical and luminescence properties across the wafer and compare them to the available literature.

The student will assist the acquisition of data on the electron probe microanalyzer (EPMA) in the Technology and Innovation Centre (TIC), imaging the sample surface using electron microscopy and collecting information on composition using wavelength dispersive X-ray analysis and on optical emission using cathodoluminescence. If time allows, the student could be exposed to other relevant techniques such as photoluminescence and UV-vis spectrophotometry.

Aim: Analyse the structural, chemical and optical properties of h-BN

Semester 1 Tasks: Literature survey on h-BN and introduction to the electron microscopy techniques involved in the project. Assist the data acquisition, and introduction to analysis software and methods.

Semester 2 Tasks: Complete data analysis.

Key references:

[1] Gil et al., Nanophotonics 9, 3483 (2020) https://doi.org/10.1515/nanoph-2020-0225
[2] Izyumskaya et al., Adv. Electron. Mater. 3, 1600485 (2017) https://doi.org/10.1002/aelm.201600485
[3]

Theory: 40% **Comp:** 40% **Exp:** 20%

Recommended Background: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386).

Attendance to "Topics on Solid State Physics" module (PH453) is strongly recommended.

Safety Training (if applicable): Technology and Innovation Centre building induction training

Suitable for: Mphys, BSc, BSc Maths and Physics, BSc Physics and Teaching

Misc:

Quantum Dots Nanolasers

Project ID: FP1

Primary Supervisor: Francesco Papoff **Email:** f.papoff@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gian-Luca Oppo

Project Background: Quantum Dots Nanolasers are one of the most promising ways to achieve the ultimate miniaturizzation of laser sources. While their small size is very interesting for applicatiions, it also allows us to investigate fundamental collective effects in anti-bunching, a quantum regime of emission not accessible to macroscopic lasers. In this project we will determine how the the thresholds beween different emission regimes depend on the size's distribution of the Quantum Dots.

Aim: Determine the thresholds beween thermal, anti-bunching and laser emission regimes.

Semester 1 Tasks: 1) Review the litterature and familiarize with existing theoretical model. 2) Modify the theoretical model and/or numerical code to include Quantum Dots of different size.

Semester 2 Tasks: 1) Perform simulations to determine numerically the effect of the size's distribution

Key references:

[1] W.W Chow, F. Jahnke and C. Gies. Emission properties of nanolasers during the transition to lasing. Light: Science & Applications 3, e201 (2014).

[2] M. Florian, C. Gies, F. Jahnke, H.A.M. Leymann and J. Wiersig. Equation-of-motion technique for finite-size quantum-dot systems: Cluster expansion method . Phys. Rev. B 87, 165306 (2013).

[3] S. Kreinberg, W.W. Chow, J. Wolters, C. Schneider, C. Gies, F. Jahnke, S. Höfling, M. Kamp and S. Reitzenstein. Emission from quantum-dot high-β microcavities: transition from spontaneous emission to lasing and the effects of superradiant emitter coupling. Light: Science & Applications 6, e17030 (2017).

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Working knowledge of Mathlab or Python, good marks in Electromagnetism and Quantum Mechanics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Up to two students can work on variations of this project

Modelling Nanolasers

Project ID: FP2

Primary Supervisor: Francesco Papoff **Email:** f.papoff@strath.ac.uk **Division:** Optics

Secondary Supervisors:

Project Background: Nanolasers can be modelled by deriving coupled differential equations for the expectation values of the light intensity, polarization and population inversion operators. However, these equations contain expectation values of products of these operators. In this project we will find how to approximate the expectation values of products of operators in order to have simple and efficient models with a finite number of equations.

Aim: Derive a simple model of nanolaser and verify its predictions

Semester 1 Tasks: 1) Review the literature and familiarize with the existing theoretical model 2) Simplify the theoretical model using expectation values

Semester 2 Tasks: 1) Perform simulations to evaluate the reliability of the model

Key references:

[1] H.A.M. Leymann, A. Foerster and J. Wiersig. Expectation value based equation-of-motion approach for open quantum systems: A general formalism. Phys. Rev. B 89, 085308 (2014)
[2] M. Florian, C. Gies, F. Jahnke, H.A.M. Leymann and J. Wiersig. Equation-of-motion technique for finite-size quantum-dot systems: Cluster expansion method . Phys. Rev. B 87, 165306 (2013).
[3]

Theory: 70% **Comp:** 30% **Exp:** 0%

Recommended Background: Working knowledge of Mathlab or Python, good marks in Electromagnetism and Quantum Mechanics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Up to two students can work on variations of this project

Memory effects in nanolasers

Project ID: FP3

Primary Supervisor: Francesco Papoff **Email:** f.papoff@strath.ac.uk **Division:** Optics

Secondary Supervisors:

Project Background: Resonance frequencies in nonlinear systems depend on the systems' state and this can lead to hysteresis in the systems' response to external forcing. When hysteresis is present, the response of the system depends on its history and this property can be used to build memory elements. Macroscopic lasers do not exhibit hysteresis, but very recent theoretical work suggest that hysteresis can be observed in nanolasers. If confirmed, this would be very important as nanolasers are the smallest sources of light that we can build.

Aim: Model the nonlinear response of nanolasers

Semester 1 Tasks: Review literature and learn to use existing codes

Semester 2 Tasks: Identify numerically the control parameter region where hysteresis is present

Key references:

[1] M. Carroll et al., PHYSICAL REVIEW LETTERS 126, 063902 (2021)
[2] W.W Chow, F. Jahnke, and C. Gies, Light Sci. Appl. 3, e201 (2014).
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background:

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Lloyd's mirror in standing wave microscopy

Project ID: GMcC1

Primary Supervisor: Gail McConnell **Email:** g.mcconnell@strath.ac.uk **Division:** Nano

Secondary Supervisors: Yu Chen

Project Background: Standing wave microscopy is a super-resolution imaging method and has been recently demonstrated for live cell imaging. In standing wave microscopy, a fluorescent specimen is located on top of a first surface reflector. The excitation light source is propagated through an objective lens, through the specimen, and retro-reflects from the mirror. This results in a standing wave pattern that can be used to excite the specimen with a 3D illumination pattern. The planes of constructive interference are lambda/4*n thick (where lambda = excitation wavelength and n is the refractive index of the specimen), and are around 120 nm thick for optical microscopic imaging. However, the presence of the destructive interference planes (where there is no light) means that the constructive interference planes are separated by lambda/2*n, and so the 3D image of the specimen is incomplete. This project explores the application of Lloyd's mirror to create the standing wave independently of the microscope in order to simplify the experimental design. Specifically the student will predict the resolution performance (i.e. by calculating the thickness of the antinodal planes expected) and also to investigate whether the position of the antinodal planes can be shifted relative to the cell specimen in order to fill in the information gaps normally found in standing wave microscopy.

Aim: The aim of the project is to understand if Lloyd's mirror can be used for standing wave microscopic imaging of cells

Semester 1 Tasks: The student should perform a literature review, and an analysis task on existing work. They should familiarise themselves with the basic physics of standing waves (including their application in microscopy), and how Lloyd's mirror can be used to create a standing wave.

Semester 2 Tasks: The student should choose a common wavelength in optical microscopy (e.g. 532nm) and model how the standing wave would form at that wavelength, specifically calculating the anti-nodal spacing and full-width at half-maxima, and then, time permitting, considering how the optical power would be distributed within the anti-nodal planes within the depth of field of a standard microscope objective lens (e.g. a 10x/0.5 N.A. lens). For this, the student should consider also how they would build an experimental apparatus to test that Lloyd's mirror would generate a standing wave suitable for use in optical microscopy. Student needs to write a ~30 page report worth 50% of the final mark.

Key references:

[1] Humphrey Lloyd, A.M., M.R.I.A, On a New Case of Interference of the Rays of Light, read January 27, 1834, Transactions of the Royal Irish Academy, Vol. XVII, page 171, printed by P. Dixon Hardy in 1837.
[2] Amor R, Mahajan S, Amos WB, McConnell G. Standing-wave-excited multiplanar fluorescence in a laser scanning microscope reveals 3D information on red blood cells. Sci Rep. 2014;4:7359. Published 2014 Dec 8. doi:10.1038/srep07359
[3] Tinning PW, Scrimgeour R, McConnell G. Widefield standing wave microscopy of red blood cell membrane morphology with high temporal resolution. Biomed Opt Express. 2018;9(4):1745-1761. Published 2018 Mar 16. doi:10.1364/BOE.9.001745

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: An interest in optics and measurement

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Removing ambiguity in standing wave microscopy using spiral interferometry

Project ID: GMcC2

Primary Supervisor: Gail McConnell **Email:** g.mcconnell@strath.ac.uk **Division:** Nano

Secondary Supervisors: Alison Yao

Project Background: In 2005, Fürhapter et al presented a surprising modification of optical interferometry. By introducing a spiral phase plate into the light path of a standard microscope the interference fringes produced the shape of spirals instead of closed contour lines as in traditional interferograms. Standing wave microscopy produces contour lines but without a priori knowledge of the shape of the object studied it is impossible to know whether surfaces are facing or opposing the observer. This project aims to understand whether using the spiral interferometry method of Fürhapter et al can remove the directional ambiguity in standing wave microscopy. If so, this may open up new opportunities for standing wave microscopic imaging of fixed and living cells.

Aim: The aim of the project is to explore whether spiral interferometry can resolve the ambiguity of directionality in standing wave microscopy

Semester 1 Tasks: In Semester 1, the student will learn the background to the project, and perform a literature review, including a critical analysis of existing work in the field. The student will begin by reproducing the results of Fürhapter et al

Semester 2 Tasks: In Semester 2 the student will amend this existing model to consider fluorescence rather than brightfield/phase contrast data.

Key references:

[1] Severin Fürhapter, Alexander Jesacher, Stefan Bernet, and Monika Ritsch-Marte, "Spiral interferometry," Opt. Lett. 30, 1953-1955 (2005)
https://www.osapublishing.org/ol/abstract.cfm?URI=ol-30-15-1953
[2] Amor, R., Mahajan, S., Amos, W. et al. Standing-wave-excited multiplanar fluorescence in a laser scanning microscope reveals 3D information on red blood cells. Sci Rep 4, 7359 (2014). https://doi.org/10.1038/srep07359
[3] Schniete, J.K., Tinning, P.W., Scrimgeour, R.C. et al. An evaluation of multi-excitation-wavelength standing-wave fluorescence microscopy (TartanSW) to improve sampling density in studies of the cell membrane and cytoskeleton. Sci Rep 11, 2903 (2021). https://doi.org/10.1038/s41598-020-78282-6

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: MATLAB or Python skills advantageous

Safety Training (if applicable): None

Suitable for: All

Misc: -

Opto-mechanics of Bose-Einstein Condensates in Optical Cavities

Project ID: GLO1

Primary Supervisor: Gian-Luca Oppo **Email:** g.l.oppo@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gordon Robb

Project Background: Bose-Einstein Condensates (BEC) inside an optical cavity and under the action of a coherent laser, can display exotic oscillations and even deterministic chaos [2]. This is quite unexpected for a quantum gas moving along the cavity via the tunnelling effect, a purely quantum phenomenon. The chaotic oscillations can also be enhanced by small modulations of the driving laser amplitude [2].

Aim: This project aims at investigating a new physical state of Bose-Einstein Condensates (BEC) in optical cavities. When the cavity finesse is low, experiments in Zurich have revealed that opto-mechanics leads to unusual oscialltions [1]. We investigate this phenomenon via theoretical and simulation methods to discover the basic mechanisms that combine cavity scattering and strong coupling between light and ultra-cold atoms. Please note that numerical codes are already in operation.

