PH450

Draft Project List 1st September 2020

All information is provisional and subject to change.

Plasma Division

Title: High-power THz Radiation Generated by Extended Interaction Oscillators

Project ID: AC1R

Primary Supervisor: Adrian Cross **Email:** a.w.cross@strath.ac.uk

Secondary Supervisors: Liang Zhang

Project Background: Producing high power radiation is challenging at the THz frequency range. In this project, the student will learn how to generate coherent radiation using a free-electron beam. The student will learn how to calculate the eigenmode in a cavity structure, and how to define the properties of the electron beam to resonance with the cavity structure.

Aim: Study the principle of coherent THz radiation generated by the interaction between the free electron beam and the eigenmode in a metallic structure.

Semester 1 Tasks: Review the physics of slow-wave beam-wave interaction. Survey the literature of THz application, THz generation and the sheet electron beam device. Derive the resonance conditions of the beam-wave interaction.

Semester 2 Tasks: Carry out the simulations of extended interaction circuits to generate the THz radiation.

Key references:

[1] Study of a 0.35 THz Extended Interaction Oscillator Driven by a Pseudospark-Sourced Sheet Electron Beam, DOI: 10.1109/TED.2019.2957760

[2] Experimental demonstration of a terahertz extended interaction oscillator driven by a pseudospark-sourced sheet electron beam, doi: 10.1063/1.5011102.

[3] Simulation and experiments of a w-band extended interaction oscillator based on a pseudospark-sourced electron beam, doi: 10.1109/Ted.2015.2502950.

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 Microwave / Particle Studio.

Safety Training (if applicable): No special training required

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

Misc:

Title: Investigation of a Microwave undulator for Free-Electron Laser

Project ID: CD1

Primary Supervisor: Craig Donaldson **Email:** craig.donaldson@strath.ac.uk

Secondary Supervisors: Adrian Cross \ Liang Zhang

Project Background: Microwave undulators can serve as useful alternatives to traditional permanent magnet undulators when a shorter undulator period is desired for a free-electron laser. In this project, the student will learn how a free-electron laser works, and how to design a microwave undulator to generate the X-ray radiation.

Aim: Understanding the principle of a free-electron laser. Design a microwave undulator to generate X-ray radiation.

Semester 1 Tasks: Review the theory of free-electron laser, understand its physics. Survey literature on the different types of undulators in free-electron lasers. Study the waveguide and cavity theory to understand how to calculate the eigen frequency of the desired operating mode.

Semester 2 Tasks: Derive the required parameters of the microwave undulator by giving the photon energy. Based on the theoretical study, carry out the design of a microwave undulator and evaluate its performance.

Key references:
[1] Systematic study of a corrugated waveguide as a microwave undulator, DOI:10.1107/S1600577518014297
[2] microwave undulator, DOI:10.1107/S1600577518014297
[3] Coupling Structure for a High-Q Corrugated Cavity as a Microwave Undulator, DOI:10.1109/TED.2019.2933557

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 Microwave / Particle Studio.

Safety Training (if applicable): No special training required

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

Misc:

Title: RF-gated Thermionic Injector Gun for Free-Electron Laser

Project ID: LZ1

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

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:

Title: Analysis of Muon Ionisation Cooling Experiment

Project ID: AY1

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

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:

Title: Numerical simulation of cyclotron maser amplifiers

Project ID: AY2

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

Secondary Supervisors: Kevin Ronald

Project Background: Applications including communications, fundamental physics research and medicine require the amplification of electromagnetic wave signals greater than possible with solid state electronics. Free electron techniques using an electron beam accelerated to a high level of kinetic energy can amplify microwave signals as they induce a deceleration of the particles.

Aim: Investigate cyclotron maser amplifiers using a multi-dimensional Finite-Difference Time-Domain method to self consistently model the evolution of the EM fields and particles.

Semester 1 Tasks: Review literature on the Cyclotron Maser Instability and helically corrugated waveguides. Calculate the cold dispersion of a helically corrugated waveguide

Semester 2 Tasks: Model beam-wave interaction in a helically corrugated waveguide.

Key references:
[1] He W. et al, 2013, Phys. Rev. Lett., 110, art 165101
[2] Bratman V.L. et al, 2000, Phys. Rev. Lett., 84, pp2746-2749
[3] Denisov G.G. et al, 1998, Phys. Rev. Lett., 81, pp5680-5683

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

Recommended Background: Knowledge of a programming language useful

Safety Training (if applicable): No special training required

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

Misc:

Title: Beam-driven Plasma Wakefield Acceleration of electrons to highest energies

Project ID: BHD1

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

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):

Suitable for:

Misc:

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

Project ID: BHD2

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

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:

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

Project ID: BHD3

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

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):

Suitable for:

Misc:

Title: Electron beam transport modelling and machine learning in particle accelerators

Project ID: BHD4

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

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

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):

Suitable for:

Misc:

Title: Laser pulse based ionization of matter

Project ID: BHD5

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

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):

Suitable for:

Misc:

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

Project ID: BHD6

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

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):

Suitable for:

Misc:

Title: Ortho-mode transducers for polarisation control

Project ID: CW1

Primary Supervisor: Colin Whyte **Email:** colin.whyte@strath.ac.uk

Secondary Supervisors: Craig Donaldson

Project Background: High power gyro-amplifiers for space object identification require a high efficiency method of launching circularly polarised waves into a round waveguide without perturbing the elctron beam propagating in the waveguide. A number of devices designed for radio astronomy, such as turnstiles and ortho-mode converters may be useful in this application. This project will use CST studio to build computer models of these devices and simulate their performance. A scale model will be constructed and tested should lab work be possible.

Aim: Using CST studio, simulate a device for launching left hand or right hand circular, or linear polarised waves in a round waveguide

Semester 1 Tasks: Review literature on Ortho-mode transducers and turnstile junctions. Analyse stability criteria for Gyro-amplifiers.

Semester 2 Tasks: Design and simulate waveguide junction to launch circularly polaricsed waves.

Key references:

[1] A Compact High-Performance Orthomode Transducer for the Atacama Large Millimeter Array (ALMA) Band 1 (31-45 GHz). IEEE ACCESS Volume: 1 Pages: 480-487. DOI: 10.1109
[2] Development of a high-performance W-band duplexer for plasma diagnosis using a single band with dual circular polarization. DOI: 10.1016 /j.nima.2019.162712.
[3] Quasi-Optical Orthomode Splitters for Input-Output of a Powerful W-Band Gyro-TWT. IEEE T-ED. Vol 65 Issue: 10 Pp: 4600-4606 DOI: 10.1109/TED.2018.2866030

Theory: 20% **Comp:** 50-80% **Exp:** 30-0%

Recommended Background: Students should be comfrotable using CAD type packages. Programming is not required

Safety Training (if applicable): None.

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

Misc:

Title: Ion Channel Laser with Large Oscillation Amplitude

Project ID: BE1

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

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; write 12-page report.

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 18-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:

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

Project ID: DJ1

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

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 radi

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): none

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

Title: Simulation and optimisation of a high-k scattering diagnostic for fusion plasma turbulence studies

Project ID: DCS1

Primary Supervisor: David Speirs **Email:** david.c.speirs@strath.ac.uk

Secondary Supervisors: Kevin Ronald

Project Background: Plasma turbulence underpins a wide range of phenomena, including the formation of stars and galaxies, the dynamics of the Earth's magnetospheric plasma and (critically for this project) the confinement of plasmas in magnetic confinement fusion (MCF) experiments. It is complicated by feedback mechanisms that couple space and time scales spanning many orders of magnitude. Predictive modelling of multi-scale plasma turbulence is extremely challenging, and requires detailed experimental data to formulate reduced models capturing the essencial physics. This project will simulate and optimise the design of an RF based scattering diagnostic to measure large-wavenumber turbulence deep within the MAST-U tokamak plasma at Culham Laboratory.

Aim: The optimisation and simulation of a quasi-optical, RF based scattering diagnostic to measure plasma turbulence on the MAST-U fusion experiment at Culham Lab, UKAEA.

Semester 1 Tasks: Perform literature review on the principles and physics of EM wave scattering from density fluctuations in plasma. Determine the key criteria that must be satisfied to ensure scattered RF components are (a) detectable above background noise and (b) sufficiently localised in both physical and wavenumber space to inform the predictive modelling research. The student will also familiarise themselves with full-wave and beam / ray-tracing modelling techniques to develop simulations of the RF launching and detection system.

