Photo: Alan Segar

Trinity Term - 2016

Physics

MPhys Projects Trinity Term

2016

Contents

Contents Cont'd

Contents Cont'd

Foreword

The MPhys project, as a major part of the MPhys course has often been considered the most enjoyable part of the course. From the comments made by students over several years, many students get a real buzz from a good project. Read this booklet carefully to find out which projects are available and what you have to do.

You will start your Major Option Classes and your MPhys project Michaelmas Term 2016. You may be given some reading or work to do over the long vacation, and you will therefore be a little better informed and prepared. The project may be your first insight into life in a physics research group and be a chance to see developments at the cutting edge of the subject. It is also a first look at problems whose solution may well be unknown, to both you and your supervisor.

To get the most out of your project you must choose carefully and prepare well. Contact potential project supervisor early and please complete the project choice form (see **Appendix A**) by the end of 6th week.

Please do contact me or the Assistant Head of Teaching (Academic) if you have any questions.

Prof. Jonathan Jones, Head of the Physics Teaching Faculty

The information in this handbook is accurate as at 15 April 2016, however there may be changes, in particular to the projects listed.

Choosing your MPhys project

How to go about choosing a project

Around two thirds of the 4th year students may expect to be allocated one of their choices of project. For the remaining third we try to allocate a project in a similar area of interest and also taking the students choice of Major Options into account. Some projects are more popular than others, for instance projects relating to Biophysics, therefore you are advised to select carefully your lower choices. Perhaps there is a project that you would like to do, but this is not listed in the handbook, in which case you may approach potential supervisors with your ideas.

Please inform the Assistant Head of Teaching (Academic) of the topic, the title and the supervisor, if you have made your own arrangements. You are also encouraged to write a short statement on the back of the choice form if you have any particular strengths or experience relating to your choices, or if you are choosing a project with your future career in mind.

Although every effort is made to include all possible information about and on the MPhys projects offered, new projects may become available after the publication of the *MPhys Projects Trinity Term 2016*, and infrequently a project may have to be withdrawn. All changes will be communicated by e-mail.

Project allocation

Projects are allocated by the Assistant Head of Teaching (Academic) using the student's choices on the *Project Allocation: CHOICE FORM,* see **Appendix A**.

For the allocation exercise, the student name and college are hidden to prevent any bias. All the project choice forms are entered into an access database. All eight choices are listed in order of preference and additional comments are recorded.

For very popular choices we use the following procedure:

(i) Supervisors are consulted as they may be contacted by prospective students about the projects they are offering, although this is not essential for the allocation of the project. Supervisors' input is essential in trying to match projects to students;

(ii) The outcome of the third year, Part B, ranking will also be used to assign students to projects;

(iii) Should it still prove difficult to assign the project, each student who wishes to be allocated the specific project is assigned a number and then the winner is drawn from a hat;

(iv) The PJCC (Physics Undergraduate Consultative Committee) is also consulted on an annual basis about the process. If you are not happy with the MPhys project you have been allocated, you are encouraged to discuss other possibilities with the Assistant Head of Teaching (Academic).

Project risk assessment

Assessing risks is an essential element of training for project work. It is good practice for students and supervisors to complete the risk assessment associated with the project before starting. Please see http://www2.physics.ox.ac.uk/study-here/mphys-and-ba-project-information.

Project assessment

A Project Assessment Committee is set up every year to assess all the MPhys projects. The assessors are appointed by the relevant physics sub-Departments, the Physics Department or less frequently from another department of the University. The assessors on this committee are usually not Physics Finals examiners, but they may serve in this capacity.

The **expert (junior)** assessor will generally come from the sub-department to which the project is assigned and they will have more specialist knowledge in the field of the project, or one closely related. The **non-expert (senior)** assessor will generally work in a different area of physics from the subject of the report and will mark reports chosen from other physics sub-Departments. Each written MPhys report will be assessed by a junior and a senior assessor.

Each MPhys candidate will be expected to attend a meeting ('viva') with the two assessors of their project to discuss the written report. The purpose of this meeting is to help the assessors with assessing the candidates written report. Crucially the meeting helps clarify any issues that the assessors have after having read the written report. The assessors will read the supervisor's report on the project to learn what special difficulties were encountered, the extent of the initiative shown by the candidates, and so on.

The meeting will last about 20 minutes and will be rather informal. It will not require the preparation of a special presentation; indeed no visual aids other than your report (and your log book, if appropriate) will be allowed. The candidate will be expected to start the meeting by giving a short summary of the project, typically not lasting more than a few minutes, followed by a question and answer period.

The meetings with the candidates have been provisionally scheduled for Monday and Tuesday of 5th week in Trinity Term. The precise criteria for the overall assessment of the project will finalised by the examiners. How the final project mark is calculated will be published in the Examination conventions produced by the examiners. The overall assessment embraces the quality both of the underlying scientific work and the presentation in the report.

The *MPhys Project Assessment form* will be published on the Examination Matters webpage http://www.physics.ox.ac.uk/teach/exammatters before the end of Hilary Term.

Examination Conventions

The Examiners are responsible for the detailed weightings of papers and projects. The precise details of how the final mark is calculated is published on the Examination matters webpage at www.physics.ox.ac.uk/teach/exammatters.htm. Students are notified by e-mail when they become available.

Weightings for the MPhys and Papers

The precise details of how the final mark is calculated is published in the *Examination Conventions* on the Examination matters webpage at www.physics.ox.ac.uk/teach/exammatters.htm.

Project Outcomes

The outcomes of projects are very flexible and the results may not be precisely as described by the project description in this handbook. Remember that they are intended as an introduction to research and the unexpected often happens!

According to the QAA benchmark statements for physics 'Open-ended project work should be used to facilitate the development of students' skills in research and planning (by use of data bases and published literature) and their ability to assess critically the link between theoretical results and experimental observation' ref.: Quality Assurance Agency for Higher Education, subject benchmark: Physics, astronomy and astrophysics 2008.

Project prizes

There are a number of prizes which may be awarded for excellence in various aspects of the MPhys projects including but not limited to the list below:

(a) The Winton Capital Prize for Best MPhys Research Project.

(b)The Gibbs Prize for the best use of experimental apparatus in an MPhys project.

(c) A Physics Prize for an MPhys project in Atomic and Lasers Physics.

(d)The BP Prize for an MPhys project in Theoretical Physics Project.

(e) The Johnson Memorial Prize for an MPhys in Astrophysics.

(f) The Johnson Memorial Prize for an MPhys in Atmospheric, Oceanic and Planetary Physics.

(g) The Met Office Prize for a Project in Atmospheric, Oceanic and Planetary Physics.

(h) A Physics Prize for an MPhys Project in Condensed Matter Physics.

(i) The John Thresher Prize for an MPhys Project in Particle and Nuclear Physics.

(j) The Metaswitch Prize for the best use of software in an MPhys Project.

(k) The Rolls-Royce Prize for Innovation in an MPhys Project.

(l) The Tessella Prize for Programming in Software in an MPhys Project.

Timetable for students

Trinity Term 2016

Week 0 Publication of the *MPhys Projects Trinity Term 2016* **http://www.physics.ox.ac.uk/teach**

Before deciding on a project students are encouraged to discuss any projects, in which they are interested, with supervisors, but there is no obligation to do so and allocation of projects does not depend on doing this**.**

Week 6 (Fri 3 pm) Complete the *Project Choice Form* **Physics Teaching Faculty**
[Hand in the *Project Choice Form* by internal post or by e-mail]

July -August **Provisional Allocation of Projects**
Third year results published and provisional allocations made
Majority of MPhys Project allocations made

September **Publication of the Project Allocation List** http://www.physics.ox.ac.uk/teach
Students read the introductory papers on their project

Michaelmas Term 2016

Week 0 (Mon) Publication of the *MPhys Projects Handbook* **http://www2.physics.ox.ac.uk/students/undergraduates**
[e-mail notification] Talk to your college tutor about the project you have been allocated.

Weeks 1 & 2 **Compulsory Safety Lecture and Risk Assessments** **Consult lecture list**
Completion and submission of your *Risk Assessment Acknowledgement* form. Compulsory attendance of the safety lecture. You will **NOT** be allowed to start your project if you have not completed and submitted your *Risk Assessment Acknowledgement* form to the **Physics Teaching Faculty**. Students meet supervisors to get instructions including alternate arrangements if the supervisor has to leave Oxford during the project period.

Week 3 Project period starts. Please note: the total effort devoted to the project should be equivalent to 20 working days full time activity, plus about six weeks for analysis, write up and literature review during Michaelmas and Hilary terms. Students should discuss with the supervisor(s) a project plan to accommodate both their project and Major Option Classes

Students need to understand that outcomes of projects are uncertain and the project may change from the description originally provided. Projects are an introduction to research and are not necessarily predictable.

Weeks 7 Discuss plan of project report with supervisor(s). Students must prepare a short progress report (one side of an A4 sheet of paper) outlining plan for the project and/or literature review. This must be handed into the **Physics Teaching Faculty.** This progress report is for your College tutors.

Hilary Term 2017

Weeks 1 - 8 MPhys project period continues

Week 2* 'How to write an MPhys Project Report' lecture **Please consult the lecture list for details**

Week 3 or 4 Talk to your college tutor about the progress of your project.

Week 9 Hand in a draft (as complete as possible) of MPhys report to your supervisor. You and your supervisor must complete and sign the *MPhys Draft Form* (see **Appendix A**).

Week 10 Deadline for receiving comments from supervisor.

The schedule for handing in the draft report and receiving comments can be changed by mutual agreement. Please let Carrie Leonard-McIntyre know of changes of more than one week.

Trinity Term 2017

Week 1 (Mon 12 noon) MPhys project reports handed in. **Examination Schools**
Three copies of project or essay & the Declaration of Authorship & a copy of the report in pdf format on a CD or a memory stick(which is not returned).

***subject to change, see lecture list**

Timetable for supervisors

Hilary Term 2016

Week 1-8 Call for MPhys Projects starting in Michaelmas Term 2016 starts. **E-mail**

Trinity Term 2016

Week 0 Publication of the *MPhys Projects Trinity Term 2016*
http://www2.physics.ox.ac.uk/students/undergraduates

Students may contact you to learn more about your projects. They are not obliged to do this and the allocation of projects is not in any way dependent on them doing so.

July -August **Provisional Allocation of Projects**
Third year results published and provisional allocations made.

September **Publication of the Project Allocation List** **http://www2.physics.ox.ac.uk/students/undergraduates**
Students read the introductory papers on their project

Michaelmas Term 2016

Weeks 1 & 2 **Compulsory Safety Lecture and Risk Assessments** **Consult lecture list**
Completion and submission of your *Risk Assessment Acknowledgement* form. Compulsory attendance of the safety lecture.
Students will **NOT** be allowed to start their projects if they have not completed and submitted their *Risk Assessment Acknowledgement* form to the **Physics Teaching Faculty**. Students meet supervisors to get instructions including alternate arrangements if the supervisor has to leave Oxford during the project period.

Week 3 Project period starts. **Please note:** the total effort devoted to the project should be equivalent to 20 working days full time activity during Michaelmas and Hilary terms. [Guidance: the total effort devoted to the project should be equivalent to 20 working days full time activity, plus about six weeks for analysis, write up and literature review during Michaelmas and Hilary terms.] You must discuss with the student(s) the project plan to accommodate both their project and Major Option Classes.

Weeks 7 Discuss plan of project report with your supervisor(s). Student to have prepared a short progress report (one side of an A4 sheet of paper outlining plan for the project and/or literature review

Students need to understand that outcomes of projects are flexible and the project may change from the description originally provided. Projects are not necessarily predictable and can be an introduction to research.

Hilary Term 2017

Weeks 1 - 8 MPhys project period: during this period all of the experimental and theoretical work necessary for the project should be completed. You should meet the student regularly and leave your contact details for the student to contact you should the need arise. You should encourage the student to begin the project write-up as early as possible.

Week 9 Full as possible draft of the MPhys report handed in by student to you and *MPhys Draft Form* (see Appendix A). The completion of the *MPhys Draft Form* confirms that the draft report has been seen and the form must be sent to **Physics Teaching Faculty**, signed by both student and supervisor. Please notify the Physics Teaching Faculty of any delay in returning the completed form.

Week 10 Comments by supervisor on draft report is given to the student.

The schedule for handing in the draft report and receiving comments can be changed by mutual agreement. Please let Carrie Leonard-McIntyre know of changes of more than one week.

Trinity Term 2017

Week 1 MPhys Student hands in copies of the final report to Examination Schools.
Deadline for return of Supervisor's Report Form.

MPhys project descriptions

Atomic and Laser projects

A&L01 Understanding ultra-fast plasma dynamics using a free-electron laser

Free-electron lasers (FELs) are a new paradigm in creating bright pulses of XUV and X-ray light. In a series of experiments at the FLASH FEL in Hamburg (http://flash.desy.de) and the LCLS FEL in California (http://lcls.slac.stanford.edu) our group has shown how a focused beam from an FEL can create dense plasmas on femtosecond time scales (1e-15 s) in conditions relevant to the laboratory study of planetary and stellar interiors, as well as to inertial fusion applications.

In a recent experiment at the FLASH FEL we split a 13nm XUV pulse of light in two, using the first sub-pulse to create a dense plasma from thin foil, and the second to probe its properties taking a series of snapshots at varying time delay. This series of pictures forms a movie of the evolution of the plasma opacity with femtosecond time resolution.

The student will use the raw data taken in the experiment and analyse it to form a coherent picture of how the radiative properties evolve as the systems undergoes the solid-to-plasma transition. This work will be complemented with theoretical calculations to see if the observed behaviour agrees with predictions from models currently used in the study of laser-plasma interactions and astrophysics.

Reading: S.M. Vinko, Journal of Plasma Physics 81 365810501 (2015)

Supervisor: ***Dr S M Vinko***
Email: ***Sam.Vinko@physics.ox.ac.uk***

A&L02 QED with high power lasers

With the advent of high power laser facilities, it is now possible to reach regimes where the electron at the laser focus experiences enormous accelerations – comparable only to those found near the event horizon of black holes. This results in a wealth of exotic processes that may be observable in current or proposed laboratory experiments. This project will focus in defining the experimental platform and perform estimates for the detection of QED processes occurring at the laser focus of these powerful lasers.

For further details contact the supervisor (Prof G Gregori)

Supervisor: ***Prof G Gregori***
Email: ***Gianluca.Gregori@physics.ox.ac.uk***

A&L03 Kondo effect in a finite lattice

In this project, the student will analyze the quantum dynamics of particles in a finite lattice subject to collisions with a localized impurity; this is a minimal model of physical systems such as conduction electrons in quantum dots with magnetic impurities. To this end, the student will solve the Schrödinger equation to determine the eigenstates of the system, as well as study the time-dependent evolution in a variety of non-equilibrium initial conditions. The goal of the project is to understand how the presence of the impurity affects the transport properties of the lattice and, in particular, the existence of bound states in the continuum or their conversion into Fano resonances.

The student is *not* expected to know in advance what the Kondo effect, Fano resonances, or bound states in the continuum are.