Semester 1 Tasks: Reading and undersanding the background literature; becoming familiar with the given Matlab codes; produce and understand plots that reproduce results in the literature

Semester 2 Tasks: Update codes to describe the specific device of interest; explore new regions of parameters using the new codes; produce plots of interest for the final report; understand the physics of the model equations and the obtained results

Key references:

[1] F. Brennecke, S. Ritter, T. Donner, T. Esslinger, "Cavity Optomechanics with a Bose-Einstein Condensate", Science 322, 235 (2008)

[2] M. Diver, G. R. M. Robb, and G.-L. Oppo, “Nonlinear and chaotic dynamics of a Bose-Einstein condensate in an optical cavity”, Phys. Rev. A 89, 033602 (2014) and “Chaotic resonances of a Bose-Einstein condensate in a cavity pumped by a modulated optical field”, Phys. Rev. A 91, 033622 (2015)

[3]

Theory: 40% **Comp:** 60% **Exp:** understanding

Recommended Background: Matlab or Phython

Safety Training (if applicable):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Weird interactions of Cavity Solitons

Project ID: GLO2

Primary Supervisor: Gian-Luca Oppo **Email:** g.l.oppo@strath.ac.uk **Division:** Optics

Secondary Supervisors: Francesco Papoff

Project Background: 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 and dark spots in driven-optical cavities (cavity solitons) have received a great deal of attention because of their applications in information processing [2].

Aim: This project aims at investigating a new kind of interaction between optical cavity solitons. Normal cavity solitons in random positions are susceptible to background noise fluctuations and can be described as a soliton gas. Above certain thresholds, however, cavity solitons in media pumped by two laser beams [1] 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.

Semester 1 Tasks: Reading and undersanding the background literature; becoming familiar with the given Matlab codes; produce and understand plots that reproduce results in the literature

Semester 2 Tasks: Update codes to describe the specific device of interest; explore new regions of parameters using the new codes; produce plots of interest for the final report; understand the physics of the model equations and the obtained results

Key references:

[1] M. Esalmi et al., “Complex structures in media displaying electromagnetically induced transparency: Pattern multistability and competition”, Phys. Rev. A 90, 023840 (2014)
[2] T. Ackemann, W. J. Firth and G-L Oppo, “Fundamentals and Applications of Spatial Dissipative Solitons”, Adv. At. Mol. Opt. Phys. 57, 323 (2009)
[3]

Theory: 40% **Comp:** 60% **Exp:** understanding

Recommended Background: Matlab

Safety Training (if applicable):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Cold Atom-Light Interactions

Project ID: GRMR1

Primary Supervisor: Gordon Robb **Email:** g.r.m.robb@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gian-Luca Oppo

Project Background: It is now possible to cool atoms down to temperatures close to absolute zero. At these temperatures, the interaction between light and atoms can change dramatically; with the optical forces acting on the atoms can play a significant effect.

Aim: Simulation of interactions involving light and cold atomic gases.

Semester 1 Tasks: 1. Review relevant theory on light-atom interactions. 2. Familiarise with code to simulate an interaction between light and a cold atomic gas. 3. Test code and benchmark code against published results.

Semester 2 Tasks: 1. Modify code and use to study variation of a parameter on the interaction e.g pump intensity. 2. Repeat 1 for other system parameters relevant to experiments e.g. pump frequency, pump profile, atom temperature

Key references:

[1] E. Tesio et al., Phys. Rev. A 86, 031801(R) (2012)
[2] G. Baio et al., Phys. Rev. Research 2, 023126 (2020).
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Some experience of using at least one of e.g. Python, MATLAB, Fortran, C, Julia would be desirable.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

BEC simulations

Project ID: GRMR2

Primary Supervisor: Gordon Robb **Email:** g.r.m.robb@strath.ac.uk **Division:** Optics

Secondary Supervisors: Gian-Luca Oppo

Project Background: When a gas of atoms is cooled to a temperature < ~1mK , it can stop behaving as a cloud of classical particles and instead behave as a “matter wave” or Bose-Einstein Condensate (BEC), whose behaviour is governed by the laws of quantum mechanics [1]. The project will involve simulating the behaviour of a BEC under different physical conditions e.g. in a trap, interacting with light,...

Aim: Simulation of Bose-Einstein condensates under various physical conditions

Semester 1 Tasks: 1. Review relevant theory on BEC. 2. Familiarise with code to simulate a BEC under certain conditions (TBC). 3. Test code and benchmark code against published results.

Semester 2 Tasks: 1. Modify code and use to study variation of a parameter on the interaction e.g BEC density profile. 2. Repeat 1 for other system parameters relevant to experiments e.g. trap geometry…

Key references:

[1] Allan Griffin, D. W Snoke, S Stringari , Bose-Einstein condensation Cambridge, New York : Cambridge University Press (1995).
[2] G. R. M. Robb et al., Phys. Rev. Lett. 114, 173903 (2015).
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Some experience of using at least one of e.g. Python, MATLAB, Fortran, C, Julia would be desirable.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

Interactive Physics simulations

Project ID: GRMR3

Primary Supervisor: Gordon Robb **Email:** g.r.m.robb@strath.ac.uk **Division:** Optics

Secondary Supervisors: Nigel Langford

Project Background: Many interactive Physics simulations have been developed over the years in a variety of different languages e.g. JAVA, Adobe Flash, Shockwave etc. However, for several reasons many existing simulations have now become obsolete, e.g. Most modern browsers do not run JAVA easily, as it is perceived as a security risk; Many existing simulations cannot run on tablets or mobile phones.

The project will involve developing one or more interactive Physics simulations using HTML5 & Javascript, which allows them to be run on modern browsers and on mobile devices. Recent examples of such simulations and teaching activities which use them can be found in [1].

Aim: Develop one or more interactive simulations on a physics topic to be decided.

Semester 1 Tasks: 1. Decide on physics topic, design simulation and review relevant theory. 2. Familiarise with EJS/EJSS package [2]. 3. Develop preliminary simulation .

Semester 2 Tasks: 1.Extend previous simulation or design and write new simulation which builds on first. 2. Conduct numerical "experiment" using extended simulation.

Key references:

[1] https://phet.colorado.edu
[2] https://www.um.es/fem/EjsWiki/
[3]

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: The physics topic and the exact method of developing the simulation can be adjusted to suit the student's degree programme and level of previous programming experience.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

Modelling narrow linewidth semiconductor disk lasers

Project ID: JEH1

Primary Supervisor: Jennifer E. Hastie **Email:** jennifer.hastie@strath.ac.uk **Division:** IoP

Secondary Supervisors: Paulo Hisao Moriya, George A. Chappell

Project Background: Semiconductor disk lasers (SDLs) have been investigated as suitable coherent light sources for cold atom quantum technologies due to a unique combination of high brightness, low intrinsic linewidth and noise, and potential for miniaturisation. SDL gain structure design plays an important role in the overall laser system performance as it influences not only the laser wavelength and power, but also frequency/intensity noise. In this project, the student will learn how to design a gain structure and predict its performance. A comparison of the theoretical findings with existing SDLs structures will be performed.

Aim: The aim of this project is to compare the effect of the design of semiconductor disk laser gain structures in its laser operation and noise performance.

Semester 1 Tasks: Review of SDL literature. Familiarisation with existing SDL gain structure design MathCAD code. Review of existing AlGaInP SDL gain structures designed for green and blue pumping. Creation of a Python/Matlab code based for gain structure design. Design a SDL cavity and investigate its stability.

Semester 2 Tasks: Use Kuznetsov and Rigrod models to predict laser performance. Compare theoretical findings with existing experimental results provided by the group.

Key references:

[1] M. Guina, A. Rantamäki and A. Härkönen, “Optically pumped VECSELs: review of technology and progress”, Journal of Physics D 50, 383001 (2017).
[2] P.H. Moriya et al., "Sub-kHz-linewidth VECSELs for cold atom experiments," Opt. Express 28, 15943-15953 (2020).
[3] P.H. Moriya et al., "InGaN-diode-pumped AlGaInP VECSEL with sub-kHz linewidth at 689 nm," Opt. Express 29, 3258-3268 (2021).

Theory: 40% **Comp:** 50% **Exp:** 10%

Recommended Background: Python, Matlab, Origin skills useful. Student will require independent access to PC and internet.

Safety Training (if applicable): No safety training required.

Suitable for: MPhys, BSc, BSc Maths and Phys (?)

Misc:

Structural investigation of zincblende and wurtzite nitride semiconductor thin films

Project ID: JB1

Primary Supervisor: Jochen Bruckbauer **Email:** jochen.bruckbauer@strath.ac.uk **Division:** Nano

Secondary Supervisors: Carol Trager-Cowan

Project Background: Nitride semiconductor thin films, which are the basis of blue, green and UV-LEDs, are usually grown with the thermodynamically stable wurtzite crystal structure; however, they can also be grown with the zincblende crystal structure. The zincblende crystal structure has advantages for the production of more efficient LEDs, particularly in the green spectral region. Certain growth conditions result in GaN thin films containing both crystal structures (polytypes). The scanning electron microscope technique of electron backscatter diffraction (EBSD) can be used to analyse and map the structural properties of materials, including crystal structure and the crystal orientation.

Aim: Interrrogate the structural properties of nitride semiconductor thin films containing regions with the wurtzite (hexagonal lattice) or with the zincblende (cubic lattice) crystal structure, through analyse of electron backscatter diffraction (EBSD) data.

Semester 1 Tasks: Review basics of crystallography. Literature survey on electron backscatter diffraction (EBSD) and the analysis of electron backscatter patterns (EBSPs). Literature survey of zinblende GaN.

Semester 2 Tasks: Analyse a number of EBSD datasets acquired from nitride semiconductors containing both the wurtzite and zincblende polytypes. The data analysis will require programming skills using a MATLAB-based toolbox (MTEX).

Key references:

[1] C. J. M. Stark et al., Appl. Phys. Lett. 103, 232107 (2013)
[2] C. Bayram et al., Adv. Funct. Mater. 24, 4492 (2014)
[3] A. J. Schwartz et al, Electron Backscatter Diffraction in Materials Science (Springer, 2009)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: An aptitude and enthusiasm for programming and for crystallography is essential. The project involves data analysis using MATLAB-based code and programming.

Safety Training (if applicable): None

Suitable for: MPhys, BSc, BSc Maths and Physics.

Misc:

Python model of single-photon technologies

Project ID: JH1

Primary Supervisor: Johannes Herrnsdorf **Email:** johannes.herrnsdorf@strath.ac.uk **Division:** IoP

Secondary Supervisors: tbc

Project Background: Recent advances in silicon semiconductor device engineering enabled chip-scale single-photon sensitive detectors in a range of different formats. These devices are now being applied to imaging, communications, and also other areas. When operating in the few-photon regime, the system performance is affected by the quantum fluctuations of the individual photons, but also by a range of effects in the semiconductor device (e.g. so-called "dead time", "dark counts", and "afterpulsing"). To gain insight into the complex interplay of quantum fluctuations and device response, numerical simulation is required.

Aim: To understand the influence of quantum fluctuations and external noise on the performance of imaging and optical data transfer with single-photon detectors.

Semester 1 Tasks: Familiarisation with pre-existing code, following two different approaches (a number state model and a temporal evolution model). Understanding the code in the context of background literature. Run existing code to explore some of the parameter space covered already by the existing models.

Semester 2 Tasks: Unify the two aforementioned approaches into a combined model. Generalisation to systems with more than one detector. Numerical optimisation of the code. Extension of the model to further device properties that have not yet been implemented in the model (currently, only the dead time and thermal noise are implemented).