Semester 2 Tasks: Perform relevant simulations and data analysis to optimise the required optical system comfiguration and subcomponent performance characteristics for high spatial / wavenumber resolution plasma turbulence measurement on the MAST-U fusion experiment.

Key references:
[1] Overview of new MAST physics in anticipation of first results from MAST Upgrade., J.R. Harrison et al., https://doi.org/10.1088/1741-4326/ab121c
[2] A collective scattering system for measuring electron gyroscale fluctuations on the National Spherical Torus Experiment, D.R. Smith et al., http://dx.doi.org/10.1063/1.3039415
[3] Localized measurement of turbulent fluctuations in tokamaks with coherent scattering

of electromagnetic waves, E. Mazzucatto, https://doi.org/10.1063/1.1541018

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

Recommended Background: It would be useful for the student to be familiar with progamming in Python or Matlab for simulation development and data analysis. These skills will be developed during the project. Proficiency in working with Linux based computer systems would be an adv

Safety Training (if applicable): N/A

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

Misc:

Title: Chemical evolution of galaxies

Project ID: JM2

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

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:

Title: Atomic physics of high Z elements in fusion

Project ID: MOM1

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

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:

Title: Atomic Processes for Astrophysical Plasmas I

Project ID: NB1

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

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:

Title: Atomic Processes for Astrophysical Plasmas II

Project ID: NB2

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

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:

Title: Photoionization modeling of AGN winds

Project ID: JM1

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

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:

Title: Spectral properties of reflected laser light from expanding plasma targets

Project ID: MK1

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

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):

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

Misc:

Title: Optimisation of bremsstrahlung radiation from laser-dense plasma interactions

Project ID: RG1

Primary Supervisor: Ross Gray **Email:** ross.gray@strath.ac.uk

Secondary Supervisors: Paul McKenna, Martin King

Project Background: The interaction of an intense laser pulse (>10^18 W/cm2) with a solid density foil will rapidly heat electrons to energies in the range of keV-MeV, with a broad energy spectrum. The interaction of these electrons with ions present in the dense foil target will produce bremsstrahlung radiation. A number of studies have shown that the properties of this radiation are sensitive to a wide range of laser and plasma parameters including laser intensity, laser energy, target material and target thickness. Finding the exact laser and plasma conditions which optimise the bremsstrahlung radiation is therefore not a straight forward task, as a high dimensional parameter space must be considered. This project will use a combination of numerical modelling and a custom tool which enables the generation of high dimension data sets to reveal the optimal conditions for bremsstrahlung production in laser-dense plasma interactions.

Aim: To determine an optimised regime for bremsstrahlung radiation production from laser-dense plasma interactions by modelling a high-dimensional parameter space

Semester 1 Tasks: Conduct a thorough literature review. Run 1D simulations and produce spectra of the generated electrons and bremsstrahlung radiation. Gain experience in using the EPOCH simulation code and the BISHOP multidimensional data set code.

Semester 2 Tasks: Investigate the optimisation of Bremsstrahlung radiation in laser-dense plasma interactions by simulating and analysing EPOCH simulation data across a high dimensional parameter space.

Key references:
[1] S. C. Wilks, et al. Phys. Rev. Lett. 69, 1383 (1992)
[2] C.D. Armstrong et al., Plasma Phys. Control. Fusion 61, 034001 (2019)
[3] C.D. Armstrong et al., High Power Laser Sci. Eng. 7 E24 (2019)

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

Recommended Background: Previous experience of Python is essential. Some previous experience of plasma physics would also be useful

Safety Training (if applicable):

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

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

Project ID: RW1

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

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): None

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

Title: 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

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 wit

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): None

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

Misc:

Title: Electromagnetic radiation from laser wakefields excited in plasma

Project ID: ZS2

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

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 co

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): None

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

Misc:

Optics Division

Title: Lenses for cooling atoms

Project ID: AA1

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

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 ~18 page report in the form of an extended paper worth 30% 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): N/A

Suitable for: MPhys only

Misc:

Title: Grating magneto-optical trap modelling

Project ID: AA2

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

Secondary Supervisors: Paul Griffin

Project Background: Magneto-optical traps are ubiquitous in many atomic physics experiments, providing a dense source of ultracold atoms which can be utilised to obtain ultra-precise measurements [1]. However, such traps require six input laser beams and thereby suffer from optical complexity which can inhibit portable applications. We have pioneered the use of grating magneto-optical traps to circumvent this problem [2-3].

Aim: In this project you will model the acceleration in different kinds of magneto-optical trap to see how the atom number collected scales with laser input power and geometry. An ideal extension of this project will be to compare your theoretical results to l

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

Semester 2 Tasks: You need to write a ~18 page report in the form of an extended paper worth 30% of the final mark. This report should concentrate on and consolidate your findings regarding atomic trapping.

Key references:
[1] 10.1103/PhysRevLett.59.2631
[2] 10.1364/OE.23.008948
[3] 10.1038/NNANO.2013.47

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

Recommended Background: Mathematica/Matlab/Python skills useful.

Safety Training (if applicable): N/A

Suitable for: MPhys only

Misc:

Title: Simulation of non-Markovian dynamics of an impurity in a reservoir gas

Project ID: AD1

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

Secondary Supervisors: Rosaria G. Lena

Project Background: Ultracold atoms provide an invaluable platform for simulations of physical systems in condensed matter and solid state physics, thanks to the high tunability of key parameters such as interactions and trapping frequencies. The experimental progress in the context of dual species components, combined with the extreme tunability of these parameters, offers an ideal playground for the study of open quantum systems, where a small system (e.g., an impurity atom) is coupled to a large reservoir gas. In particular, we can explore memory effects of the reservoir that lead to non-Markovian dynamics of an impurity in a trapped gas, where the size of the reservoir and its geometry play a key role in determining these memory effects.

Aim: Simulate the dynamics of a two-level impurity in a non-Markovian superfluid reservoir

Semester 1 Tasks: Review literature on Markovian vs non-Markovian open quantum systems, with focus on current models and challenges in the description of non-Markovian dynamics. Revise the description of a two level atom in a bosonic field (e.g. atom in a cavity), reproducing the corresponding background calculations.

Semester 2 Tasks: Simulation of the non-Markovian dissipative dynamics of a two-level impurity immersed in a superfluid reservoir that undergoes memory effects. These are characterised by the finite size of the environment, with coupling to a finite number of modes and edg

Key references:
[1] "The theory of open quantum systems", H.-P. Breur and F. Petruccione
[2] Dynamics of non-Markovian open quantum systems, I. de Vega and D. Alonso, https://doi.org/10.1103/RevModPhys.89.015001
[3] Single-atom cooling by superfluid immersion: A nondestructive method for qubits, A.J.Daley et al., https://doi.org/10.1103/PhysRevA.69.022306

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

Recommended Background: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations.

Safety Training (if applicable): No special training required

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

Misc:

Title: Building the spectra of quasicrystals in magnetic fields

Project ID: AD2

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

Secondary Supervisors: Callum Duncan

Project Background: Before the 1960s, all ground states of matter were considered to be periodic, this changed with the discovery of aperiodic phases of matter. The physics of aperiodic systems (including quasicrystals) is currently not well understood. There has been recent interest in investigating the physics of these systems using the tools of quantum simulators. This includes the study of their spectra and states in the presence of a magnetic field. This is a non-trivial problem due to the lack of periodicity in the problem. This project will examine how we can take a regular periodic system and build in the properties of quasicrystals in a magnetic field by introducing incommensurate staggered magnetic fluxes.

Aim: Investigate the spectral and state properties of square lattice systems in the prescence of quasicrystal inspired magnetic fields.

Semester 1 Tasks: Review the physical properties of quasicrystals. Survey literature on the spectral and state properties in the presence of a magnetic field in periodic and aperiodic lattices. Calculate numerically the Hofstadter butterfly on periodic and quasicrystal lattices in the presence of a constant magnetic field.

Semester 2 Tasks: Add incommensurate staggered magnetic fluxes into the periodic lattice. Investigate the relation of this new lattice to the case of a quasicrystal in a magnetic field. Investigate the state and spectral properties as a function of the magnetic fluxes and

Key references:
[1] C. W. Duncan et al., Topological models in rotationally symmetric quasicrystals, Phys. Rev. B 101, 115413 (2020) https://doi.org/10.1103/PhysRevB.101.115413
[2] D. T. Tran et al., Topological Hofstadter insulators in a two-dimensional quasicrystal, Phys. Rev. B 91, 085125 (2015) https://doi.org/10.1103/PhysRevB.91.085125
[3] D. R. Hofstadter, Energy levels and wave functions of Bloch electrons in rational and irrational magnetic, Phys. Rev. B 14, 2239 (1976) https://doi.org/10.1103/PhysRevB.14.2239

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

Recommended Background: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations.