Previous knowledge or skills required:

The project will involve the use and development of Matlab computer code. Previous Matlab knowledge will thus be desirable though not a pre-requisite.

Supervisor: ***Dr J Mur-Petit***
Email: ***jordi.murpetit@physics.ox.ac.uk***

A&L04 Development and application of machine learning techniques to unveiling the non-linear dynamics of laser-fusion plasmas

Extreme states of plasmas are created when intense laser pulses are shone onto matter. Controlling these plasmas, having temperatures >10,000,000 C and pressures > billion atmospheres, opens the way to new cancer therapies, possible fusion energy sources, as well as many studies of fundamental high field physics. In this project, we will advance the state of the art by developing and applying machine learning (ML) techniques to data from advanced kinetic simulations. We will begin by analysing the dynamical trajectories undertaken by particles under these extreme conditions, using supervised and unsupervised ML techniques to classify and cluster like trajectories and identify topical mechanisms of particle acceleration.

Supervisor: ***Prof P Norreys***
Email: ***Peter.Norreys@physics.ox.ac.uk***

A&L05 How big is a petawatt laser-accelerated "hot" electron?

Petawatt (1015 W) lasers are the most powerful light sources on earth, and as a consequence of their illumination of dense matter, copious numbers of electrons are accelerated to near the speed of light. All applications of petawatt laser technology, including inertial confinement fusion energy sources and medical ion beam sources, make use of these "hot" electrons in one manner or another. In spite of this fact, the precise number of hot electrons accelerated by the laser is unknown, mainly due to the nonlinear conditions of the interaction. In this project, we will apply recent analytical advances to derive the cross section for hot electron acceleration in topical situations, to be informed and validated using advanced kinetic simulation codes.

Supervisor: ***Prof P Norreys***
Email: ***Peter.Norreys@physics.ox.ac.uk***

A&L06 Dipolar Rydberg lattices

Arrays of cold trapped Rydberg atoms provide a controllable, clean and versatile realisation of a many-body quantum system with long range dipolar interactions. These lattices can mimic idealised solid state systems and are thus a candidate platform for implementing quantum simulators.

In this project the student will study the physics of a lattice of Rydberg atoms excited to *ns* and *np* states which interact via the dipole-dipole interaction. The research will focus on the case of few *np* excitations with asymmetric level shifts hopping through the lattice. The main aim is to determine whether and how this setup enables the creation of artificial gauge fields affecting the dynamics of these excitations.

The project requires a combination of analytical and numerical techniques. The numerical calculations will be carried out using either Mathematica or MATLAB. The student should have excellent grounding in quantum mechanics and a keen interest in theoretical aspects of physics.

Reading:

To become familiar with several of the theoretical techniques in treating Rydberg atoms and their interactions the following may help*:

a. T. F. Gallagher, Rydberg Atoms (Cambridge University Press 1994).

b. A. R. Edmonds, Angular Momentum in Quantum Mechanics (Princeton University Press 1957).

For an introduction to artificial Gauge fields and excitons on a lattice please see*:

c. D. Jaksch and P. Zoller, New J. Phys. 5, 56 (2003).

d. Chapter I in D. Xiao et al., Rev. Mod. Phys. 82, 1959 (2010).

e. H. Zoubi and G. C. La Rocca, Phys. Rev. B 72, 125306 (2005). f. A. V. Gorshkov et al., Phys. Rev. A 84, 033619 (2011).

To gain familiarity with the experimental aspects, including how and what types of cold atom systems/Hamiltonians can be created and what can be measured, see: g. K. Jiminez-Garcia et al., Phys. Rev. Lett. 108, 225303 (2012).

h. J. Struck et al., Phys. Rev. Lett. 108, 225304 (2012).

i. M. Aidelsburger et al., Phys. Rev. Lett. 107, 255301 (2011).

Papers on recent and related research about Rydberg atoms can be found in: j. M. Kiffner, W. Li, and D. Jaksch, Phys. Rev. Lett. 110, 170402 (2013).

k. P. Schauss et al., Nature 491, 87 (2012).

l. D. Barredo et al., Phys. Rev. Lett. 114, 113002 (2015).

Supervisors: ***Dr M Kiffner, Prof D Jaksch, Dr S Al-Assam*** and ***Dr J J Mendoza-Arenas***
Email: ***Martin.Kiffner@physics.ox.ac.uk***

A&L07 Guiding of relativistic intense laser pulses in plasma for fusion energy

Remarkable progress towards the realisation of controlled fusion energy has been made recently using the National Ignition Facility in the United States [H.S. Park et al., Phys. Rev. Lett. 112, 055001, (2014); O. Hurricane et al., Nature (London) 506, 343 (2014)]. There physicists have used exquisite control of the laser pulse drive shape to drive an appropriately shaped black-body radiation drive to both compress and heat isotopes of hydrogen to fusion conditions. These papers show that dramatic progress is being made in understanding the underlying physics, but obstacles still remain. My team have looked recently at supplementing the deposited energy in the hot-spot surrounding the compressed fusion fuel by precision stopping of relativistic electron beams generated by petawatt laser pulses. The concept looks very promising and we have proposed a "proof-of-concept" experiment using the ORION laser facility to make the first demonstration in the laboratory. The student will help in the design of this experiment by undertaking a computational and theoretical study to determine the best position for focusing these petawatt laser pulses in the coronal atmosphere. The idea is to prevent beam filamentation and allow whole-beam self-focusing to occur and direct most of the accelerated energy into the hot spot.

Supervisor: ***Prof P Norreys***
Email: ***Peter.Norreys@physics.ox.ac.uk***

A&L08 Photon acceleration in beam-driven wakefield accelerators

The AWAKE project at CERN is starting in 2016 and uses the Super Proton Synchrotron beam (450 GeV energy) to drive a large amplitude plasma wakefield accelerating structure over 10 m distance. The aim of the project is to find a new route to a TeV e-e+ collider, making use of existing infrastructure in the Large Hadron Collider. A method to diagnose the formation of wakefields there is to use the concept of photon acceleration, which occurs when a co-propagating laser probe pulse experiences changes in the refractive index of the plasma. This project is to develop further the photon acceleration diagnostic with oblique angles of incidence, instead of co-propagation. In this case, there is a lower bound for the crossing angle. If the angle is less than this limit, the interaction distance will be longer than the Rayleigh length of the modulated part of the probe pulse. This means that it has already started to expand while interacting with the wakefield. That causes the measurement to read lower values than it should. The objective is to find the analytical expression relating plasma wakefield density and the frequency modulation of the laser pulse for this case. The student will also need to check the expression by doing 2D particle-in-cell simulations of high performance computing platforms.

Supervisor: ***Prof P Norreys***
Email: ***Peter.Norreys@physics.ox.ac.uk***

A&L09 Amplification of extreme laser pulses in plasma by parametric scattering

One limitation for practical applications of intense laser pulses is the requirement for very large optics to operate within known damage limits. One possible route to overcoming these obstacles is to use parametric amplification in plasma. The use two counter-propagating intense laser pulses promises a revolution in energy and peak power delivery. My team is working closely with colleagues at America's leading optics laboratory, the Laboratory for Laser Energetics at the University of Rochester, New York, to design the first large-scale demonstration of this concept. The student will use sophisticated computer simulations to help in the design of the seed laser pulse to optimise its fidelity during amplification and also with subsequent data analysis.

Supervisor: ***Prof P Norreys***
Email: ***Peter.Norreys@physics.ox.ac.uk***

A&L10 Experimental Quantum Computing in Ion Traps

This will be a lab-based project contributing to apparatus development for experiments in trapped-ion quauntum computing. The specific work will depend on the status of our research at the time. Please contact Dr D.Lucas d.lucas@physics.ox.ac.uk for more info about details of the project, and see www.physics.ox.ac.uk/users/iontrap for background information about the research group.

Supervisor: ***Dr D Lucas***
Email: ***david.lucas@physics.ox.ac.uk***

A&L11 Storage time extension of quantum optical memories for global synchronized networking

Large-scale quantum photonic networks promise to revolutionize computational processing and communication with the use of fundamental quantum-mechanical concepts. Limited by scalability, the field of quantum information processing is so far lacking a real world, large-scale implementation that can allow for quantum computation and long distance quantum communication. These applications have distinct advantages over their classical counterparts: quantum computation promises to provide unprecedented speed-up in processing for problems that are intractable for classical computers, while remote entanglement generation and swapping would allow long distance quantum networking. Integral to a functioning quantum network is a quantum optical memory, a device allowing for the faithful storage and recall of quantum states of light using a strong and controllable light-matter interaction.

An attractive candidate for a quantum memory for light is the Raman protocol in warm atomic vapour which offers a platform for efficient, noise free and broadband operation within a scalable architecture. The working principle is that a quantum input signal (such as a single photon) is mapped to a coherence within the ground states of caesium via a strong control pulse inducing a two-photon Raman absorption process. The resulting coherence, referred to as a spin-wave, is then read-out with another control pulse at a later time, mapping back the atomic excitation to a photonic field, completing the memory operation. However, the characteristic storage time of the spin-wave is limited by both atomic diffusion of the caesium and noisy magnetic fields inducing decoherence on the ground state energy splitting. These phenomena limit the quantum memory lifetime to the microsecond regime thereby limiting the size of the quantum network.

This experimental MPhys project will aim to extend the storage time of room temperature Raman quantum memories beyond the microsecond regime by characterizing and solving the issues of diffusion and magnetic fields. The results of this project will drive the design of next generation quantum memory architecture for long distance quantum networking technologies. The student will become familiar with Raman light-matter interactions, atomic diffusion physics, passive and active magnetic shielding as well as modelling of these phenomena and data analysis.

Supervisors: ***Dr P Ledingham*** and ***Prof I Walmsley***
Email: ***patrick.ledingham@physics.ox.ac.uk, Ian.Walmsley@physics.ox.ac.uk***

A&L12 Complex temporal shaping and characterization of laser pulses for quantum memories

Quantum memories have been identified as enabling technology for scalable quantum information networks. However, this requires high efficiency memories with a large time-bandwidth product. Our approach to realizing such a quantum memory is based on Raman transitions in warm Caesium vapour, which offer a large bandwidth and reasonable storage times. In this realization, the memory interaction is mediated by a bright control pulse with several nanoseconds duration, which allows for simple and reliable synchronization of the memory to an external clock. On the downside, the control pulse induces an AC Stark shift in the Caesium, which leads to time-varying atomic resonance frequencies. One way to overcome this is to deploy tailored control pulses with a time-varying instantaneous frequency, which negates the detrimental effects of the AC Stark shift.

Typically, complex shaping of pulses—that is controlling both their amplitude and phase—is realized in the spectral domain, and their generation and characterization has been a long lasting research field in our group. In the case of the memory, the pulses have durations of several nanoseconds, which leave their spectra too narrow to utilize spectral techniques. Consequently, the spectral shaping and characterization techniques have to be transferred to the time domain.

This master's project will optimize the shaping and characterization of nanosecond laser pulses, which will be used in a quantum memory experiment. The pulse shaping is realized with a fast, phase-sensitive electro-optic modulator, driven by an arbitrary waveform generator. The characterization will utilize the MICE algorithm, developed in our group, to analyse time traces of a fast photo detector (~10GHz bandwidth). Work on this project is focussed on experimental work in a quantum optics laboratory, but also includes the theoretical modelling of Raman interaction and temporal pulse shaping, as well as the numerical analysis of measurements.

Supervisors: ***Dr B Brecht*** and ***Prof I Walmsley***
Email: ***benjamin.brecht@physics.ox.ac.uk, Ian.Walmsley@physics.ox.ac.uk***

A&L13 Cavity Quantum Optomechanics

Cavity quantum optomechanics is one of the newest and fastest growing areas of quantum science internationally. Central to optomechanics is radiation pressure – the force exerted by the reflection of light – which is used to control the motion of micro- and nano-scale mechanical resonators at a quantum level. This avenue of quantum optics provides a route to generate quantum states of motion of mechanical resonators comprising billions of atoms and thus test quantum mechanics at a macroscopic scale. This MPhys project will theoretically develop new techniques for macroscopic quantum state preparation, state characterisation, and even explore the potential to test quantum gravity. Students should be passionate about theoretical quantum optics and be desiring to continue their studies with a DPhil. For more information please contact Dr Michael Vanner

Supervisor***: Dr M Vanner***
Email***: michael.vanner@physics.ox.ac.uk***

A&L14 Quantum-enhanced microscopy

One of the most exciting new frontiers in the application of quantum physics is biological sensing and imaging. Biological samples are often fragile and highly photosensitive, with optical damage proving the limiting factor in many biophysical experiments. Quantum physics allows us to circumvent the sensitivity limitations which these constraints impose, using the intrinsic sensitivity of quantum systems to probe physical parameters at resolutions beyond those accessible with classical systems (quantum metrology). This project will focus on construction of a quantum-enhanced microscope, utilising entangled light in a pump-probe based microscopy system. The project is predominantly experimental, and prior experience in experimental optics and laser systems will be valuable, but not required. Experience in programming languages, including Matlab and/or Labview, would also be helpful for analysing data and creating user interfaces, however are not crucial.

Supervisors: ***Dr H Chrzanowski*** and ***Prof I Walmsley***
Email: ***helen.chrzanowski@physics.ox.ac.uk, Ian.Walmsley@physics.ox.ac.uk***

A&L15 Role of Generalized Pauli Constraints in time evolutions

A recent breakthrough in quantum information theory has shown that fermionic occupation numbers do not only obey Pauli's exclusion principle but are even further restricted by so-called generalized Pauli constraints (GPC) [1]. Various recent studies of concrete systems have confirmed the physical relevance of the GPC for ground states (see e.g. [2,3]): The corresponding occupation numbers were found to (approximately) saturate some GPC. This so-called pinning effect leads to a variety of remarkable implications. One of them is that quantum systems with pinned occupation numbers may have a restricted time evolution [4]. This generalizes the well-known consequence of the exclusion principle, namely that electrons in atoms or solid materials cannot fall down to lower lying occupied energy shells. In this project, time evolutions for two systems (a harmonic toy model and the few site Hubbard model) should be analytically discussed and the role of the GPC therein should be explored. For instance, can a transition from pinning to non-pinning be induced in the Hubbard model by an external magnetic field? In the ideal case, also a concrete experiment should be suggested allowing to measure the pinning effect and thus experimentally verify the GPC.

[1] M.Altunbulak, A.Klyachko, Commun. Math. Phys. 282, 287 (2008)

[2] C.Schilling, D.Gross, M.Christandl, Phys. Rev. Lett. 110, 040404 (2013)

[3] F.Tennie, D.Ebler, V.Vedral, C.Schilling, arXiv:1602.05198 (2016)

[4] C.Schilling, Phys. Rev. B 92, 155149 (2015)

Requirements: Strong analytical background, basic knowledge of harmonic oscillator states and of the second quantization

Supervisors: ***Dr C Schilling*** and ***Prof V Vedral***
Email: ***Christian.Schilling@physics.ox.ac.uk, vlatko.vedral@qubit.org***

A&L16 Ptychographic imaging with a visible laser

X-ray microscopy provides offers the potential for near atomic scale resolution and the ability to perform element-specific imaging. However, the poor quality of X-ray optics mean that conventional microscopy techniques are not possible in this region. Instead, a new class of "lensless" imaging techniques has been developed [1].