Key references:

[1] Koczyk, Wiewior, Radzewicz, Photon counting statistics - Undergraduate experiment, Am. J. Phys. 64, 240 (1996), https://doi.org/10.1119/1.18211

[2] Tapster, Rarity, Satchell, Generation of Sub-Poissonian Light by High-Efficiency Light-Emitting Diodes, Europhys. Lett. 4, 293 (1987), https://doi.org/10.1209/0295-5075/4/3/007

[3] Dutton et al. A SPAD-Based QVGA Image Sensor for Single-Photon Counting and Quanta Imaging, IEEE Trans. Electron Dev. 63, 189 (2016), https://doi.org/10.1109/TED.2015.2464682

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Knowledge of Python or a similar programming language will be benefitial

Safety Training (if applicable): NA

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Up to 2 students can take this project

Quantum Lidar

Project ID: JJ1

Primary Supervisor: John Jeffers **Email:** john.jeffers@strath.ac.uk **Division:** Optics

Secondary Supervisors: Nigam Samantaray/Jon Pritchard - TBA

Project Background: Quantum Lidar is supposedly better than classical lidar at recognising the presence of objects. This project will investigate whether it is so.

Aim: Calculate detection statistics for a quantum lidar

Semester 1 Tasks: Study the quantum electromagnetic field, beam splitters, thermal states, photodetectors,etc. Calculate and simulate the detection statistics produced by a thermal state.

Semester 2 Tasks: Study the detection statistics produced by a thermal signal reflected off a target, then a quantum lidar signal.

Key references:

[1] https://doi.org/10.1117/12.2555390
[2]
[3]

Theory: 75% **Comp:** 25% **Exp:** 0%

Recommended Background: A high mark in Quantum Physics and Electromagnetism. Good Integral and differenetial calculus. combinatorics. Probability theory.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum Volume for Rydberg Atoms

Project ID: JP1

Primary Supervisor: Jonathan Pritchard **Email:** jonathan.pritchard@strath.ac.uk **Division:** Optics

Secondary Supervisors: Natalie Pearson, Andrew Daley

Project Background: Quantum computers promise to outperform their classical counterparts to achieve unprecedented computational challenges by leveraging the properties of quantum mechanics. How good is your quantum computer really though? The quantum volume provides a metric that describes the maximum size of the circuit that can be run on a digital quantum computer to answer this question for any hardware. Rydberg atoms are one of such hardwares which promising a competitive scalable quantum computer. A motivated student will simulate a Rydberg atom experiment to determine the quantum volume of such a system.

Aim: Investigate the quantum volume of a Rydberg atom quantum computer

Semester 1 Tasks: Perform a literature review on quatum volume, become familiar with QUEST quamtum simulator, understand the basic mechanisms of Rydberg atoms

Semester 2 Tasks: Implement simulation of algorithm to determine quantum volume for Rydberg system

Key references:

[1] https://journals.aps.org/pra/abstract/10.1103/PhysRevA.100.032328
[2] https://questlink.qtechtheory.org/
[3] https://arxiv.org/pdf/2011.03031.pdf

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: quatum mechanics, mathematica or python

Safety Training (if applicable):

Suitable for: MPhs

Misc:

Laser noise stabilisation for NISQC.

Project ID: JP2

Primary Supervisor: Jonathan Pritchard **Email:** jonathan.pritchard@strath.ac.uk **Division:** Optics

Secondary Supervisors: Nicholas Spong

Project Background: Laser noise stabilisation is an essential technique in modern quantum optics, where power fluctuations can contribute dominant errors to sensitive experimental quantum measurements such as those at the heart of modern NISQCs. Recently, highly excited 'Rydberg' atoms (https://www.sciencemag.org/news/2018/09/arrays-atoms-emerge-dark-horse-candidate-power-quantum-computers) have emerged as possible building blocks of NISQCs, realisable in the short-term. Strathclyde is home to one such project. The SQuAre project seeks to develop such a device, following similar projects recently established in Harvard (https://www.nature.com/articles/s41586-021-03582-4) and Paris (https://www.nature.com/articles/s41586-021-03585-1). Laser noise stabilisation is an essential part of the SQuAre project, being integral to several of the key laser systems used to manipulate atomic states. In this project, the student will develop a viable laser noise stabilisation based on feedback provided to an acousto-optic modulator for use in the SQuAre project.

Aim: Implementation of modern laser noise stabilisation based on feedback to an acousto-optic modulator for use in a noisy intermediate-scale quantum computer (NISQC).

Semester 1 Tasks: Review of relevant literature. Familiarisation with project optics & electronics. Simulation of analog circuitry using LTSpice and Servo design.

Semester 2 Tasks: Servo fabrication. Implementation and testing. Laser intensity noise analysis.

Key references:

[1] Power stabilization of a diode laser with an acousto-optic modulator – F. Tricot et al. - https://arxiv.org/abs/1808.09777
[2] Quantum Phases of Matter on a 256-Atom Programmable Quantum Simulator – Ebadi et al. - https://arxiv.org/abs/2012.12281
[3] Laser Intensity Stabilisation – Thesis – C. Giehr https://tiqi.ethz.ch/content/dam/ethz/special-interest/phys/quantum-electronics/tiqi-dam/documents/semester_theses/semesterthesis-caspar_giehr.pdf

Theory: 50% **Comp:** 0% **Exp:** 50%

Recommended Background: Knowledge of Arduino programming language "wire", analog circuit simulator 'LTSpice' and/or Python, familiarity with basic experimental optics.

Safety Training (if applicable): Laser safety training required

Suitable for: Mphys

Misc: Yes

Photoionization modeling of AGN winds

Project ID: JM1

Primary Supervisor: Junjie Mao **Email:** junjie.mao@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Nigel Badnell

Project Background: Active Galactic Nuclei (AGN) are the observed manifestation of inflow of matter onto supermassive black holes. Winds driven by AGN have also been observed in the high-resolution cosmic X-ray and UV spectra. AGN winds provide an attractive solution to several observation properties of the circumnuclear environment and beyond. Detailed photoionization modeling is essential to interpret the observed spectra.

Aim: Explore the impact of spectral energy distribution on the density diagnostics of AGN winds

Semester 1 Tasks: Review density diagnostics of AGN winds in the literature. Use available broadband spectral energy distribution (from optical to X-ray) to explore the impact on the density diagnostics of AGN winds.

Semester 2 Tasks: Review the spectral energy distribution of AGN in the infrared band in the literature. Compose broadband spectral energy distribution (from infrared to X-ray) and explore the impact on the density diagnostics of AGN winds.

Key references:

[1] Mao et al. 2017, A&A, 607, 100
[2] Mehdipour et al. 2016, A&A, 596, 65
[3] Mehdipour & Costantini 2018, A&A, 619, 20

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be familiar with scientific programming. Background knowledge of astronomy would be a plus but not required.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc:

Chemical evolution of galaxies

Project ID: JM2

Primary Supervisor: Junjie Mao **Email:** junjie.mao@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Nigel Badnell

Project Background: Emission lines from various elements stand out in the observed cosmic X-ray spectra. These fingerprints are left by various enrichment processes throughout the evolution of galaxies. Chemical evolution models are required to understand the time-integral abundance pattern observed.

Aim: Explore how the elemental abundance patterns depend on the stellar yields, star formation rate and history of the galaxy

Semester 1 Tasks: Review the chemical enrichment models widely used in the field of X-ray astronomy. Explore the chemical evolution model built by non-X-ray astronomers. Summarize the common and distinct features between the two types of models.

Semester 2 Tasks: Bridging the gap between the two communities by integrating various building blocks of the two types of codes into one.

Key references:

[1] Mao et al. 2019, A&A, 621, 9
[2] Yan et al. 2019, A&A, 629, 93
[3] Loewenstein, 2013, ApJ, 773, 52

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be familiar with python (Jupyter notebook). Background knowledge of astronomy would be a plus but not required.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc:

Machine learning for quantum vortex detection.

Project ID: KW1

Primary Supervisor: Kali Wilson **Email:** kali.wilson@strath.ac.uk **Division:** Optics

Secondary Supervisors: Jasminder Sidhu

Project Background: A dilute gas Bose-Einstein condensate (BEC) is a rarified quantum fluid, meaning that the physical state of the fluid is described by a wavefunction with density and phase profiles. Consequently the ultracold gas of atoms supports quantum vortices, wavefunction nodes surrounded by 2pi phase windings. A vortex is observed as a sharp dip in the bulk density of the BEC. Such vortices serve as robust indicators of the state of the quantum fluid and studying their behaviour gives access to a range of interesting phenomena such as turbulence and chaos. Studying such phenomena requires being able to identify the precise location of vortex cores, and ideally to track them in time. However, experimental limitations often result in loss of information, so vortex detection techniques need to work with just the condensate density profile, or in presence of noise.

Aim: Use machine learning techniques to identify density dips associated with quantized vortices in Bose-Einstein condensates.

Semester 1 Tasks: Review of current imaging and image analysis techniques for ultracold atoms. Learn how to use existing codes to generate arbitrary vortex distributions in BECs. Test existing vortex identification methods on simulated data.

Semester 2 Tasks: Apply vortex identification methods to a previously acquired experimental data, determining an optimal strategy for handling experimental noise. Develop a vortex tracking algorithm.

Key references:

[1] F. Metz et al., Mach. Learn.: Sci. Technol. 2 035019 (2021).
[2] A. Rakonjac, et al., Phys. Rev. A 93, 013607 (2016).
[3] T.W. Neely et al., Phys Rev Lett 104 160401 (2010).

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Student should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations and image analysis. Recommended modules PH462 Topics in Quantum Optics, PH455 Topics in Photonics, PH459 Topics in Atomic Physics.

Safety Training (if applicable):

Suitable for: Mphys, BSc, BSc Maths and Physics, BSc Physics with Teaching.

Misc:

Parametric Scattering and Coupling of Microwaves in Plasma

Project ID: KR1

Primary Supervisor: Kevin Ronald **Email:** K.Ronald@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Bengt Eliasson, Colin Whyte

Project Background: Parametric scattering can arise when powerful EM waves proagate in a non-linear medium like plasma. These can arise in laser plasma interactions where they can be useful (Scattering of laser beams on Langmuir waves can give rise to useful energy transformation processes), or detrimental - Brillouin interactions are believed to cause undesired and damaging scattering of drive laser signals in inertial confinement fusion experiments. Similar dynamics arise when powerful radio waves are used to modulate the ionospheric plasma. In magnetically confined fusion plasmas the next generation of tokamak (ITER) will be difficult to drive with lower frequency signals (Ion Cyclotron Heating and Lower Hybrid Current Drive) as the antenna will need to be stood back from the hot, dense plasma to avoid damage. Coupling the energy across the evanesent 'vacuum gap' presents a difficult matching problem. In spherical aspect tokamaks like MAST, an attractive approach for future power generation, the grossly overdense plasma resulting from their exceptional confinement performance makes them inaccessable for electron cyclotron drive. Driving the plasma resonances by beating two powerful and higher frequency signals may be an attractive way to circumvent both issues. A 'linear' plasma experiment is being completed which will enable the fundamental underpinning physics to be studied in the microwave frequency range (directly relevant to magnetically confined fusion parameter space and of a normalised intensity as to be relevant to laser-plasma and ionospheric physics) in a cool tenuous plasma amenable to diagnostics. The project will aim to make numerical predictions of the dynamics whch may be expected in these experiments.

Aim: To numerically study microwave parametric interactions relevant to a new experimental facility

Semester 1 Tasks: Undertake literature review of the relevant parametric scattering processes and applications; understand numerical and experimental methods to be used; develop computer model in appropriate simulation tool; perform initial calculations in simple cases.

Semester 2 Tasks: Undetake more complete investiatons of simpler cases and compare/contrast with theoretical expectations. Seek to explore more complex ranges of density and magnetic field. It may be possible to undertake some experiments however this is tentative at this time.

Key references:

[1] R.M.G.M. Trines et al, 2011, Nature Physics 7, 87
[2] M.R. Amin and R.A. Cairns, 1990, Nucl. Fus. 30, 327-342
[3] Norin L. et al, 2009, Phys. Rev. Lett., 102, art. 065003

Theory: 15% **Comp:** 65% **Exp:** 20%

Recommended Background: Strong background in EM theory, vectors and vector calculus and mechanics/dynamics and lab skills important. VERY Strongly recommend students should be taking PH452 and (in due course) PH560. Programming skills beneficial, though no specific language pre-requisite. Students may find skills in matlab/python/maple useful in understanding theory and interpreting results.