Safety Training (if applicable): No special training required

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

Misc:

Title: Topological band structures and edge states with ultra-cold atoms in optical lattices

Project ID: AD3

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

Secondary Supervisors: Gerard Pelegri

Project Background: : Over the last 20 years, advances in quantum optics have now made it possible to create experimental "quantum simulators" consisting of ultra-cold atoms confined in an optical lattice, that allow us to investigate dynamics in novel lattice geometries in a highly controllable environment. In particular, there has been great interest in recent years on realising topological band structures in these experimental systems, as the study of topological materials has become a prominent topic in condensed matter physics [3]. One of the main features of these exotic systems is that they can manifest edge states that are robust to certain types of defects and disorder. Besides being fascinating by themselves, these states could have important applications in novel quantum technologies.

Aim: Investigate and simulate the robustness of topological band structures for atoms in optical lattice experiments, for the Su-Schrieffer-Heeger (SSH) model and the two-dimensional rotated Lieb lattice.

Semester 1 Tasks: Literary review on cold atoms in optical lattices and implementation of topological models. This period should also consist of a short numerical study of the SSH model where the student should write code in a choice of Matlab/Python/C++, to reproduce known results.

Semester 2 Tasks: Apply acquired background to extend results to study edge states in the rotated Lieb lattice and introduce imperfections and defects that are realistic for a realisation with ultra-cold atoms in an optical lattice.

Key references:
[1] N. Batra and G. Sheet, Resonance, 25 765 (2020) (arXiv:1906.08435).
[2] N. R. Cooper, J. Dalibard, and I. B. Spielman, Rev. Mod. Phys. 91, 015005 (2019) (arXiv:1803.00249).
[3] L. Madail, S. Flannigan, A. M. Marques, A. J. Daley, and R. G. Dias, Phys. Rev. B 100, 125123 (2019).

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

Recommended Background: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations.

Safety Training (if applicable): No special training required

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

Misc:

Title: Nonlinear Propagation of Fully Structured Light

Project ID: AMY1

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

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):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Control of spatially rotating structures in diffractive Kerr cavities

Project ID: AMY2

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

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):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Asymmetry and cavity solitons in nonlinear cavities

Project ID: AMY3

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

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):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Computational Modelling of X-ray Free Electron Lasers

Project ID: BMcN01

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

Secondary Supervisors: Gordon Robb

Project Background:

Aim:

Semester 1 Tasks:

Semester 2 Tasks:

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

Theory: **Comp:** **Exp:**

Recommended Background:

Safety Training (if applicable):

Suitable for:

Misc:

Title: The theory of X-ray Free electron Lasers

Project ID: BMcN02

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

Secondary Supervisors: Gordon Robb

Project Background:

Aim:

Semester 1 Tasks:

Semester 2 Tasks:

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

Theory: **Comp:** **Exp:**

Recommended Background:

Safety Training (if applicable):

Suitable for:

Misc:

Title: Characterisation of Digital Cameras

Project ID: DO1

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

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 processin

Safety Training (if applicable): No special training required

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

Misc:

Title: Fine Pointing for Satellite Quantum Communication

Project ID: DO2

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

Secondary Supervisors: TBA

Project Background: Sending single photons thousands of km between space and the Earth requires very precise pointing. This is usually achieved using laser beacons to guide the pointing system. It is desirable to minimise the amount of power required for this, hence accurate modelling of the performance of these systems is important. This project will examine the design and analysis of space quantum communication beaconing.

Aim: Analyse pointing requirements in satellite quantum communications

Semester 1 Tasks: Review satellite quantum key distribution, pointing and tracking methods. Survey literature on other satellite quantum communication missions and extract performance numbers. Analyse free-space channel propagation losses.

Semester 2 Tasks: Perform simulation of position accuracy. Determine laser power levels to ensure specified performance level.

Key references:

[1] CubeSat quantum communications mission, D.K.L. Oi et al., https://doi.org/10.1140/epjqt/s40507-017-0060-1
[2] QUARC, L. Mazzarella et al., https://doi.org/10.3390/cryptography4010007
[3] Quantum Optics for Space Platforms, W. Morong et al., https://doi.org/10.1364/OPN.23.10.000042

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

Recommended Background: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations.

Safety Training (if applicable): No special training required

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

Misc:

Title: High Precision Timing for Satellite Quantum Communication

Project ID: DO3

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

Secondary Supervisors: TBA

Project Background: Detecting single photons sent thousands of km through space requires very precise timing to pick out signals from noise. This is usually achieved using additional bright laser pulses. This project will examine the beacon pulse characteristics and local oscillator performance necessary for accurate timing and synchronisation to support satellite quantum communication experiments.

Aim: Determine timing requirements in satellite quantum communications

Semester 1 Tasks: Review satellite quantum key distribution timing synchronisation methods. Survey literature on other satellite quantum communication missions and extract performance numbers. Calculate pulse power and detector noise requirements.

Semester 2 Tasks: Perform simulation of timing accuracy. Determine laser performance required for jitter requirements.

Key references:
[1] CubeSat quantum communications mission, D.K.L. Oi et al., https://doi.org/10.1140/epjqt/s40507-017-0060-1
[2] QUARC, L. Mazzarella et al., https://doi.org/10.3390/cryptography4010007
[3] Quantum Optics for Space Platforms, W. Morong et al., https://doi.org/10.1364/OPN.23.10.000042

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

Recommended Background: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations.

Safety Training (if applicable): No special training required

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

Misc:

Title: Innovation and translation of a miniature atomic clock platform

Project ID: SS1

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

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 t

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): N/A

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

Misc:

Title: Quantum Dots Nanolasers

Project ID: FP1

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

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 dostribution

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

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):

Suitable for:

Misc:

Title: Domain Walls in Optical Fibre Resonators

Project ID: GLO1

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

Secondary Supervisors: Alison Yao

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

Aim: This project aims at investigating domain walls between left and right circular polarizations in an optical fibre resonator. In particular, we study and compare the formation of periodic structures, locked domain walls and solitons in theoretical and comp

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] R. Gallego et al., "Self-similar domain growth, localized structures, and labyrinthine patterns in vectorial Kerr resonators", Phys. Rev. E 61, 2241 (2000);
G.-L. Oppo et al, "Characterization, dynamics and stabilization of diffractive domain walls and d
[2] J.K. Jang et al., "Controlled merging and annihilation of localised dissipative structures in a driven damped nonlinear Schrödinger system" New Journal of Phys. 18, 033034 (2016)
[3]

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

Recommended Background: Matlab

Safety Training (if applicable):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Opto-mechanics of Bose-Einstein Condensates in Optical Cavities

Project ID: GLO2

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

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 increased, experiments in Hamburg have revealed that opto-mechanics with resonant momentum transfer takes place [1].

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] H. Keßler et al., “Optomechanical atom-cavity interaction in the sub- recoil regime”, New Journal of Physics 16, 053008 (2014)
[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 fi
[3]

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

Recommended Background: Matlab

Safety Training (if applicable):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Weird interactions of Cavity Solitons

Project ID: GLO3

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

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, howe

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:** 0%

Recommended Background: Matlab

Safety Training (if applicable):

Suitable for: Mphys, BSc Maths and Phys

Misc:

Title: Cold Atom-Light Interactions

Project ID: GR1

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

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:

Title: BEC simulations

Project ID: GR2

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

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:

Title: Interactive Physics simulations

Project ID: GR3

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

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:

Title: Thermal Quantum Lidar

Project ID: JJ1

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

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): N/A

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: How many photons make an image?

Project ID: JJ2

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

Secondary Supervisors: Nigam Samantary

Project Background: There is considerable interest in imaging with fewer than one photon per pixel on average. Quantum Imaging schemes rely on reaching close to or beyond this limit.

Aim: Decide the minimum possible number in the title question.

Semester 1 Tasks: Study quantum theory of electromagnetic field. Photodetection. Build up from single pixel, two pixel, n-pixel linear images. Derive minimal basis sets for images. Extend to multiple counts.