Ptychography [2] is one such technique. In this method a series of diffraction patterns produced by illuminating localized, overlapping regions of the object are recorded. From these data it is possible to deduce the amplitude and phase of the optical field transmitted by the object, i.e. the image of the object can be retrieved without the use of an imaging system.

In this project this technique will be demonstrated by imaging microscopic objects with a visible laser. The student will be required to develop control software for automating the ptochographic scans and to analyze data with the e-PIE software code.

If time permits enhancements to the basic approach will be explored, such as compensating for instabilities in the illuminating beam. It may also be possible to compare ptychography with coherent diffraction imaging, in which a single diffraction pattern from the entire object is recorded; in this case the object is reconstructed iteratively using a phase-retrieval algorithm.

The project would ideally be suited to a student with an interest in both experimental and computational physics.

Further reading

[1] H. N. Chapman & K. A. Nugent, "Coherent lensless X-ray imaging," Nature Photonics, 4, 833–839. (2010). DOI: http://dx.doi.org/ 10.1038/nphoton.2010.240

[2] J. M. Rodenburg, "Ptychography and Related Diffractive Imaging Methods," Advances in Electron and Imaging Physics 150. 87 – 184 (2008). DOI: http://dx.doi.org/10.1016/S1076-5670(07)00003-1

Supervisor: ***Prof S Hooker***
Email : ***Simon.Hooker@physics.ox.ac.uk***

A&L17 Implementation and Characterisation of an External Cavity Diode Laser

This project is focussing on the assembly and operation of a grating-stabilized diode laser system in the Littrow configuration, and the subsequent characterisation of this system using Fabry-Perot interferometers and absorption spectroscopy in Rubidium vapour.

Supervisor***: Dr A Kuhn***
Email***: axel.kuhn@physics.ox.ac.uk***

A&L18 Difference-frequency locking of a pair of diode lasers

The beat note between two independent lasers will be used to detect and monitor their difference frequency, and to lock it to an ultra-stable radio-frequency reference. The locking circuitry is primarily based on radio-frequency electronics. Once the lasers are locked, these will be used for driving Raman transitions in Rubidium.

Supervisor***: Dr A Kuhn***
Email***: axel.kuhn@physics.ox.ac.uk***

A&L19 Electrostatic trapping and manipulation of non-spherical particle

More details from the supervisor.

Supervisor : ***Prof C Foot***
Email : ***Christopher.Foot@physics.ox.ac.uk***

A&L20 Precise shaping of laser beams for trapping ultracold atoms

More details from the supervisor.

Supervisor : ***Prof C Foot***
Email : ***Christopher.Foot@physics.ox.ac.uk***

A&L21 tbc

More details from the supervisor.

Supervisor : ***Prof A Steane***
Email : ***a.steane@physics.ox.ac.uk***

Atmospheric, Oceanic and Planetary Physics projects

AO01 Jet variability and the statistical moments of atmospheric flow

Atmospheric flow exhibits clear structures in its higher statistical moments such as the skewness and kurtosis. Historically these have been interpreted as signs of nonlinear flow such as the repeated occurrence of distinct weather regimes. However, recent evidence suggests that some of these features can be reproduced in much simpler systems, in particular in the presence of varying jet streams. This project will develop some very simple jet models, using a kinematic and/or vorticity-based approach. The flow statistics of these models will then be compared with observed patterns from the real atmosphere. The work will consist of reading and interpreting scientific papers and simple computer programming with a language such as Matlab.

Supervisor: ***Dr T Woollings***
Email: ***Tim.Woollings@physics.ox.ac.uk***

AO02 Measuring Rossby waves in the atmosphere

Weather patterns in the mid-latitudes are dominated by Rossby waves which consist of trains of alternating cyclonic and anticyclonic vorticity anomalies. There are several methods for identifying and measuring Rossby wave variability in the atmosphere, but these can lead to quite different results. For example, some simple methods have suggested that Rossby waves are changing as a result of the strong recent warming of the Arctic, yet other methods disagree. This project will examine a small sample of real atmospheric data to test how well some different methods work in characterising Rossby waves. The work will consist of reading and interpreting scientific papers and simple computer programming with a language such as Matlab.

Supervisor: ***Dr T Woollings***
Email: ***Tim.Woollings@physics.ox.ac.uk***

AO03 Retrospective forecasts of winter and summer large-scale circulation changes during the 20th Century

Forecasts of seasonal-mean anomalies of the climate using dynamical atmosphere-ocean circulation models based on the laws of physics are now routinely made at many operational meteorological forecast centres around the world. Such seasonal predictions provide estimates of seasonal-mean statistics of weather, typically up to four months ahead. In order to estimate how skilful seasonal forecasts are, the models are run in so-called retrospective forecast mode. This means that a period in the past, that can be verified with observations, is predicted using only information that would have been available at the time of the start of the forecasts. This project works with a long seasonal retrospective forecast data set that covers the entire 20th Century. The unusually long model forecast record allows the analysis of dominant modes of large-scale atmospheric variability, predictability and their changes on multi-decadal time scales. The student is going to analyse the existing ensemble forecast data set and compare it with a proxy data set of global observations.

Required skills: experience in programming (e.g. Matlab) and knowledge of statistics

Supervisors: ***Dr A Weisheimer, Prof T Palmer, Dr D Macleod*** and ***Dr C O'Reilly***
Email: ***Antje.Weisheimer@physics.ox.ac.uk***

AO04 Infra-red absorption of ions in the atmosphere

Tiny charged clusters of water and other species are created in the atmosphere by cosmic rays, and are known as molecular cluster-ions (MCI). In common with other polar molecules, MCI absorb a small amount of infra-red (IR) radiation through vibrational and rotational transitions, and this absorption, measured in the lab at about 9 microns, has recently been detected in the atmosphere for the first time. Since the MCI contain water, and the 9 micron band of interest is also part of the "water vapour continuum" region, we expect the absorption in this band to be affected both by MCI and water vapour in the atmospheric column. This project involves analysis of radiosonde (weather balloon) data, for an existing set of ionising radiation and IR absorption data, to investigate the relationship between IR absorption in the 9um band, MCI creation, and atmospheric water vapour. Much of the background to this project is covered in the Atmospheric Physics major option, but it is not an essential prerequisite. Students taking this project should be able to, or willing to learn, to write data analysis code in IDL or R.

Supervisor: ***Dr K Aplin***
Email: ***karen.aplin@physics.ox.ac.uk***

AO05 One-dimensional models of atmospheric escape to space

One of the key questions in planetary science is the delineation of the conditions under which planets can retain atmospheres of various types. The emergence of an ability to detect and characterize planets orbiting stars other than our own has already begun to provide opportunities to test theories of atmospheric escape that cannot be tested with any current planets in the Solar system, though atmospheric escape questions are at the heart of many questions concerning the climate evolution on Earth, Mars and Venus. Hydrodynamic escape is a particularly important form of atmospheric loss, involving macroscopic outward streaming motions supported by absorption of stellar energy by the atmosphere. Much productive work on hydrodynamic escape can be done within a simplified framework of mathematically one-dimensional radially symmetric compressible hydrodynamics, but even this simple case has proved numerically challenging. In this project, the student will explore and evaluate new numerical techniques for solving the fluid equations describing hydrodynamic escape. There will also be opportunities for testing new methods of identifying bifurcations in fluid flow problems, and in particular the switch between balanced static atmospheres and flowing, escaping atmospheres. Some familiarity with partial differential equations in one dimension, and ideally also basic fluid dynamics, is required. Fluency in some computer programming language is required. The project will be carried out in Python, so prior experience with Python would be helpful, but any student familiar with some other programming language (e.g. Matlab, Java, c++ or Fortran 90) is likely to be able to learn Python quickly enough to do the project.

Supervisor: ***Prof R T Pierrehumbert***
Email: ***raymond.pierrehumbert@physics.ox.ac.uk***

AO06 Nonlinearity, stochastic bifurcations, and climate sensitivity

One of the central questions in climate science is the dependence of the amount of warming Earth will experience on the amount of carbon dioxide human activities will add to the atmosphere. Much thinking about this problem is based on linearization of the climate system, but it can be shown that as climate sensitivity becomes high, it is inevitable that nonlinearities become important. Depending on the nature of the climate feedbacks, these nonlinearities can lead to bifurcations (loosely speaking "tipping points") if a formerly stable climate state becomes unstable. In this project the student will explore the behavior of simple nonlinear models of climate (implemented as ordinary differential equations), subject to stochastic forcing or stochastic variation of parameters. The object is to derive (through numerical exploration) bifurcation and sensitivity equations that apply to the time or ensemble mean response of the system. The general idea is that the underlying dynamics may be unstable viewed instantaneously in time, but that the stochastic exploration of phase space must always lead to mean-field equations which are in some sense stable. This project is an extension of the steady-state analysis described in Bloch-Johnson, Pierrehumbert and Abbott (Geophys. Research Letters 2015). Familiarity with ordinary differential equations and their numerical solution is required, as is ability to implement numerical algorithms in a modern programming environment. The project will be carried out in Python, so prior experience with Python would be helpful, but any student familiar with some other programming language (e.g. Matlab, Java, c++ or Fortran 90) is likely to be able to learn Python quickly enough to do the project.

Supervisor: ***Prof R T Pierrehumbert***
Email: ***raymond.pierrehumbert@physics.ox.ac.uk***

AO07 Linear Retrieval of Tropospheric Trace Gases

The Infrared Atmospheric Sounding Interferometer (IASI) is a nadir-viewing instrument on the polar-orbiting MetOp satellites, measuring the infrared emission spectra from the earth's surface. These spectra show absorption lines from various atmospheric molecules with characteristic signatures and from these it is possible to retrieve the absorber concentrations.

A simple technique is to compare radiances from two spectral points, one inside and outside an absorption line, and assume that the difference is proportional to absorber concentration.

The aim of this project is to extend this method such that the absorber concentration is deduced from a linear combination of a larger set of spectral points, the trick being to find a method of establishing the points and associated weights in order to minimise systematic errors such as interference from different molecules and varying temperature structure.

The project requires some knowledge of infrared radiative transfer and linear matrix algebra. The project is entirely computer-based so some knowledge of scientific computing and/or linux would be useful.

Supervisor***: Dr A Dudhia***
Email: ***dudhia@atm.ox.ac.uk***

AO08 Surf zones under ice shelves

In many places, the Antarctic and Greenland ice sheets discharge into the oceans, either via a near-vertical glacier terminus or via a so-called ice shelf: a tongue of ice floating atop the ocean. Melting at these ice-ocean interfaces can modify the dynamics of ice flow, hence providing a key but poorly-quantified mechanism whereby ice sheet mass loss and sea level rise can respond to changes in ocean temperature.

This project will explore the potential role of ocean internal waves for transferring heat to the ice-ocean interface and driving locally enhanced melting. Disturbances to a stratified ocean can form propagating internal gravity waves, which have the potential to transmit energy over large distances. This project will focus on the dynamics of internal gravity waves in the ocean under a sloping ice-shelf of variable depth. We will explore parallels with the more familiar setting of a so-called "surf-zone" on a beach, where ocean surface waves grow and break as they propagate into shallower waters on the beach. Theoretical modelling will be used to explore the changing amplitude of internal waves as they approach the sloping ice shelf, for a range of different ocean stratification conditions and ice shelf slopes. This will include an estimate of the resulting heat transfer that drives melting at the ice-ocean interface. There are numerous potential extensions of this approach, such as considering the influence of the coriolis effect, or allowing feedbacks where melting changes the ice-shelf geometry and thus feeds back on the wave dynamics. Such wave-induced heat transport may lead to localised regions of enhanced melting and undercutting of the ice shelf, thus contributing to structural weakness of the ice that may promote iceberg calving.

This project would suit a student interested in applying theoretical modelling approaches to a fundamental fluid dynamical problem relevant to ocean and cryosphere dynamics. A significant component of the project will involve developing and applying a theory for wave propagation, and hence the student should be comfortable with applying mathematical techniques. Certain parts of the project may also benefit from some modest computational modelling in MATLAB or a similar programming language to solve the derived equations. However, whilst some prior experience with programming would be an advantage, there is potential for a motivated student to learn the necessary skills during the project.

Supervisor: ***Dr A Wells***
Email: ***Andrew.Wells@physics.ox.ac.uk***

AO09 Student initiated projects

I am receptive to projects proposed by students who have ideas of their own they may wish to explore, so long as the fit within my general areas of interest. I would be interested in discussing potential projects in the general areas of climate change, planetary atmospheres (including chemistry), radiative transfer, or dynamical systems (esp. hamiltonian chaos) .

Supervisor: ***Prof R T Pierrehumbert***
Email: ***raymond.pierrehumbert@physics.ox.ac.uk***

AO10 Predictability of Northern Hemisphere weather in a stochastic multi-scale modeling system

Forecasting weather with atmospheric models has been studied and significantly improved upon over the last three decades with approaches derived from nonlinear dynamical systems theory. A key aspect of nonlinear dynamical systems is the sensitive dependence of their evolution to the initial conditions. Similarly, the evolution of weather forecast errors in atmospheric models depends on errors in initial conditions. Ensemble forecasting is an approach to quantify this flow-dependent error growth from initial condition errors. Another significant contribution to forecast error growth is from uncertainty in the numerical representation of the known physical equations of the atmospheric system. Stochastic physics schemes are used in current weather models to represent these model uncertainties quantitatively and to represent the physical forcing of unrepresented processes on resolved scales.

One of the biggest challenges in current atmospheric models is to represent clouds and atmospheric convection well. The parameterized convective processes in today's models lead to the largest source of uncertainty. The challenge of representing cloud processes comes from their multi-scale nature with spatial and temporal scales ranging from microphysical interactions (cloud droplets) to planetary scale interactions (such as hurricanes). A recent novel and successful approach to improve upon previous approaches of parameterization of convection has been a multi-scale modeling framework (MMF) better known as super-parameterization in the climate modeling community. We are currently using this MMF approach for testing and studying weather forecasts globally.

Recent studies from the European Center for Medium range Weather Forecasting (ECMWF) using a model with parameterized convection have shown that failure to reproduce mesoscale convective systems over the North American region has often lead to reduced weather predictive skill over Europe (Rodwell et al., 2015). Furthermore, studies with a multi-scale climate model (SP-CAM, Kooperman et al. 2013) have shown improved representation of mesoscale convective systems (MCSs) over North America compared to parameterized climate models.

In this project, the student will analyze model forecasts from a stochastic MMF and a model with parameterized convection to build insights and identify differences in the evolution of the model forecast errors for MCSs over North America. These lessons will then be used to understand how these errors translate to forecast errors over Europe days later.

The overarching scientific objective is to identify and explain differences in the nonlinear convective dynamics of a super-parameterized model compared to a parameterized model for forecasts of mesoscale convective systems over North America. We have fresh ideas on how to approach the problem in a targeted way to achieve the goals of the project.