Safety Training (if applicable): General lab safety inductions appropriate at outset in case lab experiments are undertaken. Specific ABP lab induction will be given if this is to take place on high power RF and microwave safety.

Suitable for: MPhys, BSc. Project particularly well suited to students with good mathematical ability and strong experimental skills and for extension in the following year of Mphys

Misc: 2 projects possible with different mix of supervisors

RF-gated Thermionic Injector Gun for Free-Electron Laser

Project ID: LZ1

Primary Supervisor: Liang Zhang **Email:** liang.zhang@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Adrian Cross

Project Background: A thermionic injector gun has the advantages of a long lifetime and high average power. In this project, the student will learn to define the specifications of an RF-gated thermionic gun from the requirement of the accelerator. From the physics, concept to design and optimize the electron geometry. The student will learn how to bridge physics with a practical device.

Aim: Investigate the properties of an RF-gated thermionic injector gun in the application of Free Electron Laser

Semester 1 Tasks: Review the physics of thermionic emission and electron gun. Survey literature on the electron emission model and the Pierce type electron gun. Derive the equations that determine the gun structure.

Semester 2 Tasks: Carry out simulations on the RF gated electron gun and achieve the optimal result.

Key references:

[1] Electron injector based on thermionic RF modulated electron gun for particle accelerator applications, DOI: 10.1109/TED.2019.2954778

[2] A Gridded Thermionic Injector Gun for High-Average-Power Free-Electron Lasers, DOI: 10.1109/TPS.2012.2201962

[3] Review of x-ray free-electron laser theory, DOI: 10.1103/PhysRevSTAB.10.034801

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be comfortable with using Matlab, or Python for numerical calculations, also will need to learn a new simulation tool CST Particle Studio.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Generation and characterisation of photon pairs in parametric processes

Project ID: LC1

Primary Supervisor: Lucia Caspani **Email:** lucia.caspani@strath.ac.uk **Division:** IoP

Secondary Supervisors: Michael Strain

Project Background: The possibility to generate and characterise quantum states of light is at the core of many quantum technologies. Nonlinear processes such as spontaneous parametric down-conversion and spontaneous four-wave mixing are among the most widespread methods for generating single/entangled photons. For applications in quantum technologies, it is fundamental to optimise such processes using specific crystals or waveguides and define the required measurements for characterising the quantum properties of the generated light.

Aim: The student will investigate nonlinear processes for the generation of quantum states of light

Semester 1 Tasks: The student will perform a literature review on the nonlinear processes exploited to generate quantum states of light and their characterisation (coincidence measurements, etc.)

Semester 2 Tasks: The student will desing an optical setup for the genearion of photon pairs using nonlinear media and for the collection and analysis of the quantum properites of the light.

Key references:

[1] R. W. Boyd, “Nonlinear Optics”, 4th ed. (Academic Press, 2020).
[2] L. Caspani et al., "Integrated sources of photon quantum states based on nonlinear optics," Light Sci. Appl. 6, e17100 (2017).
[3]

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: Recommended module PH455 (Topics in Photonics). Previous experience with Matlab will be useful but not essential. An understanding of optics and electromagnetic fields will be a useful background.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

One-way quantumc omputation using photons

Project ID: LC2

Primary Supervisor: Lucia Caspani **Email:** lucia.caspani@strath.ac.uk **Division:** IoP

Secondary Supervisors: Michael Strain

Project Background: Among the different models for quantum computations, one-way (or measurement-based) quantum computing offers the advantage of shifting the complexity of the computation from the implementation of the logic gates to the generation of the initial quantum state. Photonics is particularly suited as a resource for one-way quantum computing, owing to the possibility of generating photons in the required entangled state (cluster state).

Aim: The student will investigate an all-optical one-way quantum computer

Semester 1 Tasks: The student will perform a literature review of the different photonics approaches for generating cluster states and the required measurements to perform a quantum algorithm.

Semester 2 Tasks: The student will design an optical setup based on integrated circuits for the generation of cluster states for one-way quantum computation

Key references:

[1] Takeda et al., "Toward large-scale fault-tolerant universal photonic quantum computing", APL Photonics 4, 60902 (2019).
[2] Raussendorf et al., "A one-way quantum computer", Phys. Rev. Lett. 86, 5188 (2001).
[3]

Theory: 70% **Comp:** 30% **Exp:** 0%

Recommended Background: Recommended module PH455 (Topics in Photonics). Previous experience with Matlab will be useful but not essential. An understanding of optics and electromagnetic fields will be a useful background.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Focusing electron beams from a laser-plasma wakefield accelerator

Project ID: MW1

Primary Supervisor: Mark Wiggins **Email:** mark.wiggins@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Dino Jaroszynski

Project Background: Laser-plasma wakefield accelerators (LWFAs) are very compact laser-driven accelerators that have the potential to replace conventional accelerators in a broad range of applications. Highly relativistic electron beams are generated in an LWFA when a high-intensity femtosecond duration laser pulse is focused into a gaseous or plasma target. Collimating and focusing the electron beams that emerge from a LWFA, by using quadrupole magnet arrays, can be crucial for many potential applications such as coherent radiation production, electron diffraction and radiotherapy. For example, very high energy electron radiotherapy is predicted to deliver a higher volumetric radiation dose when the electron beam converges onto the target tumour.

Aim: Study and optimise the evolution of electron beams as they are transported through magnetic arrays for a given application.

Semester 1 Tasks: Literature review of the background topic areas (laser-plasma accelerators, electron beam transport, applications). The student will become familiar with the MAD-X numerical simulation package and generate basic data.

Semester 2 Tasks: Concentrating on a particular application, the student will optimise the beam focusing system for a variety of accelerator scenarios to inform future experiments. Detailed literature review in that application area, comparing simulations results with published work.

Key references:

[1] T. Eichner, et al., "Miniature magnetic devices for laser-based, table-top free-electron lasers", Phys. Rev. ST Accel. Beams 10, 082401 (2007). https://doi.org/10.1103/PhysRevSTAB.10.082401
[2] S. M. Hooker, "Developments in laser-driven plasma accelerators", Nature Photon. 7, 775 (2013). https://doi.org/10.1038/nphoton.2013.234
[3] K. Kokurewicz, "Focused very high-energy electron beams as a novel radiotherapy modality for producing high-dose volumetric elements", Sci. Rep. 9, 10837 (2019). https://doi.org/10.1038/s41598-019-46630-w

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Knowledge of computational physics. Interest in high-power lasers, radiation and applications

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Suitable for 1 or 2 students

Spectral properties of reflected laser light from expanding plasma targets

Project ID: MK1

Primary Supervisor: Martin King **Email:** m.king@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Paul McKenna, Ross Gray

Project Background: The interaction of an intense laser pulse with a foil target results in ionisation of the target and the formation of a dense plasma. The laser light is then reflected from the critical surface where the plasma frequency is greater than the laser frequency. Due to the speed of the expansion/recession of this critical surface, the reflected light can experience a temporally varying Doppler shift. Understanding the resultant spectral properties of the reflected light can give insight into the underlying plasma dynamics that occur which is relevant for producing high energy ion beams and bright, X-ray sources that have applications in a range of fields such as medicine and science.

Aim: Determine the effect plasma expansion/hole-boring has on the spectrum of intense reflecting laser light

Semester 1 Tasks: Conduct a thorough literature review. Run 1D simulations and produce spectra of the incoming and outgoing pulse for a low intensity and high intensity pulse.

Semester 2 Tasks: Investigate the change in reflection spectra by varying plasma temperature, laser intensity and the impact of introducing a chirp to the input laser pulse.

Key references:

[1] S. C. Wilks, et al. Phys. Rev. Lett. 69, 1383 (1992)
[2] A. P. L. Robinson, et al. Plasma Phys. Control. Fusion, 51, 024004 (2009)
[3] A. Macchi, et al. Rev. Mod. Phys. 85, 751 (2013)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: MATLAB, Python, good understanding of EM theory and an interest in plasma physics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Atomic physics of high Z elements in fusion

Project ID: MOM1

Primary Supervisor: Martin O'Mullane **Email:** martin.omullane@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Nigel Badnell

Project Background: High Z metals will be part of fusion devices, either as structural components (JET and ITER) or as liquid metal divertors (DEMO). The balance between charge states and the power radiated depends on the metastability of each stage. The number of metastables can be determined from fundamental atomic data.

Aim: Investigate the influence of metastable (long lived) atomic states of tungsten and tin ions and the consequences for plasmas found in fusion experiments.

Semester 1 Tasks: Broadly review the use of metals in tokamak plasmas with emphasis on the atomic and radiation aspects. Explain the quantities in the ionization balance rate equations. Install Linux on your laptop (if windows based). Install python and a fortran compiler and ADAS codes for the project (deploying these as a container could be explored).

Semester 2 Tasks: Run ADAS codes, and define the criteria, to determine the number of metastables for a set of ions. Illustrate the effect on the radiated power from an ion. Consider how to include a large number of metastables in the ionization balance equations.

Key references:

[1] R. Neu et al., Nuclear Fusion, 45, p209 (2005)
[2] G. Doyle et al, A&A, L29 (2005)
[3] H P Summers et al, PPCF, 48, p263 (2006)

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc: Up to two students can take this project.

Atomic physics of high Z elements in fusion

Project ID: MOM1

Primary Supervisor: Martin O'Mullane **Email:** martin.omullane@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Nigel Badnell

Project Background: High Z metals will be part of fusion devices, either as structural components (JET and ITER) or as liquid metal divertors (DEMO). The balance between charge states and the power radiated depends on the metastability of each stage. The number of metastables can be determined from fundamental atomic data.

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Key references:

[1] R. Neu et al., Nuclear Fusion, 45, p209 (2005)
[2] G. Doyle et al, A&A, L29 (2005)
[3] H P Summers et al, PPCF, 48, p263 (2006)

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc: Up to two students can take this project.

Photon pair generation in integrated ring resonator devices

Project ID: MS1

Primary Supervisor: Michael Strain **Email:** michael.strain@strath.ac.uk **Division:** IoP

Secondary Supervisors: Lucia Caspani

Project Background: Photon pair generation is a key resource for quantum optical systems such as Quantum Key Distribution encryption schemes and optical computing systems. Non-linear optical processes can be used to generate pairs of correlated\entangled photons in micron scale devices such as ring resonators. The performance of these devices depends strongly on the material they are fabricated from, their geometry and the wavelength of the optical signal used to generate the photon pairs.

Aim: To design optimised photonic structures for the high-rate generation of correlated\entangled photon pairs.

Semester 1 Tasks: A review of the literature on photon pair generation in waveguide devices will be carried out to compare various material platforms, pump schemes and wavelength ranges. The student will be provided with a simulation tool in Matlab and will familiarise themselves with its operation and how parameter sweeps can be implemented to allow optimisation studies. A selection of test parameters will be made.

Semester 2 Tasks: Simulations will be carried out to calculate the classical non-linear optical performance of ring resonator devices based on the parameters defined in semester 1. These efficiencies will then be translated into photon pair generation rates and optimal devices designed.

Key references:

[1] Grassani, D. et al. Micrometer-scale integrated silicon source of time-energy entangled photons. Optica 2, 88–94 (2015).
[2] Azzini, S. et al. Ultra-low power generation of twin photons in a compact silicon ring resonator. Opt. Express 20, 23100–23107 (2012).
[3] Azzini, S. et al. From classical four-wave mixing to parametric fluorescence in silicon microring resonators. Opt. Lett. 37, 3807–9 (2012).