Semester 2 Tasks: Move to nxm square images. The continuous limit in for linear and 2d images.Temporal images.

Key references:
[1] Appl. Phys. Lett. 116, 260504 (2020)
[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):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Ghost Displacement

Project ID: JJ3R

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

Secondary Supervisors: Nigam Samantary

Project Background: Ghost imaging is a recognised technique in imaging objects using light that has not interacted with them. Ghost Displacement uses a more complicated form of measurement, and as a consequence, might be better.

Aim: Decide how good ghost displacement might be at increasing conditioned photon numbers.

Semester 1 Tasks: Study coherent states, thermal states, beam splitters, detection statistics. Calculate basic ghost displacement effect.

Semester 2 Tasks: Attempt to optimise ghost dispacement either for covert object detection or for detection of weakly-reflecting objects.

Key references:
[1] N/A
[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): N/A

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: New schemes for microwave Rydberg sensing

Project ID: JP1

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

Secondary Supervisors: Aurelien Chopinaud

Project Background: Many applications in communication, medicine or navigation require precise characterisation of electric fields in the microwave and terahertz domains making the need for a powerful sensor essential. Rydberg atoms are highly excited atoms which offer great potentiality for the development of such a sensor due to their large sensitivity to electric fields in these domains. The aim of the project is to study new sensing schemes based on electromagnetically induced transparency and four wave mixing. The student will develop models to test the feasibily of such schemes and if successful design a prototype experimental setup.

Aim: Study the feasibility of new Rydberg sensing schemes to measure the properties of microwave fields.

Semester 1 Tasks: Review the different methods of sensing using Rydberg atoms, get familiar with the underlying physics and understand the limits of each methods. Study ways to overcome these limits. Study the principle of four or more wave mixing and why this could be relevant to measure the phase of the electric field.

Semester 2 Tasks: Study the feasibility of the new schemes by performing simulations to determine the sensor sensitivity and efficiency. Draw a prototype setup and define the required lasers and devices.

Key references:
[1] Atom-Based Vector Microwave Electrometry Using Rubidium Rydberg Atoms in a Vapor Cell https://doi.org/10.1103/PhysRevLett.111.063001
[2] Real-time near-field terahertz imaging with atomic optical fluorescence https://doi.org/10.1038/nphoton.2016.214
[3] Collimated UV light generation by two-photon excitation to a Rydberg state in Rb vapor https://doi.org/10.1364/OL.44.002931

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

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

Safety Training (if applicable): N/A

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

Misc:

Title: ‘Cool’ simulations of atomic qubits

Project ID: JP2

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

Secondary Supervisors: Nicholas Spong

Project Background: Quantum information processing with neutral atoms offers an exciting and scalable platform for performing both digital quantum computation and quantum simulation, with controllable long-range interactions mediated by highly excited Rydberg levels. A dominant limitation in the performance of atom qubits to date arises from finite temperature effects, with atomic motion limiting coherence for atoms confined within microscopic dipole traps. This can be overcome using the technique of resolved-sideband cooling, as used for trapped-ion qubits, to cool atoms to the motional ground state of the harmonic potential by performing coherent operations between motional quantum states.

Aim: Model ground-state Raman cooling of atomic qubits in optical traps

Semester 1 Tasks: Review theory of Raman transfer and literature review of different approaches to Raman sideband cooling. Initial results will focus on determining optimum transitions for repumping to minimise heating.

Semester 2 Tasks: Develop model for Raman cooling in an atomic trap, determinining optimal strategy for cooling pulses and exploring impact of pulse-shaping on final temperature.

Key references:
[1] Quantum dynamics of single trapped ions https://doi.org/10.1103/RevModPhys.75.281
[2] Cooling a Single Atom in an Optical Tweezer to Its Quantum Ground State https://doi.org/10.1103/PhysRevX.2.041014
[3] Molecular Assembly of Ground-State Cooled Single Atoms https://doi.org/10.1103/PhysRevX.9.021039

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

Recommended Background: Students should be able to use Python (Scipy). Recommended modules PH462 Topics in Quantum Optics, PH459 Topics in Atomic Physics

Safety Training (if applicable): N/A

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

Misc:

Title: Generating Arbitrary Arrays for Quantum Information Processing

Project ID: JP3

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

Secondary Supervisors:

Project Background: Quantum information processing with neutral atoms offers an exciting and scalable platform for performing both digital quantum computation and quantum simulation, with controllable long-range interactions mediated by highly excited Rydberg levels.

A key advantage of neutral atoms is the ability to cool and trap large numbers of qubits, with experiments demonstrating deterministically loaded arrays of arbitrary geometry in both 2D [1] and 3D [2] using holographic traps created with spatial light modulators (SLM's). This project will explore novel approaches to generating arrays of optical traps for trapping atoms in both the ground state and Rydberg state.

Aim: Study techniques for generating holographic trap arrays for neutral atoms and Rydberg states

Semester 1 Tasks: Review of current holographic trapping techniques and implement algorithm for generating arrays of red detuned traps in 2D and 3D.

Semester 2 Tasks: Explore optimal trapping geometries for blue-detuned traps for atoms and characterise trap potential for Rydberg atoms.

Key references:
[1] An atom-by-atom assembler of defect-free arbitrary two-dimensional atomic arrays https://doi.org/10.1126/science.aah3778
[2] Magic-wavelength optical traps for Rydberg atoms http://dx.doi.org/10.1103/PhysRevA.84.043408
[3] Three-Dimensional Trapping of Individual Rydberg Atoms in Ponderomotive Bottle Beam Traps https://doi.org/10.1103/PhysRevLett.124.023201

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

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

Safety Training (if applicable): N/A

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

Misc:

Title: Optical Cavities

Project ID: NL1

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

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): None

Suitable for: BSc Physics

Misc:

Title: Switching in optical loop mirrors

Project ID: NL2

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

Secondary Supervisors: Backup supervisor or assisting PDRA

Project Background: Laser Physics

Aim: Develop a model to describe all optical switching in

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): None

Suitable for: BSc Physics

Misc:

Title: Using quantum sensors to measure human heart activity

Project ID: PG1

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

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):

Suitable for: MPhys, BSc

Misc:

Title: Simulation of Maxwells equations for optical design of quantum technologies

Project ID: PG2

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

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 desi

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:

Title: Atomic Physics Simulation for Outreach and Learning

Project ID: SI1

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

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. These will be the subjects of a preliminary report (12 pages). 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):

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

Misc:

Title: Synchronisation in open quantum systems

Project ID: PK1

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

Secondary Supervisors: TBA

Project Background: Quantum systems always interact with their surrounding environment. These open quantum systems can be described using a variety of tools both numerical and analytical. In this project we will use sophisticated numerical tools to find the behaviour of a model of two spin-1/2 particles which interact with each other through their environment.

Aim: Calculate the synchronisation phase diagram of the multispin spin -boson model

Semester 1 Tasks: Background literature on spin-boson physics, quantum synchronisation, numerical methods for open systems. Reproduce known spin-boson physics using the Time-Evolving-Matrix-Product-Operators algorithm [2].

Semester 2 Tasks: Analysis of multi-spin problem. Examine dynamics around the synchronisation phase transition. Comparison to Markovian theories.

Key references:
[1] PP. Orth et al Phys. Rev. B 82, 144423 (2010)
[2] A. Strathearn et al Nat. Commun. 9, 3322 (2018)
[3] The Theory of Open Quantum Systems, Breuer and Petruccione

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

Recommended Background: Experience of coding, running simulations and data analysis in python

Safety Training (if applicable):

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

Misc:

Title: Quantum correlations in nano-lasers

Project ID: PK2

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

Secondary Supervisors: TBA

Project Background: Lasers provide the prototypical example of a non-equilibrium phase transition. The state of light in the cavity changes dramatically as the device is pumped above threshold. Recently it has been possible to engineer lasers with only a few emitters. In this project you will use a combination of analytical and numerical techniques to examine the quantum correlations which can occur in these systems.

Aim: Examine the behaviour of correlations between emitters in a simple model of a laser

Semester 1 Tasks: Background literature on quantum models of simple two-level lasers. Mean-field equations of motion and linear stability analysis. Background on cumulant expansions and permutation symmetric simulations which will be used in semester 2.

Semester 2 Tasks: Permutation symmetric simulations of 2-level model. Comparison to cumulant expansions. Calculating quantum correlations and examining dependence on system size.