There may be opportunity for an interested student to also further analyze these simulations and study differences in forecasts over the entire North Atlantic ocean region. This is not a core element of the project, but would be accessible to students making good progress. The project will involve programming in Python/MATLAB or equivalent software for plotting and analysis. We have model runs with the required forecast variables to be analyzed already prepared. Further targeted model runs can be performed, if necessary. No prior experience of using Python/MATLAB is necessary.

References:

Rodwell, MJ, 2015, Using ensemble data assimilation to diagnose flow-dependent forecast reliability, ECMWF Newsletter No. 146, pg 29-24

Kooperman, GJ, Pritchard, MS, Somerville, CJR, 2013, Robustness and sensitivities of central U.S. summer convection in the super-parameterized CAM: Multi-model intercomparison with a new regional EOF index, GRL, Vol. 40, 3287–3291, doi:10.1002/grl.50597, 2013

Supervisors: ***Prof T Palmer, Dr A Subramanian*** and ***Dr S Juricke***
Email: ***subramanian@atm.ox.ac.uk***

AO11 Evolution and dynamics of Jupiter's cloudy atmosphere

Since the spectacular observations of Jupiter by the two Voyager spacecraft in 1979, the atmosphere, and especially the clouds of Jupiter have fascinated planetary scientists and public alike. Further space missions, such as Galileo (1995 – 2003) and Cassini (2000) have made follow-up observations, but these have been for limited periods only or with limited data downlink. In the meantime, the capability of ground-based observations has grown exponentially. Starting in 1995 a continuous programme of observations has been conducted by collaborators at the Jet Propulsion Laboratory using NASAs Infrared Telescope Facility (IRTF) in Hawaii. In this programme Jupiter has been observed numerous times with a set of near-infrared filters that either detect sunlight reflected off clouds at different levels in Jupiter's atmosphere or detect thermal emission from below the clouds. The data from this ongoing programme cover a 20-year period during which Jupiter's atmosphere has changed hugely: the Great Red Spot has changed from oval to become nearly circular; several 'White Spots' have merged and/or changed colour; and the South Equatorial Belt has faded and then revived. The data thus constitute a unique record of changes in Jupiter's atmosphere during this period of upheaval, but surprisingly have never been systematically sorted, calibrated and analysed. In this project, these observations will be assessed, processed and interpreted with our world-leading radiative transfer and retrieval tool, Nemesis, to determine the composition and cloud structure of key Jovian cloud features and determine how they have evolved during the last 20 years. This analysis will shed light on the underlying dynamics of Jupiter's atmosphere and will also provide an invaluable reference benchmark against which to test the observations of Cassini and Galileo, and the forthcoming observations of NASA's Juno spacecraft, due to go into orbit about Jupiter in July 2016.

A familiarity with Unix systems would be highly desirable and some knowledge of programming languages such as Fortran, C, or IDL etc. is essential.

Supervisor: ***Prof P Irwin***
Email: ***Pat.Irwin@physics.ox.ac.uk***

AO12 Turbulence closure in jet dynamics

The ocean contains a vigorous and turbulent mesoscale eddy field at spatial scales from 100 km and smaller, evolving over time scales from weeks to months. These eddies are important in establishing the ocean's circulation, such as the Gulf Stream. However ocean models need to parametrize their effect due to their poor spatial resolution. The representation of such turbulent sub-grid processes has often relied on mixing/diffusive (downgradient) operators therefore ignoring key mechanisms which transport momentum upgradient (an anti-diffusive behaviour). The goal of this project is to explore a new closure of unresolved turbulent eddies which relies on conditional probability distribution functions (PDFs) of the eddy forcing conditioned on the gradient of (potential) vorticity, leading to upgradient momentum fluxes.

In this project, the student will be involved in relating theories of non-newtonian viscous flows and fluid instabilities to turbulent ocean dynamics. Moreover the student will be able to use the empirically derived PDFs from a high resolution simulation to explore their impact on the simulated energy and enstrophy (vorticity squared) and to attempt to derive a theory for their evolution.

This project will require a strong interest in fluid dynamics, theoretical physics and mathematical analysis. The project will also involve the use of Matlab (or an equivalent software).

Suggested Reading:

P.G.L. Porta Mana, L. Zanna: Toward a Stochastic Parameterization of Ocean Mesoscale Eddies.

Submitted to Ocean Modelling. http://www.earth.ox.ac.uk/~laurez/files/Mana-Zanna-2013.pdf

Rivlin, R. S. (1957). The relation between the flow of non-Newtonian fluids and turbulent Newtonian fluids. Q. Appl. Math., 15(2):212–215.

Gent, P.R., Willebrand, J., McDougall, T.J., McWilliams, J.C., 1995. Parameterizing eddy induced transports in ocean circulation models. J. Phys. Oceanogr. 25, 463–474.

Supervisor: ***Dr L Zanna***
Email: ***Laure.Zanna@physics.ox.ac.uk***

AO13 Fjord circulation, mixing, and the ablation of ice sheets. As easy as F=ma?

Melting of the Greenland ice sheet is a key concern for future projections of sea level rise. The resulting freshwater fluxes may also perturb ocean circulation and heat transport, thus providing a feedback on climate. The Greenland ice sheet discharges into the ocean through a diverse array of hundreds of narrow fjords, which act as buffers for the transfer of heat between far-field ocean and the ice. Recent observations link warming of ocean waters around the Greenland coast to enhanced melting of submerged ice faces, and acceleration of ice sheet discharge from the land. However, the response of individual glaciers to regional ocean warming is far from homogenous, and can varying significantly between nearby fjords. One potential cause may be dynamical differences in ocean circulation and heat transfer through fjords of different geometries.

The goal of this project is to investigate the combined impact of fjord circulation and ocean mixing on ice ablation rates, using an idealised conceptual model of a Greenland fjord. The idealised model considers turbulent meltwater flows along a submerged glacier snout, and their coupling with the evolving stratification in the fjord subject to buoyancy-driven exchange flow with the far-field ocean. This leads to a simplified set of 1-D partial differential equations for the vertical structure of the flow, that allow us to build understanding of the key physical mechanisms and efficiently explore a range of configurations. The project will explore the nonlinear dynamics of the circulation, and characterise possible flow states as the fjord geometry is varied. The goal is to investigate whether differences in melting rates between fjords can be explained by bifurcations between different circulation regimes, resulting from subtle variations in the imposed fjord geometry.

This project would suit a student interested in studying fluid dynamical problems and nonlinear dynamics using mathematical and computational approaches. In addition to theoretical modelling, the student will have the opportunity to learn more about numerical simulation methods for solving partial differential equations. Whilst prior experience with a programming language such as MATLAB/Fortran/C/etc. would be an advantage, there is potential for a motivated student to learn the necessary skills during the project.

Supervisor***: Dr A Wells***
Email: ***Andrew.Wells@physics.ox.ac.uk***

AO14 Measurement of Isotopic ratios in the Stratosphere

Some of the major infrared absorbing molecules in the atmosphere are assumed to maintain their surface ratios of minor isotopes, e.g. fraction of CO_2 molecules with ^{13}C atoms compared to the normal ^{12}C. Others, e.g. H_2O, are known to vary due to the mass-dependence of various chemical processes.

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is part of the payload of the European Space Agency's ENVISAT satellite launched in March 2002. MIPAS is a fourier-transform spectrometer which measures the infrared emission spectra of the earth's atmosphere from 4-15 microns with sufficient spectral resolution to identify minor isotopic lines of a number of different molecules.

This project is to investigate simple techniques which can be applied to such spectral signatures to extract isotopic ratios, and compare the results with previous measurements or predictions.

The project is entirely computer-based so some knowledge of scientific computing and/or linux would be useful.

Supervisor***: Dr A Dudhia***
Email: ***dudhia@atm.ox.ac.uk***

AO15 Ocean Heat Uptake and Transient Climate Change

The ocean is one of the primary natural factors mitigating the human impact of climate. It is a "sink" for over 30% of carbon emissions from fossil fuel burning and 90% of the excess heat trapped by atmospheric CO2. The ocean heat uptake has long been recognised as critical in setting the pace of climate change and is likely responsible for the recent "hiatus" in global warming. However, observations and coupled general circulation model simulations suggest that the geographic pattern of uptake is neither uniform nor steady. On time scales longer than a few decades, the ocean can also be a source (rather than a sink) of anthropogenic CO2 and heat but as these tracers are transported via ocean circulation back to the surface where they can impact the atmosphere and hence climate. Understanding the physical processes setting the uptake of heat and carbon by the ocean and their pathways between the surface and the interior is thus a critically important problem in climate science.

The aim of the project will be to quantify the role of the momentum and energy input via atmospheric forcing (e.g., wind, temperature) and that of the ocean circulation in the regional uptake of heat and carbon and assess the feedback of the ocean onto global mean temperature change. The primary tool will be the mathematical machinery of Green functions, which allows to describe the advective-diffusive transport of tracers in any geophysical fluid such as the ocean and atmosphere. Green functions allow us to rigorously quantify ventilation, ocean interior pathways and subsequent re-emergence of water "tagged" with climatically important tracers such as heat and anthropogenic CO2. The student will calculate and simulate Green functions (and their adjoint) in idealised and in complex models.

This project will suit a student with an interest in fundamental fluid mechanics and climate dynamics. Some basic Matlab and Fortran code will be provided as a starting point. Previous experience with Matlab would be an advantage but is not required.

Suggested Reading:

Marshall and Zanna: A Conceptual Model of Ocean Heat Uptake under Climate Change. J. of Climate, 27, 8444-8465

Meehl et al, 2011, Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. Nature Climate Change, 1, 360–364, (2011), doi:10.1038/nclimate1229

Khatiwala, S., F. Primeau, and T. Hall, 2009: Reconstruction of the history of anthropogenic CO2 concentrations in the ocean. Nature, 462, 346-349, doi:10.1038/nature08526.

Holzer, M., and T.M. Hall, 2000: Transit-time and tracer-age distributions in geophysical flows. J. Atmos. Sci., 57, 3539-3558, doi:10.1175/1520-0469(2000)057<3539:TTATAD>2.0.CO;2.

Supervisors: ***Dr L Zanna*** and ***Dr S Khatiwala***
Email: ***Laure.Zanna@physics.ox.ac.uk***

AO16 Understanding the Thermal Scattering Function of the Lunar Surface

Thermal infrared measurements of airless bodies such as the Moon or asteroids can tell us a huge amount of information about their surfaces including their surface temperature, composition and texture. To obtain this information the measured thermal emission from the Moon or asteroid must be compared to a computer 3D thermal model of the surface. Typically, these models combine topography and compositional data using a combination of ray tracing techniques and solutions to the 1D thermal diffusion equation. This allows the model to calculate the expected radiance at the spacecraft.

These models generally do a good job at matching the measured radiance from the e.g. the lunar surface; however, in regions where the incidence angle of the incoming solar light is low and the dominate source of heat transfer is thermal re-radiation they have significant errors. Most 3D thermal models assume that light is scattered equally in all directions - a Lambertian surface, however it is believed that this assumption is incorrect particularly at high incidence angles.

Here at Oxford Physics we are tackling this problem and have developed a unique piece of lab equipment known as a goniometer, similar to a 3D protractor. This instrument allows us to measure the angular distribution of emitted and scattered thermal radiation in a space-like environment that can then be used with a 3D thermal model. Samples used in the instrument are simulants of lunar-like materials and this project will give you chance to work both with the lab instrument and the computer based models.

Depending on the student this project could include helping to upgrade the goniometer to include a visible or infrared light source or developing our own 3D thermal model using ray-tracing type techniques.

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. For the computer based elements programming experience be useful. For the lab-based elements a basic knowledge of electronics will be useful but is not required.

Supervisors: ***Dr T Warren*** and ***Dr N Bowles***
Email: ***Tristram.Warren@physics.ox.ac.uk; Neil.Bowles@physics.ox.ac.uk***

AO17 **Assessment of a theoretical framework for aerosol radiative perturbations on climate**

The scientific evidence for the impact of anthropogenic activities on Earth's climate is generally undisputed. Atmospheric aerosols (small airborne particles) play a key role in the climate system, despite being less prominent than greenhouse gases. Aerosol particles influence the global radiation budget directly, by scattering and absorption, as well as indirectly, by the modification of cloud radiative and microphysical properties. Contrary to the well-constrained radiative perturbation by greenhouse gases, aerosol radiative perturbations are not sufficiently understood, making them arguably the single greatest source of uncertainty in the assessment of anthropogenic climate change.

A simple theoretical model has been proposed to capture the transient behaviour of aerosol radiative effects on climate. It has been used to hypothesise that a large present-day aerosol radiative effect (cooling climate) cannot be reconciled with signals of global warming in the Earth's transient temperature record.

In this project we will use state of the art climate models and/or satellite datasets to challenge and refine some of the simplistic assumptions made in this theoretical framework. Idealised sensitivity studies with varying aerosol precursor emissions will be used to understand and quantify saturation effects in aerosol radiative perturbations. The results will be used to refine (or reject) the analytical formulation of the theoretical framework.

This project involves data analysis with Python/IDL under Linux and the opportunity to work with the code of a state of the art climate model. Ideally, you bring some basic experience in programming but this can also be learned on the job.

Supervisor: ***Prof P Stier***
Email: ***philip.stier@physics.ox.ac.uk***

AO18 **Modelling thermal emission spectra of the Moon and other airless solar system bodies**

Surface composition can tell planetary scientists a great deal about the processes that shape terrestrial solar system objects, such as magmatic evolution, impacts and space weathering. Visible and infrared spectra acquired by instruments such as the Moon Mineralogy Mapper and Diviner Lunar Radiometer are used to obtain compositional information, particularly mineral identification. While thermal infrared spectroscopy is a useful technique, its application is challenging as spectra are also influenced by mineral grain size, shape, packing, and surface texture. On an airless body, there is further complexity caused by the extreme thermal environment of these surfaces, with temperature changes of hundreds of Kelvin within the upper millimeter. The steep thermal gradient affects the positions and shapes of the diagnostic spectral features used to infer surface composition, especially for the grain sizes typical of lunar and asteroid regolith (<100μm).

This project involves contributing to the development of a radiative and thermal conductive heat transfer model of airless body regolith. One potential aspect of this is building up and validating the model itself. Possible options for this include: adding relevant materials to the model where data is available, investigating the effect of grain shape, testing ways of dealing with mineral mixtures and exploring inversion procedures. Model results will be compared to laboratory measurements taken in a lunar-like environment. Another potential aspect is conducting laboratory measurements of the optical properties of well-characterized materials. Radiative transfer models require optical constants (the wavelength-dependant real and imaginary indices of refraction) for each material that may be present. Despite being fundamental to understanding planetary surface composition, there are surprising number of common rock-forming minerals and planetary analogue materials for which these data are not available.

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. This project requires programming experience and the work will be carried out in IDL. Basic knowledge of FORTRAN will also be helpful.