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Previous experience with Matlab will be useful but not essential. An understanding of optics and EM fields will be a useful background.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: More than one student can take this project.

Investigating the optical and structural properties of β- gallium oxide semiconductors

Project ID: NG1

Primary Supervisor: Naresh Gunasekar **Email:** naresh.gunasekar@strath.ac.uk **Division:** Nano

Secondary Supervisors: Prof. Rob Martin & Dr Paul Edwards

Project Background: Gallium oxide (Ga_2O_3) has attracted massive interest in UV photodetectors and power electronics device applications due to its ultra-wide bandgap in the range of 4.6- 4.9 eV and a large breakdown field of ≈ 8 $MVcm^{-1}$. Electronic devices require control of charge carriers by controlled incorporation of various elements and dopants (such as silicon, tin, indium and aluminium, iron, chromium) using a variety of manufacturing methods. The knowledge and position of electronic states due to the different dopants and defects is critical for electronic device operation and reliability. Study of the light emission, and thereby the associated electronic transitions, provides an understanding of the presence of point defects and their impact on optical and electrical properties. The project will cover photoluminescence (PL) using UV lasers and cathodoluminescence (CL) in a scanning electron microscope (SEM) for studying the optical properties of tin, indium alloyed Ga_2O_3. Temperature-dependent (20 – 300 K) PL will also be performed for a detailed understanding of defect-related transitions. Secondary electron images and backscatter electron images will also be acquired using a SEM for studying the structural properties.

Aim: Study the physical properties of gallium oxide semiconductors for opto-electronics and power electronics applications.

Semester 1 Tasks: Review physics of semiconductors and opto(electronic) devices. Survey literature on optical spectroscopy of gallium oxide semiconductors. Develop familiarity with relevant spectroscopy techniques (PL, CL). Use Origin to plot and analyse CL and PL data collected by other researchers in the group.

Semester 2 Tasks: Collect spectroscopy data from labs in JA and TIC. Use peak fitting methods and analyse the acquired spectroscopy data at home.

Key references:

[1] A review of Ga_2O_3 materials, processing, and devices, S. J. Pearton et al., Applied Physics Reviews 5, 011301 (2018).
[2] Point defects in Ga_2O_3, Matthew D. McCluskey, J. Appl. Phys. 127, 101101 (2020)
[3] Luminescence spectroscopy of Cr^{3+} ions in bulk single crystalline β-Ga_2O_3, A. Luchechko et al, J. Phys. D: Appl. Phys., 53, 354001 (2020).

Theory: 50% **Comp:** 0% **Exp:** 50%

Recommended Background: PH453 Topics in Solid State Physics, PH355 Physics Skills. Students should be able to become comfortable with use of Origin for data analysis and with lasers. Prior experience with optical spectroscopy of crystals in the Physics teaching lab would be beneficial.

Safety Training (if applicable): Laser and radiological safety training, technology innovation centre safety induction will be needed.

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Thermal measurement and modelling of neural microLED probes

Project ID: NM1

Primary Supervisor: Niall McAlinden **Email:** niall.mcalinden@strath.ac.uk **Division:** IoP

Secondary Supervisors: Keith Mathieson

Project Background: As neural devices become more sophisticated more electrically active elements are being implanted in the brain. These active elements produce heat which alters the properties of the neural circuits you are attempting to study. Therefor, accurate measurement of the thermal properties of devices is critical before devices can be implanted. Thermal modelling can also be used to give new insights into temperature flow in devices and to suggest design optimisations.

Aim: To measure the thermal properties of microLED probes for neural applications. The temperature of active elements of the device will be measured in air using a thermal camera and in water using a fluorescent based technique. Furthermore a thermal model of the device will also be developed which may point to design improvements.

Semester 1 Tasks: 1) Review current technologies for illuminating brain tissue, including implantable waveguides and LEDs. 2) Survey literature on the temperature dependence of fluorophores. 3) Develop a COMSOL model to study the thermal properties of a neural probe.

Semester 2 Tasks: 1) Measure the thermal properties of a neural probe in air using a thermal camera 2) Measure the thermal properties of a neural probe in water based solution. This will be more representative of how the device will behave in tissue.

Key references:

[1] Depth-specific optogenetic control in vivo with a scalable, high-density µLED neural probe https://doi.org/10.1038/srep28381

[2] Multisite microLED optrode array for neural interfacing https://doi.org/10.1117/1.NPh.6.3.035010

[3] Injectable, Cellular-Scale Optoelectronics with Applications for Wireless Optogenetics https://doi.org/10.1126/science.1232437

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background: Students should have a strong background in photonics. Students should have access to a good internet connection, they will be required to remote login to a computer to run COMSOL simulations. Previous experience of using COMSOL is helpful but not essential.

Safety Training (if applicable): Laser safety training will be required before lab work begins

Suitable for: Suitable for MPhys, BSc Hons, BSc Maths and Physics, Physics with Teaching

Misc:

Atomic Processes for Astrophysical Plasmas I

Project ID: NRB1

Primary Supervisor: Nigel Badnell **Email:** n.r.badnell@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Junjie Mao

Project Background: Competition between ionization and recombination of Fe ions by/with electrons establishes the dominant charge state for a given temperature (and density). This in turn determines the emission lines we can expect to see and which can be used the diagnose the state of the local emitting environment.

Aim: Explore the ionization balance of iron ions in photoionized plasmas e.g. Active Galactic Nuclei.

Semester 1 Tasks: Review the possible recombination processes (the most uncertain part) and the associated literature, particularly with respect to low-charge Fe ions. Install Linux on your laptop (if windows based). Install Fortran compiler. Install program to calculate atomic data from group webpages (amdpp.phys.strath.ac.uk/autos).

Semester 2 Tasks: Use the online guide to run simple examples of atomic structure and recombination processes. Set-up inputs to describe Fe ions, calculate rates and compare with "best" currently available in the literature. Discuss.

Key references:

[1] Mazzotta et al. 1998 A&ASS 133, 403
[2] Badnell 2006, J.Phys.B 39, 4825
[3] Foster et al 2010, Space Sci. Rev. 157, 13 https://doi.org/10.1007/s11214-010-9732-1

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc: Up to two students can take this project.

Atomic Processes for Astrophysical Plasmas II

Project ID: NRB2

Primary Supervisor: Nigel Badnell **Email:** n.r.badnell@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Junjie Mao

Project Background: Diagnostic emission lines which result from electron Rydberg states in hydrogen/helium cascading down to lower levels are strongly affected by proton collisions which change the angular momentum, but not the principal quantum number of the cascading electron.

Aim: Explore the description of Rydberg transitions in cosmological primordial hydrogen and helium.

Semester 1 Tasks: Review the various treatments of “l-changing” collisions in the literature. Install Linux on your laptop (if windows based). Install Fortran compiler. Install program to calculate l-changing proton collision rates using various approximations.

Semester 2 Tasks: Compare strengths, weaknesses, accuracy(!) of various approximations. What, if any, are the cosmological implications?

Key references:

[1] Vrinceanu et al 2012 ApJ 747, 56
[2] Guzman et al 2016 MNRAS 459, 3498
[3] Foster et al 2010, Space Sci. Rev. 157, 13 https://doi.org/10.1007/s11214-010-9732-1

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Suitable for M.Phys., B.Sc., B.Sc. Maths+Physics

Misc:

Optical Cavities

Project ID: NL1

Primary Supervisor: Nigel Langford **Email:** n.langford@strath.ac.uk **Division:** Optics

Secondary Supervisors: Backup supervisor or assisting PDRA

Project Background: Laser Physics

Aim: Develop a model to describe beam propagation in optical cavities

Semester 1 Tasks: Develop program to describe beam propagation round optical cavity

Semester 2 Tasks: Extend modelling to consider different cavity configurations

Key references:

[1] McManus, J. B., Kebabian P. L., & Zahniser M. S. Astigmatic mirror multipass absorption cells for long-path-length spectroscopy, Applied Optics, Vol. 33, pp.3336, 1995.

[2]

[3]

Theory: 0% **Comp:** 100% **Exp:** 0%

Recommended Background: Knowledge of either Matlab or Python. Taking PH 455 Topics in Photonics would ne beneficial

Safety Training (if applicable): No special training required

Suitable for: BSc Physics

Misc: Up to two students can take this project

Switching in optical loop mirrors

Project ID: NL2

Primary Supervisor: Nigel Langford **Email:** n.langford@strath.ac.uk **Division:** Optics

Secondary Supervisors: Backup supervisor or assisting PDRA

Project Background: Laser Physics

Aim: Develop a model to describe all optical switching in loop mirrors

Semester 1 Tasks: Develop program to describe optical switching in loop mirrors

Semester 2 Tasks: Extend the modelling to consider different configurations of loop mirror

Key references:

[1] NJ Doran A D Wood Optics Letters Vol. 13, Issue 1, pp. 56-58 (1988)
[2]
[3]

Theory: 0% **Comp:** 100% **Exp:** 0%

Recommended Background: Knowledge of either Matlab or Python. Taking PH 455 Topics in Photonics would ne beneficial

Safety Training (if applicable): No special training required

Suitable for: BSc Physics

Misc: Up to two students can take this project

Numerical modelling of FRET in beta-amyloid

Project ID: OJR1

Primary Supervisor: Olaf Rolinski **Email:** o.j.rolinski@strath.ac.uk **Division:** Nano

Secondary Supervisors: Yu Chen

Project Background: Proteins/peptides are the compositions 20 different aminoacids, three of which (phenylalanine, tyrosine and tryptophan) are fluorescent. This allows using Phe-Tyr or Tyr-Trp pairs as donor-acceptor pairs in FRET-based fluorescence sensing. Because FRET efficiency depends on the donor-acceptor distances, changes in protein conformations due to their physiological or pathological activities can be monitored non-invasively (only by optical exciting fluorescent aminoacids and detectiong their fluorescence) by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of beta-amyloid peptides immersed in physiological water, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for beta-amyloid studies.

Aim: Generate the numerical model of intrinsic fluorescence intensity decays of Phenylalanine in the presence of Phenylalanine to Tyrosine FRET in beta-amyloid peptides.

Semester 1 Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays.

Semester 2 Tasks: Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:

[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Numerical modelling of FRET in nanostructures

Project ID: OJR2

Primary Supervisor: Olaf Rolinski **Email:** o.j.rolinski@strath.ac.uk **Division:** Nano

Secondary Supervisors: Sebastian Van de Linde

Project Background: The selection of different fluorescent donor-acceptor pairs will be studied in FRET-based fluorescence arrangements. Because FRET efficiency depends on the donor-acceptor distances, changes in conformations of several labelled nanostructures will be monitored indirectly and non-invasively by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of the labelled nanostructures immersed in physiological liquid, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for structural studies of nanostructures.

Aim: Generate the numerical model of fluorescence intensity decays of the Donor in the presence of the Donor-Acceptor FRET in selected nanostructures.

Semester 1 Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays.

Semester 2 Tasks: Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:

[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Numerical modelling of FRET in Human Serum Albumin

Project ID: OR3

Primary Supervisor: Olaf Rolinski **Email:** o.j.rolinski@strath.ac.uk **Division:** Nano

Secondary Supervisors: Yu Chen

Project Background: Proteins/peptides are the compositions 20 different aminoacids, three of which (phenylalanine, tyrosine and tryptophan) are fluorescent. This allows using Phe-Tyr or Tyr-Trp pairs as donor-acceptor pairs in FRET-based fluorescence sensing. Because FRET efficiency depends on the donor-acceptor distances, changes in protein conformations due to their physiological or pathological activities can be monitored non-invasively (only by optical exciting fluorescent aminoacids and detectiong their fluorescence) by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of the HSA immersed in physiological water, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for albumin studies.

Aim: Generate the numerical model of fluorescence intensity decays of Tyrosine in the presence of Tyrosine to Tryptophan FRET in human serum albumin.

Semester 1 Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays.