Key references:

[1] H. A. M. Leymann et al. Phys. Rev. Applied 4, 044018 (2015)
[2] Kirton and Keeling Phys. Rev. Lett. 118, 123602 (2017)
[3] Quantum Optics, Walls and Milburn

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

Recommended Background: Experience of coding, running simulations and data analysis in python

Safety Training (if applicable):

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

Misc:

Title: Numerical simulation of optical transport

Project ID: SK01R

Primary Supervisor: Stefan Kuhr **Email:**

Secondary Supervisors:

Project Background:

Aim:

Semester 1 Tasks:

Semester 2 Tasks:

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

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

Recommended Background:

Safety Training (if applicable):

Suitable for:

Misc:

Title: Photon statistics of small lasers

Project ID: TA1

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

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:

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

Project ID: TA2

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

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): n.a.

Suitable for: BSc, BSc Math and Physics

Misc:

Nanoscience Division

Title: Engineering semiconductor defects for quantum electronics

Project ID: AR1

Primary Supervisor: Alessandro Rossi **Email:** alessandro.rossi@strath.ac.uk

Secondary Supervisors: Robert Martin (TBC)

Project Background: The ability to introduce alien atomic species into microscopic regions of a semiconductor material, a technique widely known as doping, has been the cornerstone for the build-up of modern integrated electronics. In fact, this is how the electrical conductivity of semiconductors is locally controlled through ion implantation. However, during the implantation process, high energy collisions between these dopants and the semiconductor target can generate significant crystal damage. Although this may be a problem for the reliability of electronic chips, it has been shown that some atomic defects have very interesting physical properties and lend themselves to the realisation of quantum devices [1].In particular, the atomic defects created by the implantation of C atoms in silicon carbide (SiC) are spin-active and luminescent. They have been exploited in a diverse range of quantum devices, such as quantum magnetometers, quantum thermometers, single-photon emitters, as well as to encode quantum bits of information [2].

In this project, the student will be involved in designing SiC-based quantum devices. In order to improve the reliability and yield of these electronic systems, an optimisation of the implantation process will be carried out. This project will make use of Monte-Carlo simulations [3] to tune the implantation parameters and achieve desirable defect concentrations, localisation and patterning. The main expected outcome of the project is the definition of a set of process specifications to be submitted to an ion implantation facility for real sample manufacturing.

Aim: use Monte-Carlo simulations to design ion implantation process in silicon carbide chips

Semester 1 Tasks: Literature survey of fabrication of quantum defects in silicon carbide. Familiarise with the simulation software and reproduce the results of tutorials 1 and 4.

Semester 2 Tasks: Simulate implantation of carbon atoms in SiC for different doses and energies, in order to obtain the desired damage concentration profiles.

Key references:
[1] M. Atature et al., Nature Reviews Materials 3, 38 (2018)
[2] A. Lohrmann et al., Rep. Prog. Phys. 80, 034502 (2017)
[3] http://www.srim.org/

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

Recommended Background: a genuine interest for the topics in PH258 and PH358

Safety Training (if applicable): none

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

Misc:

Title: Simulating structural defects in α-Ga2O3

Project ID: BH1

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

Secondary Supervisors: Fabien Massabuau

Project Background: Recently the has been substantial international interest in the propery and applications of the oxide material Ga2O3 for new types of electronic and optical devices. This compound semiconductor occurs in several different crystal structures, but on of the promising forms for ultra-violet light sources and high power electronics is α-Ga2O3 (the same crystal structure as saphire). Currently this material is limited by the many defects that are present even in the best crystals. To improve this material, we need to understand the defects that are present as a first step towards improving this material by removing the most detrimental of them.

Aim: This project aims to understand the structure and behaviour of defects in α-Ga2O3 using large scale quantum-mechanical simulations.

Semester 1 Tasks: 1) Review literature discussing Ga2O3, extended defects in crystals (particularly dislocations, stacking faults and Σ boundaries. 2) Learn how to generate and manipulate atomistic models of crystals using the AtomSK code and its tutorials. 3) Learn, by working through tutorial materials, how to use the DFTB+ code for large scale quantum mechanical modeling using the department's parallel computing resources.

Semester 2 Tasks: 1) Generate plausible models for partial dislocations and stacking faults in α-Ga2O3 crystal models, using dislocation quadrupole geometries. 2) Optimise structures and look for the most stable (i.e. the most likely to be present). 3) Examine some of the

Key references:
[1] https://doi.org/10.1016/j.jcrysgro.2018.02.014
[2] https://aip.scitation.org/doi/full/10.1063/1.5143190
[3] https://doi.org/10.1016/j.cpc.2015.07.012

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

Recommended Background: Interest in Solid State Physics (previous attendance of PH386 Condensed Matter Physics or equivalent) and registration to attend PH453 Topics In Solid State Physics.

Safety Training (if applicable): N/A

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

Misc:

Title: Twisted nanostrutures

Project ID: BH2

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

Secondary Supervisors: Oliver Henrich

Project Background: In addition to the familiar repeating arrays of atoms in crystals, there are several other types of large ordered arrangements of atoms which occur in nature which are not periodic. For example there are many structures that are fundamentally helical in nature, these include carbon nanotubes, screw-dislocated nanowires, the tails and capsids of many viruses, amyloid fibrils, and perhaps most famously, DNA. Traditionally these are investigated by either using large clusters of atoms to describe segments of the helical structure, or as a crystal with a large number of atoms in its unit cell to include a complete twist of the helix. Both of these approaches require the simulation of very large numbers of atoms (in principle up to an infinite number in some cases), even though the fundamental repeat unit of the structure is often much smaller. This project applies the recently developed idea of simulating this fundamental repeat unit (the so called 'objective' cell) to study twisted nanostructures. Potential systems to be studied in this project are helical tubes of modern 2D materials (such as phosphorene or transition-metal dichalcogenide nanotubes).

Aim: This project applies concepts from the study of the properties of mater to understand the results of simulating complex nanostructures.

Semester 1 Tasks: 1) Review literature discussing helical nano-structures and concepts related to the electronic structure and mechanics of bending, torsion and stretching of nanostructures. 2) Learn, by working through tutorial materials, how to use the DFTB+ code for large scale quantum mechanical modeling using the department's parallel computing resources.

Semester 2 Tasks:

Key references:
[1] Formation of helices in graphene nanoribbons under torsion. Nikiforov, Hourahine, Frauenheim, and Dumitrică, Journal of Physical Chemistry Letters 5, 4083 (2014).
[2] Ewald summation on a helix: a route to self-consistent charge density-functional based tight-binding objective molecular dynamics. Nikiforov, Hourahine, Aradi, Frauenheim, Dumitrică, Journal of Chemical Physics 139, 094110 (2013).
[3] DFTB+, a software package for efficient approximate density functional theory based atomistic simulations, Hourahine et al. J. Chem. Phys. 152, 124101 (2020)

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

Recommended Background: Interest in Solid State Physics and nanoscience (previous attendance of PH386 Condensed Matter Physics or equivalent) and registration to attend PH454 Topics In Nanoscience

Safety Training (if applicable): N/A

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

Misc:

Title: Correlated quantum transport

Project ID: BH3

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

Secondary Supervisors: Andrew Daley

Project Background: Electrical conductivity in nanoscale structures is quite different from macro-scale electronic devices (for example occurring in quantized amounts, sensitive to the locations of individual atoms in structures and strongly affected by the interactions between the particles carrying charge). This project will apply large scale quantum transport simulations to examine the tunnelling of carriers in the complex oxide material magnetite (Fe3O4). This is a ferrimagnetic material and shows mixed-valence behaviour with two types of iron atom present. The interactions, particularly between the 3d electrons of the iron atoms, are also fairly strong. This leads to simple band theory breaking down and the need for correlation between the electrons to be more carefully included.

Aim: Investigate simulated transmission probabilities and current voltage behaviour for single particle and correlated models of nano-scale structures

Semester 1 Tasks: 1) Review literature discussing Fe3O4. 2) Consolidate concepts in solid state physics (band structure, density of states, magnetic ordering) and learn how they are modified by correlation effects for example in the Mott-Hubbard insulators. 3) Learn, by working through tutorial materials, how to use the DFTB+ code for large scale quantum mechanical modeling.

Semester 2 Tasks: 1) Simulate bulk crystals of Fe3O4 and investigate the effects of moderate correlation using the DFTB+U model. 2) Apply non-equilibrium Green’s function transport to bulk (and optionally wire-like) material.