Supervisors: ***Dr J Arnold*** and ***Dr N Bowles***
Email: ***jessica.arnold@physics.ox.ac.uk; Neil.Bowles@physics.ox.ac.uk***

AO19 **Signatures of Southern Hemisphere Natural Climate Variability.**

Several studies have looked at the impact of solar variability and volcanic eruptions at the Earth's surface, including work here at Oxford led by Professor Gray. One approach has been to use multiple linear regression, including indices to represent, for example, the 11-year solar cycle, volcanic eruptions and long-term trends associated with greenhouse gases. A recent study highlighted that, for example, the impact of 11-year solar variability on mean sea level pressure (mslp) and sea surface temperatures (SST) in the European / N. Atlantic sector was lagged by a quarter cycle i.e. 3-4 year. This has particular potential benefits for long-term (seasonal, decadal) forecasting since the 11-year solar cycle can be reasonably well forecast and may therefore give valuable additional capability for seasonal forecasting over Europe. A mechanism for this lag has been proposed, in collaboration with Met Office colleagues, involving an influence on the mixed layer of the ocean in winter that can be perpetuated through to the following summer and thus provides a positive feedback.

In recognition of the importance of seasonal forecasting over Europe, previous effort has been focused on the Northern Hemisphere winter response over Europe. However, there are some interesting signals apparent in the Southern Hemisphere that deserve attention, and also in summer time in both hemispheres. In this project we plan to expand the sphere of interest, to examine to examine the Southern Hemisphere response. This will be carried out using existing tools, primarily the multiple linear regression employed in previous studies. The study will examine the Hadley Centre mslp and SST datasets. There is also the potential to collaborate further with Met Office colleagues, who have a set of climate model ensembles for the period 1960-2010 with and without a solar cycle in the imposed irradiances, so that mechanisms may be further explored.

Skills required

This project is entirely computer-based, examining both observational and climate modelling data requiring experience of UNIX and IDL/Python.

Supervisor: ***Prof L Gray***
Email: ***Gray@atm.ox.ac.uk***

AO20 **Understanding the Building Blocks of Primitive Asteroids**

In September 2016 NASA's OSIRIS-REx spacecraft is due to launch to Near Earth Asteroid Bennu with the aim of sampling its surface in 2019 and returning the material to Earth in 2022. Bennu is potentially a leftover building block from the formation of the Solar System and it may be rich in organic material. OSIRIS-REx's returned sample may have important implications for how complex chemistry (e.g. life) started here on Earth.

Prior to sampling the surface, OSIRIS-REx will make a detailed reconnaissance of the asteroid using visible imaging and infrared spectroscopy to identify key mineral signatures on the surface. Being able to interpret these remote observations of the asteroid's surface will be key in identifying sampling site locations, putting the collected samples into geologic context (e.g. Are the collected samples representative of materials distributed across most of the surface or are the samples collected from unique deposits?), and putting the collected samples into context with known meteorite classes.

Here in Oxford Physics we have been heavily involved in the mission by developing libraries of spectral test using our extensive suite of infrared spectrometers and test chambers. The goal of this project is to expand this library and investigate how different methods of combining mixtures of material affects the shape of the infrared spectrum. You will be working with our terrestrial samples thought to be primitive meteorite analogues (olivine, pyroxene, phyllosilicates, sulphides, oxides and carbon) to:

(1) Characterise mineral chemistries using analytical techniques such as electron microscopy or X-ray diffraction in facilities in the Department of Physics and Department of Earth Sciences to confirm compositions are similar to those found in primitive meteorites.

(2) Characterise near infrared reflectance signatures using facilities in our Planetary Spectroscopy Facility to determine the mineral's purity and degree of sample weathering.

(3) Characterise thermal infrared emissivity signatures using facilities in our Planetary Spectroscopy Facility under Earth-like and asteroid-like conditions.

(4) Compare laboratory thermal infrared (TIR) emissivity measurements of primitive asteroid analogues to (a) previously measured laboratory TIR emissivity measurements and (b) TIR telescopic observations of asteroids.

Necessary skills:

Skills: Coursework covering the fundamentals of radiative transfer and spectroscopy e.g. from Atmos or Astro major options. This project requires programming experience in a language such as IDL, Python or Matlab for data reduction and laboratory practical skills.

Background reading: Planetary Sciences (de Pater and Lissauer), OSIRIS-REx website (http://www.asteroidmission.org).

Supervisors: ***Dr K Donaldson Hanna*** and ***Dr N Bowles***
Email: ***Kerri.DonaldsonHanna@physics.ox.ac.uk; Neil.Bowles@physics.ox.ac.uk***

AO21 **A theoretical framework for aerosol effects on precipitation**

The scientific evidence for the impact of anthropogenic activities on Earth's climate is generally undisputed. Atmospheric aerosols (small airborne particles) play a key role in the climate system, despite being less prominent than greenhouse gases. Aerosol particles influence the global radiation budget directly, by scattering and absorption, as well as indirectly, by the modification of cloud radiative and microphysical properties. These perturbations of clouds have been proposed to modulate their precipitation efficiency, which could lead to significant anthropogenic effects on regional climate and extreme events. Contrary to the well-constrained radiative perturbation by greenhouse gases, aerosol radiative perturbations are not sufficiently understood, making them arguably the single greatest source of uncertainty in the assessment of anthropogenic climate change.

It can be shown theoretically that global mean precipitation is energetically controlled, however, currently no theoretical framework exists to constrain regional or the temporal evolution of rain. In this project we will use an idealised configuration of a global climate model (aqua-planet: removing all land surfaces) with idealised aerosol perturbations to advance our theoretical understanding of aerosol effects on regional-scale precipitation. This work can have direct implications for our understanding of observed precipitation changes in heavily polluted areas, such as East Asia.

This project involves data analysis with Python/IDL under Linux and the opportunity to work with the code of a state of the art climate model. Ideally, you bring some basic experience in programming but this can also be learned on the job.

Supervisor: ***Prof P Stier***
Email: ***philip.stier@physics.ox.ac.uk***

AO22 **tbc**

More details from the supervisor.

Supervisors***: Prof M Allen***
Email: ***myles.allen@ouce.ox.ac.uk,***

AO23 **tbc**

More details from the supervisor.

Supervisor: ***Prof P Read***
Email: ***peter.read@physics.ox.ac.uk***

Astrophysics projects

AS01 & AS02 Very-high-energy gamma-ray astrophysics with the Cherenkov Telescope Array

Very high-energy gamma-ray astrophysics is an exciting field spanning fundamental physics and extreme astrophysical processes. It will soon be revolutionized by the construction of the international Cherenkov Telescope Array (CTA; http://www.cta-observatory.org/). This will be the first open observatory for very-high energy gamma-ray astronomy, and will be sensitive to photon energies up to 10^15 eV. Its science goals are:

(1) Understanding the origin of cosmic rays and their role in the Universe.

(2) Understanding the natures and variety of particle acceleration around black holes.

(3) Searching for the ultimate nature of matter and physics beyond the Standard Model.

CTA will consist of up to one hundred imaging air Cherenkov telescopes using state-of-the-art Silicon Photomultiplier detectors and high-speed digital signal processing to detect and characterize the electromagnetic air shower caused when an astrophysical gamma-ray enters the Earth's atmosphere.

I expect to be able to take up to two M.Phys. students this year working on either experimental or theoretical aspects of the CTA programme. These would suit students taking either the Astrophysics or Particle Physics options.

In the lab, we work on the design and construction of the cameras for CTA's small-sized unit telescopes. These will have ~2k pixel SiPM detectors and front-end amplifiers which feed into custom electronics using ASICs and FPGAs. This gives a system that can image at a rate of a billion frames per second.

On the theoretical/observational side of the programme, recently we have developed new theoretical models for the broad-spectrum emission from steady-state jets (Potter & Cotter 2012, 2013a,b,c) that let us use the gamma-ray observations and those at other wavelengths to investigate the physical properties of the jet and the black hole at its base. We now propose to extend these models to look in particular at (i) rapid variability and flaring in jets and (ii) entrainment of heavy particles as the jets propagate through their host galaxy, and the resulting possibility of hadronic particle processes within the jets. We will investigate how CTA may be used to determine the physical conditions that lead to flaring and the presence, and extent, of emission from hadronic processes.

References

Actis et al. 2010, http://arxiv.org/abs/1008.3703

Potter & Cotter 2012, http://arxiv.org/abs/1203.3881

Potter & Cotter 2013a, http://arxiv.org/abs/1212.2632

Potter & Cotter 2013b, http://arxiv.org/abs/1303.1182

Potter & Cotter 2013c, http://arxiv.org/abs/1310.0462

Supervisor: ***Dr G Cotter***
Email: ***Garret.Cotter@physics.ox.ac.uk***

AS03 Breaking the dark matter degeneracy using stellar proper motions

Dark matter is a pillar of our paradigm of how galaxies form. However the shape and content of dark matter in galaxies, and especially in gas-poor ones, is still poorly understood. This is because of strong degeneracies in the dark matter recovery from kinematics of external galaxies. These are due to an intrinsic non-uniqueness of the problem, when only line-of-sight kinematics are available.

A solution to this fundamental problem will soon be provided by the availability of stellar proper motions, which will finally remove the degeneracy of the problem. In this project the student will use high-resolution N-body simulations, in combination with dynamical models and a Bayesian approach, to study how well one can expect to be able to measure dark matter in external galaxies using the upcoming proper motion information.

Special skills: Knowledge of the Python programming language.

Supervisor: ***Dr M Cappellari***
Email: ***michele.cappellari@physics.ox.ac.uk***

AS04 Quantifying and classifying the cosmic web

Large structures in the Universe, formed via gravitational collapse, are distributed in lower-dimensional systems, such as cosmic filaments and sheets. This "cosmic web" can be clearly observed in simulations of structure formation as well as in galaxy surveys, and has received a fair amount of attention as an alternative cosmological observable. Different methods have been proposed to classify and quantify the elements of the cosmic web, and the aim of this project is to compare their predictions as well as their performance on simulated and observed datasets. This project will require a reasonable level of computing skills (ideally some basic experience coding in C/C++/Fortran and/or python) as well as basic knowledge of Fourier methods.

Supervisor: ***Dr D Alonso***
Email: ***David.Alonso@physics.ox.ac.uk***

AS05 Combining photometric redshift surveys and HI intensity mapping

In the next decade, a large portion of the southern sky will be observed using two potentially complementary techniques: photometric redshift surveys and intensity mapping of the 21cm line. This project would focus on producing realistic forecasts regarding the potential of cross-correlating both probes in terms of constraints on cosmological parameters and possibly mitigation of systematic uncertainties.

Supervisor: ***Dr D Alonso***
Email: ***David.Alonso@physics.ox.ac.uk***

AS06 & AS07 Extreme Astrophysics with Radio Telescopes

The most extreme phenomena in the Universe are ubiquitously associated with strong and variable radio emission, be it feedback from accreting black holes or massive exploding stars. Our group (**4pisky.org**) are the world leaders in building an empirical picture of how such extreme events are associated with feedback (e.g. Fender & Belloni, Science, 337, 540, 2012), which we do by carefully assembling and comparing observational data at a range of wavelengths. The facilities used range from orbiting space observatories to large ground-based arrays of radio telescopes. Breakthroughs in our understanding of the universe are driven in large part by large new programmes associated with new telescopes and facilities.

This MPhys. project will focus in particular on the radio emission associated with transient astrophysical events, which arises when electrons are accelerated to relativistic energies and spiral in compressed and enhanced magnetic fields. This radio emission can be used as a precise locator for such events, can be calibrated to act as a measure of the feedback of kinetic energy to the local ambient medium, and can be used to probe the properties of the ionised plasma along the line of sight.

In this project, the student will initially work on a theoretical understanding of how radio emission allows us to precisely calibrate the kinetic feedback from explosive astrophysical events. They will subsequently work with data from the AMI-LA radio telescope, on which our group runs an extensive radio transients programme, to apply their understanding to real examples of extreme astrophysical events. It is likely that the project would include a visit to the telescope array itself, in Cambridge. Existing data sets awaiting analysis include observations of accreting stellar-mass black holes and neutron stars, supernovae, runaway thermonuclear explosions on the surfaces of white dwarf stars, and the tidal disruption of stars by supermassive black holes.

The project can take one or two M. Phys. students this year, and would suit students with an interest in astrophysics. Some computing skill is desirable.

Supervisor: ***Prof R Fender***
Email: ***Rob.Fender@physics.ox.ac.uk***

AS08 The build up the 'red sequence' of passive galaxies in clusters

Galaxy clusters are the largest gravitationally bound structures in the Universe containing 100s to 1000s of galaxies within a few megaparsecs. The 'red sequence' is the name given to the tight correlation between galaxy colour and magnitude for the old, passive galaxy population within galaxy clusters. The giant galaxies at the bright end of the red sequence appear to have undergone very little evolution over the last 7 billion years. However, their less massive counterparts may have been transforming from actively star-forming systems to passive red galaxies, an observation termed `downsizing'. The somewhat controversial evidence for this comes from several detailed colour-magnitude diagram studies, which have found an increase in the relative number of faint galaxies on the red sequence of nearby clusters compared to those at moderate redshift. The transformation mechanism responsible is postulated to be either interactions/mergers of galaxies, feedback processes from supermassive black holes and/or supernovae, or the influence of the hot cluster medium.

The project will be based on analyzing state-of-the-art Hubble Space Telescope data from the CLASH and Frontier Fields galaxy cluster surveys. The student will carefully isolate the red sequence from the other galaxies in the cluster by exploiting combinations of optical and near-infrared imaging. By doing this for galaxy clusters over a range of redshifts they will be able to statistically observe the build up of the red sequence over the last 7 billion years of cosmic time.

This project may be extended to include a study of the colour gradients of the giant galaxies to look for evidence to link the build up of the red sequence to the late time growth of the most massive galaxies.

Skills: Some basic programming or IRAF experience would be useful but not essential.

Supervisors: ***Dr J Stott*** and ***Prof R Davies***
Email: ***john.stott@physics.ox.ac.uk***

AS09 Using Machine Learning on multi-wavelength data to determine photometric redshifts

Photometric redshifts, whereby redshifts for galaxies are determining from multi-band imaging rather than from spectroscopy, are key for future investigations of galaxy evolution and cosmology. Over the past decade, machine learning algorithms have been shown to provide excellent constraints on galaxy redshifts, principally based on on optical imaging data. In this project the student will extend such studies to other wavelengths and test whether the additional of near-infrared and radio data over large area surveys can provide significant improvement. Other information such as galaxy size and morphologies can also be added if time permits.

This project is computational and will involved good computing skills, and will involve manipulating large data sets.

Supervisors: ***Prof M Jarvis*** and ***Dr R Bowler***
Email: ***Matt.Jarvis@physics.ox.ac.uk***

AS10 Constraining the Milky Way at large scales with ultra-cool brown dwarfs

The searches for cool brown dwarfs to date have tended to focus on the closest stars to us, using large area photometric surveys to select these faint objects. Hence, the distribution of brown dwarfs in the Milky Way is poorly known at large radii, where the number density of these objects vastly outnumbers that of brighter stars. In this project, you will select a new sample of faint ultra-cool brown dwarfs using photometric data from the VISTA VIDEO survey. This dataset, covering 12 square degrees on the sky in the near-infrared wavelengths, will provide a unique view on the distribution of brown dwarfs in the thick disk and halo of the Milky Way. The distribution of the sample of brown dwarfs can then be fitted with a simple model for the stellar distribution, providing a new constraint on the scale height and extent of our galaxy.