Semester 2 Tasks: Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:
[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Web-based electron diffraction tool

Project ID: PE1

Primary Supervisor: Paul Edwards **Email:** paul.edwards@strath.ac.uk **Division:** Nano

Secondary Supervisors: Carol Trager-Cowan

Project Background: The diffraction of electrons provides a valuable method of characterising crystalline materials in an electron microscope. The observed "Kikuchi" diffraction pattern changes with the orientation of the crystal, and this project aims to produce web-based code for visualising this dependence. Open-source JavaScript crystal modelling software (JSmol) will be combined with a pre-calculated Kikuchi sphere to produce an interactive educational and research tool.

Aim: Implement JavaScript code for interactive visualisation of electron diffraction in a crystal

Semester 1 Tasks: Review basics of crystallography (including Miller index notation). Literature survey on electron backscatter diffraction (EBSD) and the simulation of Kikuchi patterns. Learn the basics of JavaScript/Jsmol/WebGL using online resources.

Semester 2 Tasks: Adapt existing JavaScript code to implement models of crystals (Jsmol) and display Kikuchi sphere (WebGL). Research and implement necessary code for integrating these aspects.

Key references:

[1] Electron Backscatter Diffraction in Materials Science
https://suprimo.lib.strath.ac.uk/permalink/f/1jihtat/TN_cdi_springer_primary_978-0-387-88136-2_95665
[2] Many-beam dynamical simulation of electron backscatter diffraction patterns
https://doi.org/10.1016/j.ultramic.2006.10.006
[3] Jsmol interctive scripting documentation https://chemapps.stolaf.edu/jmol/docs/

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: While prior knowledge of JavaScript is not required, an aptitude and enthusiasm for coding is essential.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Electron microscope analysis of semiconductor alloys

Project ID: PE2

Primary Supervisor: Paul Edwards **Email:** paul.edwards@strath.ac.uk **Division:** Nano

Secondary Supervisors: Robert Martin

Project Background: AlN, GaN and InN are semiconducting materials with bandgaps spanning the near-IR to the deep-UV. Mixtures of these materials have properties which are strongly dependent on the alloy composition, which can be accurately measured using wavelength-dispersive X-ray analysis. Advances in detector design and simulation software have opened up the possibility of acquiring similar information using the quicker and less expensive technique of energy-dispersive X-ray spectroscopy. This project will test how this method can be applied to nitride materials, combining simulations using the NIST DTSA-II Monte Carlo code and measurement data from our scanning electron microscope.

Aim: Simulate the generation of X-rays from semiconductor alloys in an electron microscope

Semester 1 Tasks: Review basics of electron microscopy and characteristic X-ray generation. Literature survey on the use of energy-dispersive X-ray (EDX) microanalysis in the quantitative determination of elemental compositions. Develop familiarity with the use of DTSA-II Monte Carlo simulations to generate and analyse EDX spectra.

Semester 2 Tasks: Undertake systematic range of simulations to investigate the limitations of the technique imposed by resolution and noise. Develop a model to predict the precision in elemental composition achievable for given experimental parameters.

Key references:

[1] Microcomposition and luminescence of InGaN emitters
http://dx.doi.org/10.1002/1521-396X(200207)192:1%3C117::AID-PSSA117%3E3.0.CO;2-W
[2] EDS measurements of X-Ray intensity at WDS precision and accuracy using a silicon drift detector
https://doi.org/10.1017/S1431927612001109
[3] DTSA-II documentation https://www.nist.gov/services-resources/software/nist-dtsa-ii

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Enrollment on PH453 Topics in Solid Sate Physics would be an advantage

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Using quantum sensors to measure human heart activity

Project ID: PG1

Primary Supervisor: Paul Griffin **Email:** paul.griffin@strath.ac.uk **Division:** Optics

Secondary Supervisors: Erling Riis, Iain Chalmers

Project Background: The human heart is a big muscle, that is driven by electrical signals. The standard method for measuring heart activity is through measuring the associated electric potential at the skin, a technique known as electro-carciography (ECG). However, human tissue is weakly conductive, which causes the loss of quantative information due to patient-to-patient physiological effects, such as sweat and tissue type (fat, muscle, skin). A different sensing method uses the fact that the corresponding currents give rise to a magnetic field that can be detected outside the body in a non-contact way. This magneto-cardiography (MCG) signal gives new physiological information. Additinally, as human tissue is very non-magnetic means that the signal magnitude provides additional quantative information.

Aim: The aim of the project is to demonstrate magneto-cardiography with atomic magnetometers. This includes practical measurements as well as the development of data analysis algorithms.

Semester 1 Tasks: The first semester will concentrate on a detailed understanding of the atomic magnetometer and the way it is operated. This will be supported by a literature review. Some of the technical issues relating to the data analysis will be illustrated with existing preliminary data and techniques for noise suppression will be investigated.

Semester 2 Tasks: In the second semester MCG data will be taken using an existing set of magnetometers. This will involve optimisation of the setup, computer interfacing, data recording, and analysis.

Key references:

[1] D Budker and M Romalis, Optical magnetometry. Nat. Phys. 3, 227–234, (2007), https://doi.org/10.1038/nphys566
[2] S Lau, B Petkovic, J Haueisen, Optimal Magnetic Sensor Vests for Cardiac Source Imaging. Sensors (Basel). 16 (2016). https://doi.org/10.3390/s16060754
[3]

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background: Interest in seeing an experiment through from initial planning and setting up through data acquisition to analysis

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc

Misc:

Simulation of Maxwells equations for optical design of quantum technologies

Project ID: PG2

Primary Supervisor: Paul Griffin **Email:** paul.griffin@strath.ac.uk **Division:** Optics

Secondary Supervisors: Oliver Burrow, Aidan Arnold

Project Background: Over the last decade the EQOP group has shown that holographic gratings can be used to greatly simplify the systems required for laser cooling of atoms to microkelvin temperature. However, experimental characterisation of the devices used to data has shown an unexplained loss of laser power on the nanofabricated gratings. To circumvent these problems requires more sophisticated simulation and design. This project will take the approach of numerically solving Maxwells equations for these gratings to investiagte the problem of power loss in our current system and to inform future optimised designs. Simulations will be done numerically in the MEEP, a a flexible, open-source software package for electromagnetic simulations by the finite-difference time-domain (FDTD) method.

Aim: Implement simulation of Maxwells equations for optical surfaces to design new optical components for laser cooling of atoms

Semester 1 Tasks: The first semester will concentrated on building expertise with the MEEP software and initial simulations to reproduce results from well-understood examples in electromagnetism. This work will be support by a literature review of the optical problem of diffraction gratings and other numerical methods of solving Maxwells equations.

Semester 2 Tasks: In Semester 2 the first goal will be to implement a simulation of the binary holographic gratings used in research, and to investigate the open question of the unexplained absorption of laser power. Using these results, the candidate will examine the design of next-generation devices that overcome this problem.

Key references:

[1] MEEP
https://meep.readthedocs.io/en/latest/
[2] A. F. Oskooi, et al., Computer Physics Communications 181, 687 (2010),
Meep: A flexible free-software package for electromagnetic simulations by the FDTD method
https://doi.org/10.1016/j.cpc.2009.11.008
[3] C. Nshii et al, Nature Nanotechnology 8, 321 (2013)

A surface-patterned chip as a strong source of ultracold atoms for quantum technologies

https://doi.org/10.1038/nnano.2013.47

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Project will require the use of Python and a Linux-based OS

Safety Training (if applicable): No specialised training

Suitable for: MPhys, BSc

Misc:

Measurement and feedback schemes in open quantum systems

Project ID: PK1

Primary Supervisor: Peter Kirton **Email:** peter.kirton@strath.ac.uk **Division:** Optics

Secondary Supervisors: Stuart Flannigan

Project Background: When a quantum mechanical system is measured its state is unavoidably changed. This measurement can occur either directly or via interaction with an external environment[1]. Recent experimental advances in cavity quantum electrodynamics (QED) [2] have made it possible to engineer a wide range of parameter regimes allowing the exploration of the interplay between coherent dynamics, dissipation and measurement [3]. We will investigate the behaviour of toy models of atoms confined in cavities under the influence of different forms of dissipation as well as exploring how utilising the measured information in a feedback loop can allow us engineer novel quantum states with useful properties.

Aim: To simulate measurement induced dynamics of atoms confined in cavities. We will explore the behaviour that occurs when varying the properties of the system, applying different forms of measurement and employing feedback from the measurement on the system.

Semester 1 Tasks: Literature review of open quantum systems and cavity QED

Numerical studies of methods for simulating quantum systems connected to their environments: Lindblad master equations; Stochastic Schrödinger equations; Non-Markovian quantum state diffusion.

Semester 2 Tasks: Apply acquired background to simulate the dynamics of atoms confined in cavities and assess the effects of different forms of dissipation, i.e. Markovian vs. non-Markovian. Develop and apply measurement and feedback schemes to produce and asses non-trivial quantum states.

Key references:

[1] H. Wiseman and G. Milburn "Quantum Measurement and Control", Cambridge University Press (2009)
[2] Z. K. Minev et al. Nature 570, 200 (2019)
[3] F. Damanet, et al. Phys. Rev. A. 99, 033845 (2019)

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: PH384, PH388. This project will involve a mixture of analytical and numerical calculations, and requires a strong background in mathematical and programming skills. Familiarity with Matlab/Python/julia or similar would be very beneficial.

Safety Training (if applicable):

Suitable for:

Misc:

Phase-locking of a short-pulse, high-power, microwave source

Project ID: PM1

Primary Supervisor: Philip MacInnes **Email:** philip.macinnes@strath.ac.uk **Division:** Plasma

Secondary Supervisors: Adrian W Cross

Project Background: This project is aimed at the development of a microwave source, suitable for use in a High-Power Microwave (HPM, >100MW) phased-array antenna. A phased-array is constructed of multiple discrete elements, essentially each being a radiating source in its own right, with the relative phase of the radiated signal controlled dynamically. The peak output power from such an antenna scales as the square of the number of elements, and the position of the peak, in the radiated field-pattern, may be "steered" by varying the relative phase(s) between emitters.

The source under investigation is a novel variant of the high-power Backward-Wave Oscillator (BWO), adjusted to operate at low magnetic field, and at very short pulse duration (~1ns).

The student will gain valuable experience working with industry standard tools, such as MATLAB and CST: Studio Suite, in developing their numerical analysis of the sources operation and determining the control required for effective "locking" between signals. No previous experience in MATLAB is required, though some experience of a coding language is beneficial.

Aim: The key aim is to establish the optimum operating parameters (electron beam current, voltage and geometric position) for a novel microwave source, suitable for use in phased-array applications.

Semester 1 Tasks: The literature review in Semester 1 should cover the background physics of the source-type, relevant publications in short-pulse, high-power source development and the operation of phased arrays.

The student will also develop their own numerical model(s) of the source geometry and the required analytical tools to analysis results (help will be provided as required throughout).

Semester 2 Tasks: In Semester 2 the student will focus on investigation of the operational parameter space of the source, looking at control parameters such as the electron-beam characteristics, magnetic field parameters, and geometry of the interaction region. By the end of the project the student will have developed a "map" of how the source efficiency tracks with changes to these key parameters, allowing for determination of an "optimal" design.