Key references:

[1] An efficient way to model complex magnetite: Assessment of SCC-DFTB against DFT, Liu et al. J. Chem. Phys. 150, 094703 (2019)
[2] DFTB+, a software package for efficient approximate density functional theory based atomistic simulations, Hourahine et al. J. Chem. Phys. 152, 124101 (2020)
[3] Non-equilibrium Green's functions in density functional tight binding: method and applications. Pecchia et al. New J. Phys.10 065022 (2008)

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

Recommended Background: Interest in Solid State Physics (previous attendance of PH386 Condensed Matter Physics or equivalent) and registration to attend PH453 Topics In Solid State Physics.

Safety Training (if applicable): N/A

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

Misc:

Title: Adaptive noise reduction for sCMOS cameras

Project ID: BP1

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

Secondary Supervisors: David McKee

Project Background: The camera devices used widely for scienftific 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 doen 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]

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

Recommended Background: Needs experience of Matlab. Python programming is useful. Image processing experience is also helpful

Safety Training (if applicable): It is unlikely that we will be able to provide direct access to experimental facilities.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Constructing and testing a portable holographic microscope

Project ID: BP2R

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

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, high quality scientific data can be obtained at low cost.

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

Semester 1 Tasks: Review of holographic microscopy and modular/low cost microscopy. Test the microscope code on the Nvidia Jetson. Arrange for the printing of the microscope body.

Semester 2 Tasks: Use the Knowledge in the first part of the project to conduct tests of the modular holographic microscope.

Key references:
[1] "Compact off-axis holographic slide microscope: design guidelines", https://doi.org/10.1364/BOE.11.002511
[2]
[3]

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

Recommended Background: Note, this is the project highlighted as suitable for a current summer intern

Safety Training (if applicable): Currrent candidate has previously received suitable safety induction

Suitable for:

Misc:

Title: Investigation of polytypism in nitride semiconductors

Project ID: CTC1

Primary Supervisor: Carol Trager-Cowan **Email:** c.trager-cowan@strath.ac.uk

Secondary Supervisors: Jochen Bruckbauer

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). Learn the basics of the MATLAB-based EBSD analysis software MTEX.

Semester 2 Tasks: Analyse a number of EBSD datasets acquired from nitride semiconductors containing both the wurtzite and zincblende polytypes.

Key references:
[1] C. J. M. Stark et al., Appl. Phys. Lett. 103, 232107 (2013).
[2] A. J. Schwartz et al, Electron Backscatter Diffraction in Materials Science (Springer, 2009).
[3] M Frentrup et al, J. Phys. D: Appl. Phys. 50 433002 (2017).

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

Recommended Background: Prior knowledge of MATLAB would be useful. An aptitude and enthusiasm for coding and for crystallography is essential.

Safety Training (if applicable): None

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

Misc:

Title: Modelling scattering from natural particle populations in the marine environment.

Project ID: DMcK1

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

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:

Title: Why do ocean colour chlorophyll products fail in coastal waters?

Project ID: DMcK2

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

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:

Title: Dislocations in Ga2O3: analysis of atomic resolution images

Project ID: FM1

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

Secondary Supervisors: Ben Hourahine

Project Background: Owing to a wide bandgap of about 5 eV, Gallium Oxide (Ga2O3) 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 and rectifiers.

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 Ga2O3. 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 Ga2O3 using a transmission electron microscope. The data indicate that the Ga2O3 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 Ga2O3 films, and (ii) use the available literature on defects in related material systems to inform its discussion. The results from this analysis will then be used to simulate the effect on the optoelectronic properties of dislocations in the material – this is unlikely to be conducted by the student directly but can be envisioned as a collaboration with Ben Hourahine and the student undertaking project BH01.

Aim: Identify and analyse the structure of dislocations in Ga2O3 semiconductors

Semester 1 Tasks: Literature survey on Ga2O3 materials, defects in Ga2O3, and on dislocations and stacking faults in corundum materials. Become familiar with software and methods to analyse the data.

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 synergy with project BH01).

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” courses (PH258/PH278, PH358).

Attendance to “Topics on Solid State Physics” and “Advanced Nanoscience 1: Imaging & Microscopy” courses is strongly recommended.

Safety Training (if applicable):

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

Misc:

Title: Photoconduction in wide bandgap semiconductors

Project ID: FM2

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

Secondary Supervisors: Paul Edwards

Project Background: Photoconduction is one of the fundamental properties of semiconductors where incident photons at the appropriate energy generate free carriers in the material, thus increasing its conductivity. This is one of the underlying mechanisms for solar cells and light detectors. In the case of wide bandgap semiconductors (bandgap typically >3.5 eV), photoconduction happens in the ultraviolet region of the light spectrum.

Studying photoconduction – for example, how much current is generated upon illumination, at which wavelength current is generated, or how fast the current responds to light stimuli – can reveal a great deal of information about the electronic properties of the material. However when it comes to wide bandgap materials, knowledge in that field is lacking.

Our group has recently built a setup specifically designed to conduct photoconduction measurements of wide bandgap semiconductors (such as Ga2O3, AlGaN). In the project the student will (i) produce a literature survey on photoconduction techniques and how they apply to wide bandgap semiconductors, and (ii) use these methods to guide the data acquisition on our setup and perform the resulting data analysis.

Aim: Analyse the photoconduction properties of wide bandgap semicondutors

Semester 1 Tasks: Literature survey on wide bandgap semiconductors, and on methods to analyse and interpret transient photoconduction data.

Semester 2 Tasks: Analyse transient photoconduction data.

Key references:
[1] Reynolds et al. (2017) Photoconductivity in Materials Research. In: Kasap S., Capper P. (eds) Springer Handbook of Electronic and Photonic Materials. Springer Handbooks. Springer, Cham. https://doi.org/10.1007/978-3-319-48933-9_7
[2]
[3]

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

Recommended Background: The student should be comfortable with the content of the “Condensed Matter Physics” courses (PH258/PH278, PH358).

The student is expected to attend the “Topics on Solid State Physics” (PH453/PH962) course.

Safety Training (if applicable):

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

Misc:

Title: Identifying current transport in Ga2O3-metal contacts

Project ID: FM3

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

Secondary Supervisors: Paul Edwards

Project Background: Gallium Oxide (Ga2O3) is a wide bandgap semiconductor that is inspiring substantial research effort due to its applications in ultraviolet optoelectronics as well as high power devices.

A pivotal component of semiconductor devices is the contact with the external circuit. In a facile picture, an ohmic contact implies that carriers can freely flow between the semiconductor and the metal, while a Schottky contact would only allow carriers to flow in one direction. The type of metal used as contact, the quality of the semiconductor material, and the quality of the metal/semiconductor interface are important parameters that will have an effect on the carrier transport mechanisms at the device contact.

At the moment, the physics of metal contacts on Ga2O3 is poorly understood. The project tries to fill in that gap. We have produced several contact structures on a Ga2O3 sample, which have undergone several processing methods and electrical characteristics (current-voltage (I-V) curves) were recorded.

The student will (i) review the physical models to analyse and interpret I-V characteristics of metal-semiconductor contacts, (ii) apply this knowledge to our dataset of several metal-Ga2O3 contacts, and (iii) assess whether the simulation package LTspice can reliably fit the data.

Aim: Analyse and model the electrical characteristics of Ga2O3/metal contacts structures

Semester 1 Tasks: Literature survey on Ga2O3 semiconductors, contact modelling, and carrier transport mechanisms. Start fitting the dataset.

Semester 2 Tasks: Complete the data analysis and interpretation. Use LTspice to model the contact structure.

Key references:

[1] Sze et al., Solid-State Electronics 14, 1209 (1971) https://doi.org/10.1016/0038-1101(71)90109-2

[2] Rhoderick et al., IEE Proc 129 (1982) https://ieeexplore.ieee.org/document/4642597
[3] Miller et al. Appl. Phys. Lett. 84, 535 (2004) https://doi.org/10.1063/1.1644029

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

Recommended Background: The student should be comfortable with the content of the “Condensed Matter Physics” courses (PH258/PH278, PH358).

The student is expected to attend the “Topics on Solid State Physics” (PH453/PH962) course.

Safety Training (if applicable):

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

Misc:

Title: Luminescence properties of Ga_2O_3 semiconductors

Project ID: FM4

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

Secondary Supervisors: Rob Martin

Project Background: With a bandgap of ca. 5eV, Gallium Oxide (Ga_2O_3) is a wide bandgap semiconductor that finds applications in ultraviolet detectors as well as high power devices.