This project is computational and will involve manipulating large data files, working with astronomical images and making plots etc. Any experience in this would be helpful, but should not essential.

Supervisors: ***Prof M Jarvis*** and ***Dr R Bowler***
Email: ***Matt.Jarvis@physics.ox.ac.uk***

***AS11* Intermediate-mass black holes with HARMONI**

Although there are good theoretical reasons to suspect that they exist, there is as yet no compelling observational evidence for the existence of black holes in the range 100 to 10^5 solar masses at the centres of dense stellar clusters: the present generation of telescopes simply does not have the spatial resolution to detect the dynamical effects of such “intermediate-mass” black holes.

This project will characterise how well the Oxford-led HARMONI integral field spectrograph, a first-light instrument planned for the European Extremely Large Telescope, will be able to probe the black hole mass function. It will involve learning about the dynamics and stellar populations of nuclear star clusters, constructing simple dynamical models, “observing” the models with the HARMONI simulator and finally modelling the observations to measure the black hole mass. In this manner, the project can identify the most promising candidates for future observing campaigns.

Supervisors: ***Dr J Magorrian*** and ***Dr R Houghton***
Email: ***John.Magorrian@physics.ox.ac.uk***

***AS12* Automated Parameterisation of the Adaptive Optics Point Spread Function (AO-PSF) of the European Extremely Large Telescope (E-ELT)**

Abstract: HARMONI is the first light integral field spectrograph for the European Extremely Large Telescope (E-ELT). Over the last few years, we have developed an advanced simulator (HSIM) that can quantitatively predict HARMONI’s performance for a wide range of observing programmes. HSIM’s innovative addition to typically used Exposure Time Calculators (ETCs) is the introduction of a wavelength dependent Adaptive Optics Point Spread Function (AO-PSF) that quantifies the response of the E-ELT to an unresolved source (a single star) in the sky. However, generating these AO PSFs relies on a manual, labour intensive, parameterisation of the computed response function from adaptive optics simulations. We are looking for a motivated M.Phys student, with good knowledge of programming (particularly in Python) to develop programs to automate the process of generating accurate parametric representations of a set of AO PSFs.

Supervisors: ***Dr S Zieleniewski and Prof N Thatte***
Email: ***Simon.Zieleniewski@physics.ox.ac.uk, Niranjan.Thatte@physics.ox.ac.uk***

***AS13* Measuring the accelerating expansion of the Universe with distant Supernovae: Predicting the constraints the HARMONI instrument on the E-ELT will provide**

The European Extremely Large Telescope, or E-ELT, is a revolutionary new ground-based telescope concept with a 39-metre main mirror and will be the largest optical/near-infrared telescope in the world: “the world’s biggest eye on the sky”.

The HARMONI integral field spectrograph is one of the first-light instruments for the E-ELT. The project is led by Prof Niranjan Thatte of Oxford, and will see first light on sky in about 8-9 years. It will be sensitive to wavelength between 0.5 and 2.5 μm

This project aims to simulate observations of Supernovae at redshift z=3-5 with HARMONI to measure the accelerated expansion of the universe over a wider redshift range. The student will create different input data cubes (different redshifts, SN type, instrument settings) to feed into the ‘hsim’ pipeline, and analyse the output cubes produced by ‘hsim’, in order to establish how well HARMONI will be able to detect and characterise distant Supernova.

Special skills

As this project is computational, the student is expected to have sufficient computer and programming knowledge, and a basic knowledge of python. Further knowledge in data analysis, in any language, would be advantageous.

Supervisor: ***Dr M Tecza***
Email: ***matthias.tecza@physics.ox.ac.uk***

***AS14 & AS15* Making the Milky Way : Galaxy histories with Starpy**

Understanding how the galaxies we observe in the present day Universe formed is a key problem in astrophysics. Luckily, large surveys of galaxies and powerful statistical techniques exemplified by the Starpy code developed here in Oxford mean that we can constrain when such systems formed their stars. However, at present, we have mostly worked with simplified models of star formation histories, which allow for constant star formation followed by a quench phase of varying speed and intensity. This project will extend the model with star formation histories more appropriate to galaxies with ongoing star formation, and to constrain the history of our own, slightly strange, Milky Way. The project involves using and adding to an existing Python code, and as it involves Galaxy Zoo data might include opportunities for outreach.

Supervisor: ***Prof C Lintott***
Email: ***chris.lintott@physics.ox.ac.uk***

***AS16* Origin of ultra-high energy cosmic rays**

The origin, nature, and mechanisms of acceleration of the most energetic particles in the universe, the ultra-high energy cosmic rays (UHECRs), are unknown. During their propagation from their source to Earth, they can interact with the cosmic microwave background and the extragalactic background light, and also be deflected by intervening magnetic fields (both galactic and extragalactic).

Many models have been proposed to explain how cosmic rays are accelerated to such high energies, and common candidates for sources are active galactic nuclei, tidal disruption events, and magnetars, among others.

In this project the student will use catalogues of astrophysical sources to simulate the propagation of UHECRs from possible sources to Earth, considering all relevant energy loss processes as well as deflections in magnetic fields. By analysing several models and comparing the results of simulations with measurements it will be possible to obtain model-dependent constraints on the sources of UHECRs.

Required skills:

- good knowledge of either Python or C++

Supervisor: ***Dr R Alves Batista***
Email: ***rafael.alvesbatista@physics.ox.ac.uk***

***AS17* Observational study of intrinsic alignments of galaxies around voids**

The alignments of galaxies are typically measured with respect to the positions of other galaxies. I propose an MPhys project to demonstrate the potential of another probe of alignments: the relative shapes and orientations with respect to troughs in the density field of the Universe. The plan is to use the publicly available Sloan Digital Sky Survey (SDSS) dataset to measure the intrinsic alignment of luminous red galaxies around voids in the cosmic structure. This type of galaxy has a strong alignment around over-densities, and thus we will look for the complementary signal around under-densities. To complete this project we will use:

▪ a catalogue of under-densities in the SDSS – publicly available;
▪ a catalogue of shapes for luminous red galaxies – produced by Prof. Rachel Mandelbaum (Carnegie Mellon University, USA), with whom we will collaborate;
▪ accurate distance measurements for luminous red galaxies – publicly available in SDSS;
▪ and a set of computational tools to measure the alignment signal-based on previous experience of the supervisor in measuring alignments in SDSS and in the Horizon-AGN simulation.

In general, we will also study how alignments around under-densities can be combined with previous measurements of alignments around galaxies to improve on existing models. In parallel, we will make predictions of how galaxy alignments might contaminate measurements of gravitational lensing by troughs.

The student will first work on forecasting the significance of a possible detection of galaxy alignments around voids in the cosmic structure observed by the SDSS using the current tidal alignment model. This will allow them to get familiar with the basic analytical tools to model the signal. If the result is promising, we will: 1) check for potential systematics in galaxy shapes and characterization of the SDSS geometry and void catalogue, 2) measure the alignment signal and 3) compare it to current models and draw an interpretation. Regardless of the outcome of the forecast stage, we will be able to estimate how galaxy alignments might contaminate measurements of gravitational lensing by voids, and whether their detection isolated from gravitational lensing might be achieved in the future with other surveys.

Skills required: A basic knowledge of cosmology & large-scale structure, Linux and a programming language (Python or C are preferred).

Supervisors: ***Dr E Chisari, Prof L Miller*** and ***Prof R Mandelbaum (CUM)***
Email: ***elisa.chisari@physics.ox.ac.uk***

***AS18* High Energy Gamma Rays as Probes of Intergalactic Magnetic Fields**

Magnetic fields are observed in several scales, from planets to clusters of galaxies. The origin of cosmic magnetic fields in the universe is an open problem in cosmology. There are two classes of models to explain the cosmological magnetogenesis: primordial and astrophysical mechanisms. The existence of non-zero magnetic fields permeating the whole universe, henceforth called intergalactic magnetic fields (IGMFs), may be deemed a signature of the former process, thus suggesting the existence of a ubiquitous field since early times.

High energy gamma rays can probe the universe up to relatively high redshifts as they are electrically neutral and their arrival directions can be approximately traced back to their source. The interaction of the high energy gamma rays with ambient photons from the cosmic microwave background and the extragalactic light can produce electromagnetic cascades, whose short-lived charged component is affected by intervening magnetic fields, allowing us to study these fields.

The goal of this project is to constrain IGMFs using observations of blazars by gamma ray telescopes, and confronting these data with simulations. By finding the best fit model, it will be possible to derive lower bounds on the strength and coherence length of IGMFs.

Required skills:

- good knowledge of either Python or C++

Supervisor: ***Dr R Alves Batista***
Email: ***rafael.alvesbatista@physics.ox.ac.uk***

***AS19* Characterisation of KIDSpec detector arrays**

Microwave Kinetic Inductance Detectors (MKIDs) are an emerging technology capable of detecting electromagnetic waves similar to a CCD or a CMOS sensor used at major astronomical observatories as well as in digital cameras and mobile phones. However, the crucial difference between MKIDs and CCDs is that MKIDs are capable not only of determining the intensity of the incident light, but also the energy of each incident photon. An optical photon is absorbed in a superconducting thin-film and the energy deposited breaks a proportional number of Cooper-pairs which enables us to measure the incident photon energy. These detectors offer high sensitivity, low noise and are capable of being multiplexed to thousands of pixels on a single imaging sensor. MKIDs are potential candidates for replacing CCD based photo-detectors on ground and space-based telescopes in the future.

At Oxford Astrophysics we are currently building the KIDSpec instrument (Kinetic Inductance Detector Spectrograph) based around these detectors. This is a cryogenic spectrograph working in the Ultraviolet-Optical-Infrared (UVOIR) part of the electromagnetic spectrum. The detector arrays are installed in a custom cryostat and operated at millikelvin temperatures. The MPhys student will play a hands-on role, helping to perform measurements on the MKIDs and analyse the data to study their sensitivity, ability to determine the energy of photons and any noise sources that might hamper our ability to determine the photon energy. As a part of the larger development project, we plan to test various next-generation MKID arrays and feedback the information gained into the fabrication process in order to improve their performance.

Special Requirements

The project is suitable for an enthusiastic Physics student who is motivated to work in a laboratory environment taking readings and performing data analysis. A basic knowledge of Python programming language is an advantage, but not essential.

Supervisor: ***Dr S Mahashabde***
Email: ***sumedh.mahashabde@physics.ox.ac.uk***

AS20 **Measuring Galactic rotation with HI**

Atomic hydrogen in our Galaxy (and elsewhere in the universe) emits a characteristic narrow radio emission line at a frequency of 1420 MHz.

The narrowness and precise rest frequency of this HI line means that it can be used to trace motion via the Doppler effect. HI measurements are widely used in astrophysics to measure rotation velocities, as well as a tracer of the overall expansion of the universe. In this project the student will use a small radio telescope on the roof of the DWB to map out the HI emission in the plane of our own Galaxy. The signal received from any given direction is the sum of multiple components along the line of sight with different projected velocities. By modelling the line shapes the student will determine the shape of the Galactic rotation curve and hence verify the existence of Dark Matter in the Galaxy.

Supervisors: ***Prof M Jones, Prof A Taylor*** and ***Dr J Leech***
Email: ***Angela.Taylor@physics.ox.ac.uk***

AS21 **Measurement of gravitational lensing magnification in cosmological surveys**

The clumpy distribution of dark matter in the universe causes gravitational lensing of distant galaxies, which may be measured from the statistical distortion of galaxy shapes that results. So-called "weak lensing surveys" aim to measure this effect to high accuracy and use it to constrain cosmological models. Until recently, little attention has been given to the variation in apparent sizes of galaxies caused by gravitational lensing: this aim of this project is to measure lensing size variation in a state-of-the-art cosmological lensing survey, the Kilo Degree Survey (KiDS) and test its effectiveness at measuring the cosmological matter distribution.

Supervisor: ***Prof L Miller***
Email: ***Lance.Miller@physics.ox.ac.uk***

AS22 **Exploring the Universe with KIDSpec**

Microwave Kinetic Inductance Detectors (MKIDs) are an emerging technology capable of detecting electromagnetic waves similar to a CCD or a CMOS sensor used at major astronomical observatories as well as in digital cameras and mobile phones. However, the crucial difference between MKIDs and CCDs is that MKIDs are capable not only of determining the intensity of the incident light, but also the energy of each incident photon. An optical photon is absorbed in a superconducting thin-film and the energy deposited breaks a proportional number of Cooper-pairs which enables us to measure the incident photon energy. These detectors offer high sensitivity, low noise and are capable of being multiplexed to thousands of pixels on a single imaging sensor. MKIDs are potential candidates for replacing CCD based photo-detectors on ground and space-based telescopes in the future.

The KIDSpec instrument (Kinetic Inductance Detector Spectrograph) is a medium spectral resolution optical through near-IR spectrograph being built at Oxford astrophysics. This instrument uses the intrinsic energy resolution of MKIDs to distinguish photons from multiple diffraction orders, using an échelle grating as the dispersion element. KIDSpec has the potential to revolutionise the study of time domain astronomy, including the study of transient sources, such as supernovae and gamma-ray bursts (GRBs).

The scope of the MPhys project involves studying the capabilities of KIDSpec using a Python-based simulator that has been developed by our group in Oxford. This would involve studying the spectral reconstruction of various astrophysical sources like high-redshift galaxies, supernovae, GRBs and exoplanets by passing their known spectra through the simulator. The student will quantify the potential gains from using KIDSpec on current generation 8m telescopes (such as the VLT) and explore its future use on the next generation extremely large telescopes planned to come online in the 2020's (such as the 39m E-ELT).

Special Requirements

The project is suitable for an Astrophysics student who is interested in performing simulations. A basic knowledge of Python programming language is an advantage, but not essential.

Supervisor: ***Dr Kieran O'Brien***
Email: ***Kieran.OBrien@physics.ox.ac.uk***

AS23 **C-Band All Sky Survey project s(C-BASS)**

Oxford is currently leading the C-Band All Sky Survey project (C-BASS) which is an experiment to measure the intensity and polarisation of the whole sky at 5 GHz. The primary aim of the experiment is to provide maps of and to understand the low frequency Galactic foreground emission that must be subtracted from current and future measurements of the CMB such that e.g the faint CMB B-mode signature may be detected. The experiment consists of two telescopes - one observing from California to map the northern sky and another in South Africa mapping the Southern sky. The northern survey is now complete and the Southern survey well underway. We are looking for MPhys students to work with us on a range of projects:

- Calibration and cross-calibration of the C-BASS surveys

- Detailed analysis of the Southern survey data to understand the systematics in the data

- Combined analysis of C-BASS data with WMAP and Planck

- Measurement of the variation of spectral index of Galactic Synchrotron across the whole sky in intensity and polarization

- Forecasting of requirements for a future low-frequency foreground experiment in support of up-coming ground-based and satellite CMB B-mode experiments.