Key references:

[1] Rostov V. V. et al., Physics of Plasmas 23(9), 093103, 2016 doi: 10.1063/1.4962189
[2] Shpak V. G. et al., 11th IEEE IPPC,2007 doi:10.1109/PPC.1997.674631
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background: Experience with MATLAB / Python or similar beneficial

Safety Training (if applicable):

Suitable for: Mphys

Misc:

Correlating compositional variation to the optical emission properties of tin-gallium oxide semiconductors

Project ID: RWM1

Primary Supervisor: Rob Martin **Email:** r.w.martin@strath.ac.uk **Division:** Nano

Secondary Supervisors: Dr Naresh Kumar & Dr Paul Edwards

Project Background: Gallium oxide (Ga2O3) has attracted massive interest in electronic materials research, particularly for power electronics device applications due to its ultra-wide bandgap in the range of 4.6- 4.9 eV. Besides the larger bandgap, the transmission of ≈ 90% of visible light makes Ga2O3 a leading contender for UV optoelectronics applications such as solar-blind photodetectors and scintillators. While Ga2O3 based detectors have strong UV photoresponse, alloying them with tin (Sn) to form tin gallium oxide (TGO) can outperform Ga2O3 devices by more than one order of magnitude in device response to UV light.

The project will measure the concentrations of tin and gallium using x-ray microanalysis and then study the light emission, using photoluminescence (PL) using UV lasers and cathodoluminescence in an electron microscope. The optical data will be correlated with the Sn composition, to provide an understanding of the presence of point defects and their impact on TGO photodetector response. Temperature-dependent (20 – 300 K) PL will also be performed for a detailed understanding of defect-related electronic transitions.

Aim: Analyse compositional and optical properties of tin-gallium oxide semiconductors.

Semester 1 Tasks: Review physics of semiconductors and opto(electronic) devices. Survey literature on optical spectroscopy of gallium oxide semiconductors. Develop familiarity with relevant microanalysis and spectroscopy techniques (WDX, PL, CL). Plot and analyse WDX, CL and PL data collected by other researchers in the group.

Semester 2 Tasks: Collect spectroscopy and microscopy data from labs in JA and TIC respectively. Use peak fitting methods and analyse the acquired spectroscopy data at home.

Key references:

[1] A review of Ga2O3 materials, processing, and devices, S. J. Pearton et al., Applied Physics Reviews 5, 011301 (2018).
[2] Point defects in Ga2O3, Matthew D. McCluskey, J. Appl. Phys. 127, 101101 (2020)
[3] High responsivity tin gallium oxide Schottky ultraviolet photodetectors, P. Mukhopadhyay & W. V. Schoenfeld, Journal of Vacuum Science & Technology A 38, 013403 (2020).

Theory: 50% **Comp:** 0% **Exp:** 50%

Recommended Background: PH453 Topics in Solid State Physics, PH355 Physics Skills. Students should be able to become comfortable with use of Origin for data analysis and with lasers. Prior experience with optical spectroscopy of crystals in the Physics teaching lab would be beneficial.

Safety Training (if applicable): Laser and radiological safety training, technology innovation centre safety induction will be needed.

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Self-referencing spectral interferometry as a diagnostic of relativistic induced transparency

Project ID: RW1

Primary Supervisor: Robbie Wilson **Email:** robbie.wilson@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Paul Mckenna, Ross Gray

Project Background: The interaction of an intense laser pulse (>10^18 W/cm2) with a solid density foil will heat the electrons in that foil to relativistic velocities. Due to the relativistic mass increase of the electrons their dynamics in the laser field changes, resulting in the onset of an effect known as relativistic induced transparency. Due to this effect an opaque, solid density plasma can be made to become transparent. In recent years we have shown the importance of this effect for optimising laser-driven particle accelerators by control the point in time at which the plasma becomes transparent to the laser. This project will address key issues related to a diagnostic technique which measures the onset of this effect and therefore will aid in the optimisation and control of laser-driven particle acceleration.

Aim: To model and improve a new spectral interferometry technique recently developed by the group

Semester 1 Tasks: Literature Review, Development of a simple Gaussian pulse model, Development of a two pulse spectral interferometry model to test/reproduce previously published result.

Semester 2 Tasks: Extension of the model to include specific polarisation and spatial profile effects stemming from optical transition radiation , Particle in cell simulations undertaken to compare to the model results.

Key references:

[1] Williamson et al., Phys Rev Applied (2020) -- at press
[2] A. Higginson et al, Nat. Comms. 9 (1), 1-9 (2018)
[3] V. Bagnoud et al, Phys. Rev. Lett. 118, 255003 (2017)

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background: Matlab, Python. Some previous experience of plasma physics would also be useful

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

Computational Methods in Single-Molecule Localization Microscopy

Project ID: SvL1

Primary Supervisor: Sebastian van de Linde **Email:** s.vandelinde@strath.ac.uk **Division:** Nano

Secondary Supervisors: Dr Oliver Henrich

Project Background: Super-resolution microscopy methods have the ability to overcome the classical diffraction limit of light microscopy and thus have opened the door for the study of finer cellular ultrastructure 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.

Aim: Develop software for image processing in microscopy

Semester 1 Tasks: Objectives of this project are an introduction to state-of-the-art SMLM software packages and image processing. Exercises in SMLM data analysis will be accomplished with first attempts in software coding.

Semester 2 Tasks: Depending on progress and interest of the student software for an applied microscopy project will be developed such as for (i) advanced multi-channel SMLM and/or (ii) analysis of multi-channel imaging SMLM data.

Key references:

[1] S. van de Linde. Single-molecule localization microscopy analysis with ImageJ. J. Phys. D: Appl. Phys. 52, 203002 (2019)
[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)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Experience in programming is strongly adviced.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Evaluating Spot-Finding Methods

Project ID: SvL2

Primary Supervisor: Sebastian van de Linde **Email:** s.vandelinde@strath.ac.uk **Division:** Nano

Secondary Supervisors: Dr Daniel Oi

Project Background: Finding the centre of a spot in an image is surprisingly useful in many applications, both on the Earth an in space. Distributing quantum encryption keys (QKD) from space will allow secure communication on a global scale. Strathclyde is working with collaborators both in the UK and overseas to build and fly our own quantum satellites. Acrucial element of SatQKD is the pointing system that allows quantum signals to be sent from space to a groundbased optical receiver, that is a CCD or COMS camera. The detected light appears as 2D photon distribution on the camera, which can be further analysed to extract the position of the object. Such position extraction is also the key part of super-resolution microscopy, allowing the ability to probe the structure of biological systems at small scales previously thought impossible.

Aim: Develop and comparison of spot finding methods

Semester 1 Tasks: This project will look at how we can best process images to extract spot positions. In particular, the ability to localise objects with high precision will be explored. The influence of camera parameters such as fill-factor and pixel response function on systematic and random errors in spot finding, along with finding optimum values for spot size and algorithm tuning parameters will be researched.

Semester 2 Tasks: Further a study of the trade-off between computational complexity versus accuracy and robustness of different spot finding methods such intensity weighting and Gaussian fitting will be performed. Although the project is mainly computational, at a later stage of the project experimental data of fluorescent spots originating from high-end laser microscopes will be analysed for comparison.

Key references:

[1] A. Small and S. Stahlheber, Fluorophore localization algorithms for super-resolution microscopy, Nat. Methods, 11:267 (2014)
[2] Oi DK, Ling A, Vallone G, Villoresi P, Greenland S, Kerr E, Macdonald M, Weinfurter H, Kuiper H, Charbon E, Ursin R. CubeSat quantum communications mission. EPJ Quantum Technology. 4(1):6 (2017)
[3]

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Experience in programming is strongly adviced.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Atomic Physics Simulation for Outreach and Learning

Project ID: SI1

Primary Supervisor: Stuart Ingleby **Email:** stuart.ingleby@strath.ac.uk **Division:** Optics

Secondary Supervisors: Paul Griffin, Gordon Robb

Project Background: Atomic physics and quantum technologies, such as optically pumped magnetometers, atomic clocks and rotation sensors, are increasingly important in real-world applications [1]. It is important to communicate effectively with the public on the advantages, operation and scientific basis of these technologies. However, the underlying physics is not always intuitively easy to understand. In this project you will develop a visual interface allowing students and members of the public to play with the atomic system and visualise how the sensor works.

Aim: Simulation and interactive visual representation of an atomic magnetometer

Semester 1 Tasks: Literature review and study of magnetometer theory and applications. In addition the student should begin building the code to model and display the physical system.

Semester 2 Tasks: More extensive coding work and generation of results for the report. Demonstration of increased understanding of the system and prepartion of the final report.

Key references:

[1] Roadmap on quantum optical systems, R Dumke et al., J. Opt. 18 093001 (2016)
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background: PH355 Physics Skills

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Innovation and translation of a miniature atomic clock platform

Project ID: SS1

Primary Supervisor: Susan Spesyvtseva **Email:** susan.spesyvtseva@strath.ac.uk **Division:** Optics

Secondary Supervisors: Erling Riis

Project Background: Next generation quantum technologies such as atomic clocks have the potential to change the world. Engineering quantum effects into cutting-edge quantum technologies makes possible a diverse array of exciting innovations promising previously-impossible capabilities, from entirely new methods of computing to solve currently intractable problems, to breathtakingly powerful medical imaging. In order for these new technologies to deliver maximum impact across society, both the technologies and the know-how must transfer from the academic research laboratories, via research and development in industry, and onwards to end-users. In this project, the student will consider the development of a self-contained, miniaturised device for atomic trapping designed to form one of the key building blocks for commercial atomic clocks – the most precise clocks in the world – to ultimately form a component in advanced quantum technologies such as space and global navigation systems, financial trading systems or gravitational sensors. As well as an indepth knowledge of cutting-edge quantum technologies, the student will gain an overview of translation of research products to the industrial sector, including industry R&D and start-ups.

Aim: To generate a route to market for a miniature commercial atomic clock platform

Semester 1 Tasks: Review physics of atomic trapping. Survey literature on atomic clocks with a focus on the state-of-the-art. Gain familiarity with the miniature atomic clock platform being developed at Strathclyde.

Semester 2 Tasks: Produce a comprehensive analysis of the market for a miniature atomic clock platform, considering primary (atomic trapping systems) and secondary (optical clocks and derivative technologies) markets, approximate technical specifications, cost, competing technologies, and intellectual property / patents. Design an optimum route to market for the technology, considering the main industry competitors and competing technologies.

Key references:

[1] R. Elvin et. al., Cold-atom clock based on a diffractive optic, 27 (26), 38359-38366, 2019
[2] A. D. Ludlow et al., Optical atomic clocks, Rev. Mod. Phys. 87, 637, 2015
[3] A roadmap for quantum technologies in the UK, UK National Quantum Technologies Programme, https://epsrc.ukri.org/newsevents/pubs/quantumtechroadmap/

Theory: 100% **Comp:** 0% **Exp:** 0%

Recommended Background: Knowledge of fundamentals of quantum physics and optics. Good independent research skills.

Safety Training (if applicable): No special training required

Suitable for: BSc, BSc Maths and Physics, BSc Physics with Teaching.

Misc: Please note that this project will ONLY run as a 4th year project. The project will suit a student with an interest in pursuing a career in industry research/ innovation. It would be ideal for a student with a genuine desire to learn about the process of cutting-edge technology development and commercialisation, from academia, to industry and beyond.

Photon statistics of small lasers

Project ID: TA1

Primary Supervisor: Thorsten Ackemann **Email:** thorsten.ackemann@strath.ac.uk **Division:** Optics

Secondary Supervisors: Konstantinos Lagoudakis

Project Background: There is an increasing drive to miniaturize lasers to reduce footprint, costs and energy consumption to satisfy the ever increasing demand on bandwidth in telecom and Datacom driven by the rapid growth of internet traffic [1]. “Microlasers” have dimensions of a few micrometres and “nanolasers” go below a mircometres down to the restrictions given by the wavelength. An important consequence of making lasers smaller and smaller is that the ration b of the spontaneous emission going into the lasing mode larger and larger and the laser threshold smears out. At b=1 one talks about the “thresholdless laser” [1]. This has also important consequences on the photon statistics of the laser and how coherence emerges. Abrupt spikes of emission have been seen in the output of small lasers with the intensity auto-correlation g(2) showing bunching reminiscent of thermal light [1-3]. The project will look at the output and noise characteristics of single-mode vertical-cavity surface emitting lasers (VCSEL) as an important example for microlasers. The transition through threshold will be measured and the intensity output will be analysed via histograms, RF-spectra and autocorrelation.