However Ga_2O_3 research is at its beginning, and many fundamental aspects of the material are still poorly understood. This is particularly true when it comes to defects in the crystals. On the one hand, defects such as point defects (extra/missing/misplaced atom in the crystal lattice) have been suggested to have serious implications on the electronic structure of the material. On the other hand, the question of which defect causes a given electronic transition remains an open debate. This is, however, a critical aspect to understand if we want to produce efficient devices.

In order to shed light onto the properties of this material, Ga_2O_3 films have been deposited using atomic layer deposition and subsequently annealed under various conditions to induce a range of structural variations between samples [Reference 1]. The samples will be analysed by temperature- and power-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 Ga_2O_3, (ii) analyse the photoluminescence dataset, and (iii) attempt to identify the luminescence mechanisms in the light of the processing history of the samples and available literature.

Aim: Analyse the optical properties of Ga_2O_3 films

Semester 1 Tasks: Literature survey on Ga_2O_3 semiconductors, defects in Ga_2O_3, and associated luminescence. Start analysing the dataset.

Semester 2 Tasks: Complete the data analysis and interpretation.

Key references:
[1] Moloney et al., J. Phys. D: Appl. Phys. 52, 475101 (2019) https://doi.org/10.1088/1361-6463/ab3b76

[2] McCluskey, J. Appl. Phys. 127 101101 (2020) https://doi.org/10.1063/1.5142195
[3]

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

Recommended Background: The student should be comfortable with the content of the “Condensed Matter Physics” courses (PH258/PH278, PH358).

The student is expected to attend the “Topics on Solid State Physics” (PH453/PH962) course.

Safety Training (if applicable):

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

Misc:

Title: Lloyd's mirror in standing wave microscopy

Project ID: GMcC1

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

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. This will form the basis for a ~12 page report worth 20% of the final mark.

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, consi

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): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Reducing the information gap in standing wave microscopy

Project ID: GMcC2

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

Secondary Supervisors: Sebastian van de Linde

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. More recently, we have conceived a method we call tartanSW imaging to fill in the gap. In tartanSW, we use more than one illumination wavelength to excite the specimen. Because the separation of the planes of constructive and destructive interference are wavelength dependent, it should be possible to reduce the information gap from 50%, so that more of the specimen can be seen. This project will involve modelling of the information gap in conventional standing wave microscopy and in tartanSW to calculate the difference in information gap obtained using these methods.

Aim: The aim of this project is to calculate the reduction in information gap when using tartanSW compared to ordinary standing wave microscopy

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 have a firm understanding of how changing the wavelength will change the periodicity of a standing wave. This will form the basis for a ~12 page report worth 20% of the final mark.

Semester 2 Tasks: The student should choose three common wavelength in optical microscopy (e.g. 488nm, 561nm and 633nm) and model how the standing waves would form at those wavelengths simultaneously, specifically calculating the anti-nodal spacing and full-width at half-m

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): None

Suitable for: Mphys, BSc, BSc Maths and Physics

Misc:

Title: Coarse-grained DNA simulation of DNA supercoiling

Project ID: OH1

Primary Supervisor: Oliver Henrich **Email:** oliver.henrich@strath.ac.uk

Secondary Supervisors: Benjamin Hourahine

Project Background: While we know the sequence of many genomes in great detail, we still know little as to how DNA is organised in 3D inside a living cell and of how gene regulation and DNA function are coupled to its intricate structure. There is thus great interest in developing computational models that are able to describe the structural and dynamical properties of DNA. Atomistic force fields have been very successful at modelling DNA, but cannot deliver the necessary temporal and spatial resolution to describe phenomena that occur on larger time and length scales. This is why a number of mesoscopic, coarse-grained (CG) models of DNA have emerged during the last decade. These models are indispensable for accessing timescales in the millisecond range and beyond, or when long DNA strands of tens of thousands of base pairs or more have to be considered.

The oxDNA model [1] is one of the most powerful and promising CG DNA models. oxDNA is sequence- specificand able to describe the denaturing transition ofDNA and other important structural and thermodynamic properties of both single-stranded and double-stranded DNA. It is now available in the LAMMPS code [2,3] (Large-scale Atomic/Molecular Massively Parallel Simulator, hosted by Sandia National Laboratories, USA) and used by an increasing number of groups around the world.

In this project we will study linear DNA of several thousand base pairs that is attached to a microscopic bead and substrate and can be over- and undertwist. The closed nature of the system entails certain topological constraints that restrict the conformational changes that the DNA loop can undergo. This is usually expressed through the mathematical concept of the linking number, which is preserved during conformational changes. We will study how the internal twist of the DNA diffuses along the double strand and how this influences the formation and distribution of loops of helices (aka plectonemes).

Aim: The aim of the project is to study the over- and undertwisting of DNA in close collaboration with experimentalists and simulators at the University of York.

Semester 1 Tasks: 1) Literature review, 2) Familiarising with the simulation methodology, 3) Familiarising with the software, deploying small test runs and visualising results, 4) Familiarising with HPC facility and deploying larger test runs, 5) Deploying first production runs, 6) Writing of 12 page report

Semester 2 Tasks: 7) Continuing with production runs, 8) In-depth analysis of production runs, 9) Writing of final 18 page report

Key references:
[1] [1] B. Snodin, F. Randisi, M. Mosayebi, et al., J. Chem. Phys. 142, 234901 (2015).
[2] [2] O. Henrich, Y.A. Gutierrez-Fosado, T. Curk, T. E. Ouldridge, Eur. Phys. J. E : 41, 57 (2018).
[3] [3] https://lammps.sandia.gov

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

Recommended Background: This project requires familiarising with physical theory, the simulation methodology and a number of technical aspects that are not covered in the standard curriculum. This includes for instance usage of HPC facilities, version control systems and code re

Safety Training (if applicable): N/A

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Numerical modelling of FRET in beta-amyloid

Project ID: OR1

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

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): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Numerical modelling of FRET in nanostructures

Project ID: OR2

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

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): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Numerical modelling of FRET in Human Serum Albumin

Project ID: OR3R

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

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:

Title: Web-based electron diffraction tool

Project ID: PE1

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

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:

Title: Investigating the effect of gas pressure on the electron diffraction patterns

Project ID: NK1

Primary Supervisor: Naresh Kumar **Email:** naresh.gunasekar@strath.ac.uk

Secondary Supervisors: Dr Carol Trager-Cowan

Project Background: This project is about understanding electron diffraction processes when a sample is in a gaseous environment, particularly for insulating materials of low atomic weight such as AlN, SiC and diamond. These materials are crucial for the existing and the next generation of electronic and optoelectronic devices. Electron diffraction patterns (EBSPs), acquired in the scanning electron microscope, provide information on the structural properties of materials with a spatial resolution of tens of nanometres, such information is key to engineering the physical properties of technologically important materials. Generally EBSPs are acquired with the sample in a vacuum, however, when investigating insulating samples it is useful to allow some gas into the vacuum chamber. The gas allows the dissipation of charge which can build up on the sample. To optimise the acquisition of EBSPs in a gaseous environment it is crucial to understand how the gas influences the quality of the acquired patterns.

The project involves analysing electron diffraction patterns at different electron energies and at different gas pressure and monitor the changes in the diffraction patterns. The experimental patterns obtained by other researchers in the group will be provided to the students for analysis. The computational part of this project is then to monitor the changes in the experimental diffraction patterns by comparing them with theoretical patterns produced with commercial software and with software built in-house. Finally, quantify the changes observed in the experimental patterns obtained for different materials.

Aim: Understanding the role of gas pressure on the quality of electron diffraction patterns of semiconductors acquired using a scanning electron microscope.

Semester 1 Tasks: Review electron diffraction and crystallography. Survey literature on electron backscatter diffraction (EBSD) and scanning electron microscopy. Develop familiarity with dynamical theory of electron scattering and use Esprit Dynamics software to analyse diffraction patterns collected previously by other researchers in the group.

Semester 2 Tasks: New EBSD data acquired by researchers in the group from labs in TIC. The student can view the experiments remotely. Use Esprit Dynamics software to plot and analyse diffraction patterns data at home.