All these projects will involve a large element of computing. Experience with either Matlab or python would be desirable.

More general information about the C-BASS project can be found at: http://www.astro.caltech.edu/cbass/

Supervisors: ***Prof M Jones, Prof A Taylor*** and ***Dr J Leech***
Email: ***Angela.Taylor@physics.ox.ac.uk***

AS24 **Characterising Asteroids with Spectroscopy on the PWTPhilip Wetton Telescope**

Asteroids are taxonomically classified into different types based on the shape of their spectra. Most asteroids fall into three groups: C, S, and X; but there are about 20 other rarer groups. Around 1500 asteroids currently have classifications (primarily from the SMASS survey in 2002). This is enough to understand the general population, but many asteroids remain unclassified. This project will aim to use two new spectrographs on the Philip Wetton Telescope here in Oxford to classify previously unobserved asteroids.

The Philip Wetton Telescope (PWT) is a 40-cm telescope on the roof of the Denys Wilkinson building. It has a fairly advanced control system and set of instruments, meaning that even though it is relatively small, it can make interesting observations. We have recently added a spectrograph (developed through previous MPhys projects) to the telescope, which provides the necessary capability to do this project. The project will be the first serious use of the spectrograph for science. As such, some work will be needed to refine the observation and data reduction software.

The project will involve developing some (existing) software to select appropriate asteroids for observation; setting up the observations on the PWT; taking/monitoring the observations; developing a software technique to extract the spectra from the data; classifying the asteroid spectra.

Special Requirements

The project will require some night-time work with the telescope. Some familiarity with *nix computing, IRAF, and Python would be helpful, but not necessary.

Supervisor: ***Dr F Clarke***
Email: ***fraser.clarke@physics.ox.ac.uk***

AS25 **Giant radio pulses from radio emitting neutron stars**

Over the course of the last 2 years, we have been accumulating data using the Low Frequency Array (LOFAR) to search for new pulsars and fast radio bursts. In the process, we have accumulated data from a handful of known, extremely bright pulsars. These pulsars are seen to occasionally emit extremely bright individual pulses, a phenomenon referred to typically as giant pulse emission. The low radio frequency data of LOFAR are particularly prone to propagation effects, as the radio signals travel through the magneto-ionised interstellar space. In this project, we will investigate individual pulses from this population of pulsars, with the aim of characterising the interstellar medium and the intrinsic properties of giant pulse emission. These investigations will shed light on the radio emission process of pulsars at low radio frequencies (150 MHz) and help understand potential extreme propagation events in the Galaxy. Work will be supported by pulsar group members from Astrophysics and the OeRC.

Supervisor: ***Dr A Karastergiou***
Email: ***aris.karastergiou@gmail.com***

AS26 **High-redshift disk formation**

Although unobserved as yet, galaxies in their infancy about 500 million years after the Big Bang are already being simulated by computational cosmologists. These early galaxies are predicted to form at the intersections of the cosmic web that grows out of the seed perturbations imprinted after the Big Bang. This project will study how gas streaming along filaments in the cosmic web can form rapidly rotating, dense, gaseous disks at their intersections in the high redshift Universe. In the simulations, these gaseous disks appear to be rotating as fast as the Milky Way but they are about a tenth of its size. Under such extreme conditions, a disk can become gravitationally unstable and fragment into massive gas "clumps" which could collapse into star clusters. Therefore understanding how these high redshift galaxies acquire their rapid rotation is crucial to making sense of high-redshift star formation.

The goal of this project, is to explain these rapidly rotating, small disks. This will involve converting outputs from ultra-high resolution hydrodynamical cosmological simulations into a format that is readable by a sophisticated three-dimensional visualization software, and then measuring the orientation of the filaments relative to the disk. From the geometrical information, and measurements of the gas velocities in the filaments, an explanation for the disk orientation and extreme rotational disk velocities will be constructed.

Good programming skills required.

Supervisors: ***Prof A Slyz*** and ***Dr J Devriendt***
Email: ***Adrianne.Slyz@physics.ox.ac.uk; julien.devriendt@physics.ox.ac.uk***

AS27 **Radio telescope receiver systems**

The physics department is setting up a radio astronomy lab for teaching and outreach, consisting of two small telescopes on the roof of the DWB.

This project is to develop a new control and receiver system for these telescopes, and to demonstrate the ability to make astronomical observations with it. The student will use a high-speed data acquisition system based on a Field-Programmable Gate Array to develop a digital backend that can be used to make broad-band spectral and continuum observations, and integrate this with the telescope control system so that the telescope can simultaneously track and take data. The performance of the system will be verified by observing astronomical sources. This project will require a reasonable level of computing skills as well as an inclination towards practical experimentation

Supervisors: ***Prof M Jones, Prof A Taylor, Dr J Leech, Dr K Zarb Adami***
Email: ***Angela.Taylor@physics.ox.ac.uk***

AS28 **The Possibility of Planets Orbiting Post-Common Envelope Binaries**

Post-Common Envelope Binaries (PCEB) originate from Main Sequence (MS) binaries in which one star is more massive than its companion. The more massive star leaves the MS and evolves up the Red Giant Branch RGB), leaving the companion star to complete its MS evolution. On account of expansion of the star evolving up the RGB, it forms a common envelope with the MS companion. In due course the RGB star undergoes a core helium flash and the common envelope is expelled. What remains is a MS star orbiting a hot subdwarf (the former RGB star) in a close binary where the orbital period is typically two or three hours.

Small changes in orbital periods are interpreted as light travel-time effects caused by one or more planets orbiting the binary, whose centre of mass is in orbit about the barycentre of the planetary system. There is much discussion in the literature as to whether planetary systems formed at the same time as the stars themselves and survived the expulsion of the common envelope, or whether planets formed later from gas expelled when the common envelope was lost. Other explanations of PCEB orbital period changes, not involving planets, are also proposed.

Further observations of eclipse timings are needed to confirm the existence of planets orbiting PCEB binaries. The purpose of this project is to obtain eclipse timings of a selected PCEB binary using the Philip Wetton Telescope.

For further reading see Voelschow M, Schleicher DRG, Perdelwitz V & Banerjee R, 2016 Astronomy and Astrophysics 587, 34.

Supervisor: ***Dr A E Lynas-Gray***
Email: ***tony.lynas-gray@physics.ox.ac.uk***

AS29 **Gas phase metallicities in dusty galaxies**

In astronomy the metallicity of an object is the fraction of its matter that is made up of chemical elements heavier than hydrogen and helium. The term `metal' is used for convenience to describe all other elements collectively. The metallicity of gas and stars in galaxies is a fundamental parameter that allows us to distinguish between various galaxy evolution scenarios. Metallicity depends heavily on the star-forming activity of a galaxy as well as its gas inflow/outflow history.

Traditionally, gas metallicities have relied on optical and near infrared line diagnostics. However, metallicity estimates based on optical emission lines appear to underestimate the true metal content in many dust-obscured galaxies such as ultraluminous infrared galaxies (ULIRGs) and submillimetre galaxies (SMGs). Strong evidence suggests that in these galaxies, the metallicities inferred from the dust mass are much higher (by more than an order of magnitude) than those inferred from optical emission lines.

Far-infrared lines provide an alternative way of determining metallicities avoiding the problem of extinction that plagues optical measurements. The far-infrared wavelength regime contains many fine structure emission lines radiated by various ions from various excitation levels that can be used to determine metallicities in dust-obscured galaxies.

In this project we will explore the use of far-infrared lines to estimate the metallicity of dust-obscured galaxies and compare the findings to earlier estimates based on optical emission lines. The work will involve use of the photo-ionisation code CLOUDY (and the associated plotting routines). In particular we will investigate how the line ratios depend on the shape and age of the underlying stellar population, hardness of the radiation field as well as the geometry of the medium. A brief introduction to CLOUDY will be provided. Familiarity with IDL and/or Python will be helpful although not absolutely essential.

Supervisor: ***Prof D Rigopoulou***
Email: ***Dimitra.Rigopoulou@physics.ox.ac.uk***

AS30 **High Precision Evaluation of Exponential Integrals**

The exponential integral plays an important role in molecular structure and radiative transfer, to name just two examples. In radiative transfer problems it is common to evaluate the First Exponential Integral using a Chebyshev Series, and then a recurrence formula to obtain evaluations of higher order Exponential Integrals as required. A difficulty arises because the recurrence formula is numerically unstable in some circumstances. The purpose of this project is to evaluate Exponential Integrals to high accuracy directly from power series expansions using multi-precision arithmetic and test more approximate methods commonly used. For further reading see Abramowitz M & Stegun I, 1972 "Handbook of Mathematical Functions With Formulas, Graphs and Mathematical Tables", National Bureau of Standards Applied Mathematics Series 55, Chapter 5.

Supervisor: ***Dr A E Lynas-Gray***
Email: ***tony.lynas-gray@physics.ox.ac.uk***

AS31 **tbc**

More details from the supervisor.

Supervisor: ***Dr C Terquem***
Email: ***Caroline.Terquem@astro.ox.ac.uk***

AS32 **tbc**

More details from the supervisor.

Supervisor: ***Prof S Balbus***
Email: ***Steven.Balbus@astro.ox.ac.uk***

Biological Physics projects

BIO01 **Magnetics tweezers for application of torque to the bacterial flagellar motor**

The aim of the project is to develop "magnetic tweezers" and to use them to control the rotation of the bacterial flagellar motor.

Many species of bacteria swim, propelled by a rotary electric motor embedded in their outer walls. The bacterial flagellar motor consists of a set of rings about 50 nm in diameter, the rotor, surrounded by a stator consisting of a ring of ion channels anchored to the cell wall. Ion flow through the stator is coupled to torque generation and rotation by a mechanism that is still poorly understood. The rotor is attached to a long helical propeller called the filament, which extends for several microns into the surrounding fluid.

Even measuring rotation of the motor is a challenge, given its small size. One method is to attach a relatively large plastic bead (~ 1 micron diameter) to the filament and record its rotation by light microscopy, either using video analysis or laser-scattering nanometry. This bead can also be magnetic – "superparamagnetic" beads of suitable size and surface chemistry are commercially available, and have magnetic permeabilities sufficiently anisotropic to allow application of torque via magnetic fields.

The student will work with a custom-built magnetic tweezers setup on a light microscope. Magnetic fields are generated by computer-controlled current amplifiers, enhanced by a ferrite transformer core and concentrated at the sample by soft iron pole pieces. The rotation of the magnetic beads is monitored via deflection of a focussed laser beam, recorded via computer on a position-sensitive quadrant photodiode. With this setup it has been possible to control the rotation speed up to at least 200 revs per second. Several experiments are possible. The flagellar motor has recently been shown to be a mechanosensor: the stator ring contains fewer elements at lower mechanical load. This may be involved in bacterial sensing of attachment to surfaces during biofilm formation. By controlling the motor speed with the magnetic tweezers and measuring the dependence upon speed of the stator stability, this mechanosensitivity could be quantified and models proposed for its mechanism. Alternatively, in collaboration with postdoctoral researchers, the ion flux through the motor as a function of speed might be measureable. This would be an important test of models of the motor mechanism.

Requirement: Some familiarity with optics and computer programming would be useful, but no specific prior experience is necessary. Please contact the supervisor if you are interested in the project.

Supervisor: ***Dr R Berry***
Email:***Richard.Berry@physics.ox.ac.uk***

BIO02 **Ultra-fast measurement of molecular motor rotation by polarization anisotropy microscopy of gold nanorods.**

The aim of the project is to develop and test a system for recording the rotation of bacterial flagella and other biological molecular motors.

Many species of bacteria swim, propelled by a rotary electric motor embedded in their outer walls. The bacterial flagellar motor consists of a set of rings about 50 nm in diameter, the rotor, surrounded by a stator consisting of a ring of ion channels anchored to the cell wall. Ion flow through the stator is coupled to torque generation and rotation by a mechanism that is still poorly understood. The rotor is attached to a long helical propeller called the filament, which extends for several microns into the surrounding fluid.

Even measuring rotation of the motor is a challenge, given its small size. One method is to attach a relatively large plastic bead (~ 1 micron diameter) to the filament and record its rotation by light microscopy, either using video analysis or laser-scattering nanometry. For maximum time-resolution, the filament can be removed and a gold bead (~100 nm diameter) attached to the rotor. This reduces both the compliance of the link to the bead and its rotational drag coefficient, giving large increases in time resolution. Gold beads scatter light relatively efficiently, and can be imaged at up to 100 kHz with sufficient signal-to-noise to allow localization accuracies less than 1nm. However, measuring the location of a spherical bead is intrinsically a poor way to record rotation – a well aligned bead rotating about its diameter gives no signal! A better method is to record anisotropic scattering of polarized light by a gold nano-rod.

The student will work with a custom-built back-scattering laser-dark-field microscope. Light scattered by gold nanorods will be split according to polarization and imaged either with an ultra-fast camera or a custom-built 5 x 5 avalanche photodiode array. Differences between the scattered intensity in different polarizations will be used to infer the orientation of the gold nano-rod. Gold nano-rods will then be attached to bacterial flagella and their rotation speeds recorded. Furthermore, rotation is believed to proceed in 26 steps per revolution. The nano-rod method will allow these steps to be measured with unprecedented accuracy, allowing models of the motor mechanism to be tested.

Requirement: Some familiarity with optics and computer programming would be useful, but no specific prior experience is necessary. Please contact the supervisor if you are interested in the project.

Supervisor: ***Dr R Berry***
Email:***Richard.Berry@physics.ox.ac.uk***

BIO03 **Structure/function studies of ion channels**

The project will involve determining the relationship between the structure and function of a number of different ion channels found in the membranes of living cells which control cellular electrical excitability. We principally study K+ ion channels using a combination of molecular biology, protein biochemistry and electrophysiology.

Requirement: Although no previous experience is required, some interest in biological systems is essential as there will be a certain amount of background reading required.

Supervisor: ***Dr S Tucker***
Email: ***stephen.tucker@physics.ox.ac.uk***

BIO04 Physics of cryopreservation of cell membranes

During cryopreservation cells (e.g. stem cells, sperm), tissues (ovarian tissues, umbilical cord), and even living organisms (bacteria, animal embryos) are preserved by cooling to sub-zero temperatures. A significant challenge of cryopreservation is to avoid damage caused by the formation of ice during freezing. It is known that when cells are frozen they undergo a ''cold shock'' which leads to mechanical damage to the plasma membrane and leakage of solutes across membranes. There is very little research about the physical aspects of the cell membrane freezing and thawing processes and in particular in the role of the membrane in the water structure during the freezing and thawing processes. This project aims at investigating the effect of freezing and thawing in lipid membrane models systems. It focuses in studying the role of the lipid phase/ordering on the water structure during freezing by atomic force microscopy.

Special skills: This is an experimental project but requires good data analysis skills (Matlab, python or equivalent) and willingness to pursue a multidisciplinary project.