Aim: Provide analysis of photon statistics of single-mode VCSEL microlaser going through threshold

Semester 1 Tasks: Literature review. Develop code for analysis of spectra and auto-correlation/g(2) functions of noise data of VCSEL taken by student in 2019/2020 session. Testing and validation of code.

Semester 2 Tasks: Detailed and systematic analysis of data. If lab access becomes available, measure light-current characteristic with large precision.

Key references:

[1] Martin T. Hill and Malte C. Gather, “Advances in small lasers”, Nature Photon. 8, 908 (2014)
[2] T. Wang, G.P. Puccioni, G.L. Lippi, “Photon bursts at lasing onset and modeling issues in mesoscale devices”, arXiv:1905.08639v1
[3] T. Wang, D. Aktas, O. Alibart, E. Picholle, G.P. Puccioni, S. Tanzilli, and G.L. Lippi, “Nontrivial photon statistics in small scale lasers”, arXiv:1710.02052v1

Theory: 10% **Comp:** 80% **Exp:** 10%

Recommended Background: basic knowledge of matlab and willingness to engage with coding and visualization

Safety Training (if applicable): Laser safety, if it comes to experiments in sem 2

Suitable for: BSc, BSc Math and Physics

Misc:

Analysis of time series of mode-locked lasers via permutation entropy

Project ID: TA2

Primary Supervisor: Thorsten Ackemann **Email:** thorsten.ackemann@strath.ac.uk **Division:** Optics

Secondary Supervisors: Antonio Hurtado

Project Background: Mode-locked lasers are the backbone of ultra-fast physics allowing pulse duration in the ps and fs regime. Their characterization is tradionally confined to RF-measurements and autocorrelation techniques which are working on ensembles of pulses. Recent advances in technology allow the real-time sampling of pulses with digitization rate of 200 Gs/s thus allowing the investigation of long pulse trains of pulses in the tens of ps regime in a single shot. This enables to look at variations among individual pulses and to look at variations in sequences of pulses [1]. The concept of permutation entropy [3] was introduced to look at the variations of sequences of relative amplitudes in time series independent of the absolute level, is argued to be less sensitive to noise and was used for the analysis of laser data before [2]. The project will investigate whether permutation entropy analysis can provide alternative and potentially more sensitive means to characterize the quality and stability of mode-locked pulse trains.

Aim: Compare characterization of pulse amplitude variations of mode-locked lasers done by permutation entropy analysis and conventional statistics

Semester 1 Tasks: Literature review. Develop, test and validate code for statistical analysis and permutation entropy analysis of data in [1]. Example codes from [2] can be used as a starting point.

Semester 2 Tasks: Detailed and systematic analysis of data with length of symbolic sequences and time delays.

Key references:

[1] T Malica et al., Mapping the dynamical regimes of a ML VECSEL, Opt. Exp. 26, 16624 (2018)_

[2] J. Toomey et al., Complexity in pulsed nonlinear laser systems interrogated by permutation entropy, Opt. Exp. 22, 17840 (2014)

[3] C. Bandt and B. Pompe, “Permutation entropy: A natural complexity measure for time series,” Phys. Rev. Lett. 88(17), 174102 (2002)

Theory: 10% **Comp:** 90% **Exp:** 0%

Recommended Background: basic knowledge of matlab and willingness to engage with coding and visualization

Safety Training (if applicable): No special training required

Suitable for: BSc, BSc Math and Physics

Misc: More than one student could do this project

Optical properties of metal-dielectric nanocomposites

Project ID: YC1

Primary Supervisor: Yu Chen **Email:** y.chen@strath.ac.uk **Division:** Nano

Secondary Supervisors: Francesco Papoff

Project Background: There is a strong drive for further miniaturization of lasers, photonics devices and sensors. Confining light to small, in particular sub-wavelength, scales requires high refractive index contrasts for waveguides as well as periodic photonic structures. Plasmonic nanostructures can confine electromagnetic fields into spatial regions well below the diffraction limit, resulting in significant enhancement of the fields. Specially, noble metal nanoparticles have localized surface plasmon resonance dependent on their size, shape and dielectric constant of medium [1], exhibiting tuneable refractive index when they are embedded in a dielectric matrix and form metasurfaces [2]. A recent study on the plasmonic nanoparticle superlattices found that photonic crystals based on noble metal nanoparticles of controlled spacing have high refractive indices even far away from the plasmon frequency where losses are low, suggesting a potential high performance dielectric materials based on noble metal nanoparticles [3].

Aim: The aim of the project is to understand the correlation between nanocomposite structure/composition and their refractive indices.

Semester 1 Tasks: literature search to review the optical properties of noble metal nanostructures of different structure and composition; design/select nanostructures for simulation; study FDTD simulation

Semester 2 Tasks: FDTD simulation of selected nanostructures; study the correlation between structure and refractive indices; writing report.

Key references:

[1] Eustis, S. and El-Sayed, MA. Why gold nanoparticles are more precious than pretty gold. Chem. Soc. Rev. 35, 209-217 (2006)
[2] Doyle, D. et al. Tunable subnanometer gap plasmonic metasurfaces, ACS Photonics, 5, 1012 (2018).
[3] Sun, L., et al. Design principles for photonic crystals based on plasmonic nanoparticle superlattices, PNAS, 115, 7242 (2018).

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: An interest in nanoscience and photonics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Plasmon enhanced fluorescence

Project ID: YC2

Primary Supervisor: Yu Chen **Email:** y.chen@strath.ac.uk **Division:** Nano

Secondary Supervisors: Olaf Rolinski

Project Background: Fluorescence spectroscopy and microscopy are powerful tools for non-invasive and non-destructive detection and visualization, capable of sensing and imaging at single molecule level. Despite the advantages, fluorescence technique is limited by weak emission from intrinsic fluorescence. Noble metal nanoparticles have unique optical properties dominated by localized surface plasmon effect. These plasmonic nanostructures are sensitive to local environment and can influence the optical process of adjacent molecules. As a result, they have broad applications ranging from chemical and biological sensing to light-harvesting enhancement in solar cells. Plasmonic nanostructures can enhance fluorescence emission via enhances excitation rate of a fluorescence emitter and changes the radiative and nonradiative decay rates. So far, a variety of plasmonic nanostructures has been developed to achieve fluorescence enhancement effect including metallic thin films, nanoparticles, ordered structures, waveguides and nanoantennas, resulting in increased brightness of molecular emission and improved detection sensitivity.

Aim: The aim of this project is to understand the influence of geometrical structure on enhancement factor

Semester 1 Tasks: Study basic theory about fluorescence and fluorescence enhancement processes; literature search to review the development in metal enhanced fluorescence and its application;

Semester 2 Tasks: Study the influence of geometrical structure on the enhancement factor; analyze experimental data; writing report.

Key references:

[1] Li, J. et al. Plasmon-enhanced fluorescence spectroscopy, Chem. Soc. Rev. 46, 3962 (2017)
[2] Sun, S. et al. Critical role of shell in enhanced fluorescence of metal-dielectric core-shell nanoparticles, J. Phys. Chem. 124, 13365 (2020)
[3] Yu, H. et al. Plasmon-enhanced light-matter interactions and applications, NPJ Compu. Mat. 5, 45 (2019)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: An interest in nanoscience and photonics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Electron acceleration assisted by radiation friction in ultra-intense laser fields

Project ID: ZS1

Primary Supervisor: Zheng-Ming Sheng **Email:** z.sheng@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Thomas Wilson

Project Background: With the development of high power laser technologies, one can now obtain lasers with peak power up to 10 PW (1 PW=10^15 W). Such lasers have broad applications from laser-based particle accelerators to nuclear photonics. The key technology for building such lasers is called chirped pulse amplification, for which G. Mourou and D. Strickland were awarded the Nobel Prize in Physics in 2018. With such lasers, electrons can be efficiently accelerated inside a plasma channel via betatron resonance [1,2], where the induced quasi-static azimuthal magnetic fields and radial electric fields result in electron betatron oscillation. It is also found that a transverse friction can help to improve the longitudinal acceleration of electrons [3]. In ultra-intense laser fields, the transverse fiction force can be due to radiation reaction.

Aim: This project aims to investigate the effect of transverse radiation reaction on electron acceleration. The project will be carried out mainly by solving the equation of motion of single electrons in the laser fields by comparing the two cases with or without radiation reaction force.

Semester 1 Tasks: In Semester 1, the student will read relevant papers, write a code based upon the equation of electron in a laser field to study single electron motion in a plane laser pulse to reproduce some results found in the literature, which helps to understand the electron acceleration dynamics in a laser fields.

Semester 2 Tasks: In Semester 2, the student will consider the effect of transverse friction force on electron acceleration by use of a modified equation of motion of electrons. The results will be compared to the case without the friction force.

Key references:

[1] A. Pukhov, Z. M. Sheng, and J. Meyer-ter-Vehn, "Particle acceleration in relativistic laser channels", Phys. Plasmas 6, 2847-2854 (1999).
[2] J. Meyer-ter-Vehn and Z. M. Sheng, "On electron acceleration by intense laser pulses in the presence of a stochastic field", Phys. Plasmas 6, 641-644 (1999).
[3] Z. Gong, F. Mackenroth, X.Q. Yan, A.V. Arefiev, "Strong energy enhancement in a laser-driven plasma-based accelerator through stochastic friction", arXiv:1905.02152 (2019)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Some basic knowledge on computer programming either with C, C++, or Fortran, or MATLAB, or Python for simulation and visualisation is essential

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Electromagnetic radiation from laser wakefields excited in plasma

Project ID: ZS2

Primary Supervisor: Zheng-Ming Sheng **Email:** z.sheng@strath.ac.uk **Division:** Plasmas

Secondary Supervisors: Thomas Wilson

Project Background: Electromagnetic (EM) radiation from terahertz (THz) to mid-infrared is attractive for various applications. Usually EM waves in this regime are not easily obtained, in particular, with high peak power. With the development of ultrashort intense lasers, one may obtain high power THz pulses or mid-infrared pulses with different methods, such as mode conversion from laser wakefields excited in plasma, photon deceleration in plasma, etc. One of the key issues is to improve the efficiency and spectrum controllability, which are important for practical applications.

Aim: This project aims to investigate the generation of frequency tunable EM radiation from laser interaction with underdense plasma via the laser wakefield excitation. In particular, the student will explore how the frequency spectrum, temporal profile and conversion efficiency depend upon the laser and plasma parameters.

Semester 1 Tasks: In Semester 1, the student will read relevant papers, get familiar with a one-dimensional particle-in-cell (PIC) simulation code [3], and run PIC simulations on laser wakefield excitation in underdense plasma. Reproduction of results from some papers on radiation production from laser wakefields is expected.

Semester 2 Tasks: In Semester 2, the student will study the radiation generation at mid-infrared wavelengths via frequency downshift in laser wakefields in plasma. Both cases with a single laser pulse [1] and two laser pulses [2] will be investigated.

Key references:

[1] Yue Liu, Wei-Min Wang, and Zheng-Ming Sheng, "Electromagnetic radiation from laser wakefields in underdense plasma", High Power Laser Science and Engineering 2, e7 (2014).

[2] Xing-Long Zhu, Su-Ming Weng, Min Chen, Zheng-Ming Sheng, and Jie Zhang, "Efficient generation of relativistic near-single-cycle mid-infrared pulses in plasmas", Light: Science & Applications 9:46 (2020)

[3] Particle-in-cell simulation code: EPOCH, https://www.archer.ac.uk/community/eCSE/eCSE03-01/eCSE03-01.php

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background: Some basic knowledge on computer programming either with C, C++, or Fortran, or MATLAB, or Python for simulation and visualisation is essential

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

List of Project Titles