Key references:
[1] G. E Lloyd, “Atomic number and crystallographic contrast images with the SEM: a review of backscattered electron techniques” Mineralogical magazine, Vol 51, page 3-19, March 1987.
[2] A. J. Wilkinson and P. B. Hirsch, “Electron diffraction based techniques in scanning electron microscopy of bulk materials”, Micron, Vol 28, page 279, 1997.
[3] R. A. Schwarzer, D. P. Field, B. L. Adams, M. Kumar, and A. J. Schwartz, in Electron Backscatter Diffraction in Materials Science, edited by A. J. Schwartz, M. Kumar, B. L. Adams, and D. P. Field (Springer, New York, 2009).

Theory: 30% **Comp:** 60% **Exp:** 10%

Recommended Background: PH453 Topics in Solid State Physics, PH355 Physics Skills. Students should be able to become comfortable with use of Esprit Dynamics software , ImageJ for data analysis and with scanning electron microscope. Prior experience with mat lab would be benefici

Safety Training (if applicable): Technology innovation centre safety induction may be needed in case of accessing the TIC labs.

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

Misc:

Title: Investigating the origin of red emission in gallium oxide semiconductors

Project ID: NK2

Primary Supervisor: Naresh Kumar **Email:** naresh.gunasekar@strath.ac.uk

Secondary Supervisors: Prof. Rob Martin & Dr Paul Edwards

Project Background: Gallium oxide (Ga_2O_3) has attracted massive interest in 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 dopants 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 high power UV lamps and cathodoluminescence (CL) in a scanning electron microscope for optical emission. The absorption properties will be investigated by photoluminescence excitation (PLE). Temperature-dependent (20 – 300 K) PL and PLE will also be performed for a detailed understanding of defect-related transitions.

Aim: Study the optical and electrical properties of gallium oxide semiconductors for electronic device reliability.

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 bene

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:

Title: Electron microscope analysis of semiconductor alloys

Project ID: PE1

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

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:

Title: 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

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 bene

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:

Title: Computational Methods in Single-Molecule Localization Microscopy

Project ID: SvL1

Primary Supervisor: Sebastian van de Linde **Email:** s.vandelinde@strath...

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):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Evaluating Spot-Finding Methods

Project ID: SvL2

Primary Supervisor: Sebastian van de Linde **Email:** s.vandelinde@strath...

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 st

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):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Optical properties of metal-dielectric nanocomposites

Project ID: YC1

Primary Supervisor: Yu Chen **Email:** y.chenl@strath.ac.uk

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): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Title: Plasmon enhanced fluorescence

Project ID: YC2

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

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): None

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Institute of Photonics

Title: Photonic neurons with lasers for ultrafast brain-inspired computing (I & II)

Project ID: AH1

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

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 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

Semester 1 Tasks: Background of the project, literature review, simulate the dynamics of VCSELs using Matlab and reproduce recent experimental/numerical result obtained by our group.

Semester 2 Tasks: Expand the simulation work to simulate the operation of VCSEL-based photonic neurons in spike processing tasks. 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: 80% **Comp:** 20% **Exp:** 0%

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

Safety Training (if applicable):

Suitable for: Mphys

Misc:

Title: 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

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 (nano-)optoelectronic spiking neuronal models for novel brain-inspired computing systems for future photonic neuronal network implementations for Artificial Intelligence.

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

Semester 1 Tasks: Background of the project, literature review, simulate the dynamics of RTDs using Matlab and reproduce recent results obtained by our group.

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 neuro

Key references:
[1] To be included
[2] To be included
[3]

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

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

Safety Training (if applicable):

Suitable for: Mphys

Misc:

Title: Use of ABCD matrices to design laser resonators

Project ID: AJK1

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

Secondary Supervisors: Jennifer Hastie (TBC)

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.

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 task

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.

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 parameters

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): No special training required

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

Misc:

Title: Laser specification and design for undersea LIDAR

Project ID: AJK2

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

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.

Semester 1 Tasks: This project would involve first collating the laser requirements for potential undersea lidar applications, 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,

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] O. Svelto, Principles of Lasers. New York: Plenum Press, 1998.

Theory: 50% **Comp:** 50% **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.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching. May best suit an MPhys student.

Misc:

Title: Digital modulation of light-emitting diodes

Project ID: JH2

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

Secondary Supervisors: tbc

Project Background: The emergence of light-emitting diode (LED) based energy-efficient lighting has triggered significant developments of so-called lighting-as-a-service (LAAS), where the light emitted by the LEDs is modulated with a digital signal to provide services such as indoors navigation or wireless network access through the lightbulb. These schemes need to comply with eye-safety standards, including minimisation of visual flicker. Visual flicker is normally assessed on the basis of sinusoidal or square-wave modulation. However, there is preliminary evidence that the visual flicker recognition of more complex modulation signals used for LAAS cannot be fully understood by simple comparison with the existing standards. To investigate this matter further, an experimental setup needs to be designed, including a suitable computer-controlled LED driver.

Aim: To develop a Matlab or Python based driver software for a digitally modulated light emitting diode that can be used in a user study that investigates visual flicker perception.

Semester 1 Tasks: Familiarisation with pre-existing Arduino-based LED driver and corresponding electronic and digital interfaces. Understand the structure of the digital modulation codes to be investigated, both in time and in frequency space. Familiarisation with the envisaged experimental setup.

Semester 2 Tasks: Development of a software tool in either Matlab or Python to operate the experimental setup. The software tool will contian at least one module to generate modulation sequences of interest, and one module to modulate an LED in the setup with these sequenc

Key references:
[1] Herrnsdorf et al., Positioning and Space-Division Multiple Access Enabled by Structured Illumination With Light-Emitting Diodes, J. Lightwave Technol. 35, 2339 (2017), https://doi.org/10.1109/JLT.2017.2672864
[2] Davis, Hsieh, Lee, Humans perceive flicker artifacts at 500 Hz, Sci. Rep. 5, 7861 (2015), https://doi.org/10.1038/srep07861
[3]

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

Recommended Background: Knowledge of either Matlab or Python. Additional knowledge in C will be benefitial.

Safety Training (if applicable): NA

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

Misc:

Title: Python model of single-photon technologies

Project ID: JH1

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

Secondary Supervisors: Navid Bani Hassan

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 (

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:

Title: TBA

Project ID: LC1

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

Secondary Supervisors:

Project Background:

Aim:

Semester 1 Tasks:

Semester 2 Tasks:

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

Theory: **Comp:** **Exp:**

Recommended Background:

Safety Training (if applicable):

Suitable for:

Misc:

Title: TBA

Project ID: LC2

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

Secondary Supervisors:

Project Background:

Aim:

Semester 1 Tasks:

Semester 2 Tasks:

Key references:

[1]
[2]
[3]

Theory: **Comp:** **Exp:**

Recommended Background:

Safety Training (if applicable):

Suitable for:

Misc:

Title: Photon pair generation in integrated ring resonator devices

Project ID: MS1

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

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 de

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): NA

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

Misc:

Title: 3D imaging using time of flight and photometric stereo techniques

Project ID: MS2

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

Secondary Supervisors: Graeme Johnstone

Project Background: There are a number of techniques currently used to generate 3D image information, including time of flight ranging, stereo vision capture and laser scanning reflectometry. In this project the student will work on a hybrid method that produces high resolution images using inputs from two complementary methods: time of flight and photometric stereo imaging. A major issue in 3D imaging of a scene is the effect of shadowing in the image reconstruction. The student will investigate methods by which this effect can be minimised to produce high resolution 3D images.

Aim: To use numerical rendering software to simulate complex lighting environments for 3D image reconstruction

Semester 1 Tasks: A review of current state-of-the-art fused imaging systems will be studied and key trade offs in realistic system designs identified. The student will become familiar with 3D image rendering software in order to generate a bank of test images, equivalent to experimental data.

Semester 2 Tasks: A range of images will be created using the rendering software, varying lighting conditions, vector illumination directions and camera capture conditions in order to create a data set to input into the 3D reconstruction methods. Shadowing effects will be

Key references:

[1] Griffiths, A. D. et al. Multispectral time-of-flight imaging using light-emitting diodes. Opt. Express 27, 35485–35498 (2019).

[2] Herrnsdorf, J., Broadbent, L., Wright, G. C., Dawson, M. D. & Strain, M. J. Video-rate photometric stereo-imaging with general lighting luminaires. in 30th Annual Conference of the IEEE Photonics Society, IPC 2017 vols 2017-Janua (2017).

[3]

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

Recommended Background: Previous experience with Blender will be useful but not essential.

Safety Training (if applicable): NA

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

Misc:

Index of Projects