Supervisor: ***Dr S Antoranz Contera***
Email: ***Sonia.AntoranzContera@physics.ox.ac.uk***

BIO05 Mechanical and transport properties of biomaterials for tissue engineering and 3D cell cultures

Hydrogels have applications in drug delivery, mechanical actuation and regenerative medicine. Applications in these fields require a robust characterisation of the mechanical and transport properties in their hydrated state. The most promising method for assessing mechanical properties is by nanoindentation, however there are unique challenges associated with testing hydrated materials, since they are at the same time poroelastic and viscoelastic, which requires that the fluid flow through the porous material is explicitly included in the interpretation of data. This project aims at implementing a new indentation scheme that can complete quantitative characterisation of hydrated hydrogels and analysing data using it.

Special skills: This is a computer based knowledge. Advanced level knowledge of Matlab is essential.

Supervisor: ***Dr S Antoranz Contera***
Email: ***Sonia.AntoranzContera@physics.ox.ac.uk***

BIO06 Biosensors for rapid detection of viruses

Many viruses (from the flu virus to the Zika virus) can cause debilitating and deadly diseases, and their sensitive, specific and rapid detection is a major challenge in their identification and control. We have been developing novel detection methods (in part due to two successful MPhys projects) based on single-molecule fluorescence imaging and single-particle tracking to detect the influenza virus on a compact microscope that can be used in clinical settings; the detection can be completed in just a few minutes, as opposed existing assays that require many hours.

This project will extend the previous flu biosensing work in many possible ways: optimizing detection by improving the particle illumination scheme, the current diffusion analysis, and by using simultaneous particle detection in two spectral regions; adapting the assay to clinical settings and testing variants of the flu virus; adapting the assay to a different virus (using safe simulants); and increasing the throughput and specificity of the existing assay (an exercise in "big-data" treatment, reduction, and representation).

No prior knowledge or experience of biophysics is necessary; experience in optics and programming would be an advantage. Introductory literature will be provided.

Supervisor: ***Prof A Kapanidis***
Website: ***groups.physics.ox.ac.uk/genemachines/group/index.html***
Email: ***Achillefs.Kapanidis@physics.ox.ac.uk***

BIO07 & BIO08 Super-resolution imaging of pathogenic microbes

Accurate localisation of single fluorescent molecules is at the heart of many methods that have recently shuttered the diffraction limit in optical microscopy, taking the resolution on 10 nm; the potential of these methods was acknowledged by a Nobel prize in 2014. We have been developing super-resolution fluorescence imaging and tracking methods both in fixed and live biological cells, and applied them to many organisms ranging from bacteria to mammalian cells; we are especially interested in pathogenic bacteria and viruses and their interactions with host cells. Our methods are both computational (involving image and time-series analysis) and experimental.

These two projects will focus on an aspect of super-resolution imaging and single-molecule tracking. Example projects: rapid detection and segmentation of bacterial cells (to be used towards rapid detection of antibiotic resistance); detection of influenza particles, proteins and RNAs in mammalian cells, and subsequent clustering analysis; application of theoretical models to describe diffusion and interactions of molecules inside living bacteria; and development of biosensors that probe the physiology of bacterial cells through physical descriptions of the cell interior (a novel method that can detect whether a certain antibiotic is working or not).

All projects will involve wide-field imaging of cells and extensive image analysis, and can have an experimental, computational, or modelling focus. The students are encouraged to have a discussion with the supervisor regarding the focus of the project.

No prior knowledge or experience of biophysics is necessary; experience in optics and programming would be an advantage. Introductory literature will be provided.

Supervisor: ***Prof A Kapanidis***
Website: ***groups.physics.ox.ac.uk/genemachines/group/index.html***
Email: ***Achillefs.Kapanidis@physics.ox.ac.uk***

BIO09 & BIO10 DNA Nanostructures

DNA is a wonderful material for nanometre-scale fabrication. Short lengths of DNA can be designed such that Watson-Crick hybridization between complementary sections leads to the self-assembly of complex nanostructures. Nanostructures can be used to deliver a payload into a cell, as a scaffold for protein crystallography or as both track and motor components of a molecular assembly line. The project will involve design, fabrication and characterization of a DNA nanostructure.

Supervisor***: Prof A Turberfield***
Email***: andrew.turberfield@physics.ox.ac.uk***

Condensed Matter Physics projects

CMP01 Micromagnetic Simulations

Magnetic multilayers are at the heart of modern computing, with effects such as giant magnetoresistance (which won the Nobel Prize in 2007) being integral to the continued growth of computer power. A new generation of devices aims to achieve ultrafast write operations through the use of the spin transfer torque, realising a low-power high-stability memory scheme.

The project aims at understanding the magnetisation dynamics in magnetic thin film systems. Computer simulations of the detailed position- and time-dependent magnetisation ("micromagnetism") describe these phenomena well. The ferromagnet can still be coerced into motion by applying external magnetic fields at a finite angle to the magnetisation direction. The system then moves in response, trying to minimise its Zeeman energy, such as by alignment of its lattice. Minimisation of this finite switching time by engineering magnetic anisotropies and magnetisation damping rates is an important goal in the design of fast magnetic memories. Improved understanding of precessional magnetisation dynamics is essential for the continued development of high frequency magnetic devices such as hard disk drives and spin oscillators. We also study finite-size effects that rise in nanostructures, where the demagnetisation energy plays a significant role in the dynamics.

This project will involve modelling of micromagnetic systems using NIST's Object Oriented Micromagnetic Framework (OOMMF).

Further Reading: Donahue, MJ and Porter, DG "OOMMF User's Guide, Version 1.0" NIST inter-agency report

Special skills required: As a simulation project an interest in computing and programming, particularly in Python, would be advantageous. Experience of OOMMF and micromagnetism is not required, but desirable.

Supervisor***: Dr T Hesjedal***
Email***: Thorsten.Hesjedal@physics.ox.ac.uk***

CMP02 Calculation of the magnetic properties of molecular magnets

New molecular magnets have been prepared which consist of chains of magnetic ions linked by organic groups and single molecule magnets in which the magnetic ions are embedded within single molecules [1]. The magnetic properties of such systems will be calculated using statistical mechanical techniques with the aim of exploiting the symmetry inherent in these systems [2], and an algorithm will be developed based on the Lanczos method to diagonalize very large matrices. Programs will be written using the Python computer language.

Background reading:

[1] S. J. Blundell and F. L. Pratt, J. Phys.: Condens. Matter 16, R771 (2004).

[2] R. Schnalle and J. Schnack, Phys. Rev. B 79, 104419 (2009).

Supervisor*: **Prof S Blundell***
Email*: **Stephen.Blundell@physics.ox.ac.uk***

CMP03 Quantum properties of implanted muons in muonium states

Muons implanted into materials can be used to measure local microscopic fields [1]. This theoretical and computational project will employ quantum-mechanical calculations using density matrices [2] to evaluate the spin dynamics of muons in various model situations (see [3],[4] for recent examples), including in muonium states where the muon has a strong hyperfine coupling to an electron. Programs will be written using the Python computer language.

Background reading:

[1] S. J. Blundell, Contemporary Physics 40, 175 (1999).

[2] M. Celio and P. F. Meier, Phys. Rev. B 27, 1908 (1983).

[3] J. S. Möller, D. Ceresoli, T. Lancaster, N. Marzari and S. J. Blundell, Phys. Rev. B 87, 121108(R) (2013).

[4] F. R. Foronda, F. Lang, J. S. Möller, T. Lancaster, A. T. Boothroyd, F. L. Pratt, S. R. Giblin, D. Prabhakaran and S. J. Blundell, Phys. Rev. Lett. 114, 017602 (2015).

Supervisor*: **Prof S Blundell***
Email*:**Stephen.Blundell@physics.ox.ac.uk***

CMP04 Simulations of Solid State Matter Compressed to Planetary Interior Conditions

The highest pressure solids that can be produced on Earth have conventionally been created by squeezing matter between two diamond anvils - a method that works well until the anvils break. Unfortunately, this happens at a few Mbar - about the pressure at the centre of the Earth. To get to much higher pressures, we must use dynamic techniques - such as evaporating the surface of a solid sample with a high power laser, and allowing the plasma to expand into the vacuum. The rest of the target feels a force (via Newton's third law), and is slowly compressed to tens of Mbar, and it is believed that pressures close to that at the centre of Jupiter (70 Mbar) can be obtained by this method. The trick is to keep the material close to an isentrope, and to stop the compression wave forming a shock (which will melt the sample). In this project the student will undertake hydrodynamic and multi-million atom molecular dynamics simulations of both shock and ramped-compressed targets to identify the isentropic and heating regions. Interestingly, the 'slow' compression associated with an isentrope can be as rapid as a few hundred picoseconds.

Reading

Higginbotham et al, Phys. Rev. B 85, 024112 (2012)

Supervisors: ***Prof J Wark and Dr D McGonegle***
Email: ***Justin.Wark@physics.ox.ac.uk*** and ***David.McGonegle@physics.ox.ac.uk***

CMP05 Why do 2D materials grow into nanoribbons?

Topological insulators are a very exciting new class of quantum materials that are insulating in their bulk and conducting on their surfaces. The exotic metallic surface state is topologically protected by time-reversal symmetry against a number of scattering effects. As a result, the novel phases of matter that have been known since the discovery of the fractional quantum Hall effect seem now to be in reach for room-temperature spintronic and quantum computing device applications.

The goal of this project is gain an understanding of the growth mechanism of Bi2Te3 nanostructures. Bi2Te3 is a topological insulator (TI) with a layered structure similar to graphite. Intuitively, one would expect it to grow exclusively in the form of nanoplates. However, quasi-one dimensional, single-crystalline Bi2Te3 nanoribbons are found instead. The important question is about the factors that lead to preferential growth in one direction. For the project, a selection of chemical vapour deposition (CVD) grown nanoribbons will be investigated using scanning electron microscopy (SEM). Simulation code (Comsol) will be used to simulate the temperature distribution in the CVD furnace, and other software to understand the growth process.

Reading list: P Schoenherr, D Prabhakaran, W Jones, N Dimitratos, M Bowker, T Hesjedal, Comparison of Au and TiO2 based catalysts for the synthesis of chalcogenide nanowires, Appl. Phys. Lett. 104, 253103 (2014)

Required skills: interest in materials and simulations. Desired skills: programming (e.g. Python)

Supervisor***: Dr T Hesjedal***
Email***: Thorsten.Hesjedal@physics.ox.ac.uk***

CMP06 Modelling the structural and magnetic diffraction pattern from layered materials

Many materials of current research interest for novel electronic and magnetic properties have a layered crystal structure made up of stacked two-dimensional atomic layers. When layers are weakly bonded to one another then occasionally there will be faults in the regular stacking sequence, when the origin position in a certain layer would slide by some in-plane offset to a position that is not in register with the layers below. Such faults are manifested in the x-ray diffraction pattern in a diffuse scattering signal with certain characteristics, in addition to the Bragg peaks associated with the ideal structure. The aim of this project is to develop an efficient way to calculate the diffraction pattern in the presence of such faults to compare with experimental x-ray diffraction data, and identify the microscopic types of stacking faults that occur in honeycomb magnets with novel magnetic properties stabilized by the combined effect of a strong spin orbit coupling and a two-dimensional honeycomb lattice for the magnetic ions. It is anticipated that Matlab or Python will be used to write code to calculate the expected structural and magnetic diffraction pattern with the flexibility to capture different types of stacking faults and magnetic orders.

This project would require the ability to learn independently from books and papers and a keen interest and experience in programming. Suitable for a student taking the C3 CMP option.

Supervisors***: Dr R Johnson*** and ***Dr R Coldea***
Email***: Roger.Johnson@physics.ox.ac.uk***

CMP07 Understanding the symmetry of FeSe: a building block for high temperature superconductivity

A number of iron-based materials have recently been found to support high temperature superconductivity, and are therefore at the forefront of solid-state physics research. The binary compound FeSe can be considered as a fundamental building block of the much wider class of iron-based superconductors. FeSe is itself a superconductor below 9 K, and at higher temperature this material displays complex electronic ordering phenomena associated with changes in crystal symmetry – unexpected given the apparent chemical simplicity. If we can fully understand the symmetry of the lattice, and the electronic interactions that it supports at high temperature, we will gain insight into the properties of the superconducting state at low temperature, not only in FeSe, but in the iron-based superconductors in general.

Single crystal samples of FeSe have been grown in the Clarendon Laboratory. Preliminary experiments have found evidence for subtle variations in their crystal structure that are likely to result from small deviations in the Fe:Se compositional ratio. In this project, the crystal structure of numerous single crystal samples will be measured by variable temperature x-ray diffraction, and the chemical composition will be determined through energy dispersive x-ray spectroscopy, implemented on an electron microscope. Both diffraction and spectroscopy data will be quantitatively analysed and compared, and conclusions drawn on the origin of the structural differences and the implications for high temperature superconductivity in these materials.

Suitable for a student taking the C3 CMP option

Supervisor***: Dr R Johnson***
Email***: Roger.Johnson@physics.ox.ac.uk***

CMP08 Automated dispersion compensation for femtosecond laser pulses

The duration of a sub 100-femtosecond laser pulse is susceptible to dispersion in optical elements such as windows and lenses. To compensate for the (usually positive) dispersion in optical materials such as glasses, laser pulses are “stretched” or “pre-chirp” prior to entering the experiment so that the laser pulse that arrives at the experiment is as short as possible. In this project you will construct a two-photon sensor to measure pulse duration and write software to control an existing grating based dispersion compensation unit. The software will consist of a feedback loop to dynamically maintain the shortest laser pulses at the experiment and a graphical user interface. This ideally suits a student who is keen on programming and is interested in learning about instrument and P-I-D control.

Supervisor: ***Prof M Johnston***
Email: ***michael.johnston@physics.ox.ac.uk,***

CMP09 Fourier Raman Spectroscopy of Metal Halide Perovskites

Research into organic-inorganic Perovskite materials for solar cell applications is currently an extremely active area of research. In just a few years power conversion efficiencies of these solar cells have jumped from a few percent to ~20%. In this project you will use Fourier methods to measure the Raman and infrared active modes of state-of-the-art vapour deposited perovskite thin films. The project will involve spectroscopy, and data analysis (including symmetry analysis and mode assignments). The project is best suited for someone who would like to continue research in experimental physics.

Further reading: see Nature, 501:395 and J. Phys. Chem. C 119:25703

https://www-thz.physics.ox.ac.uk/perovskites.html

Supervisors: ***Prof M Johnston*** and ***Prof L Herz***
Email: ***michael.johnston@physics.ox.ac.uk, Laura.Herz@physics.ox.ac.uk***

CMP10 Investigation of Microstructural Evolution in Organic Semiconductors

Organic semiconductors have the potential to enable inexpensive and ubiquitous electronic devices with highly tailored functionality, from solar modules to wearable sensing devices. However, many organic semiconductors remain susceptible to degradation when subjected to elevated temperature or ambient gases. The goal of the project is to better understand the role of microstructural re-organization during thin film exposure to these various stimuli. The results of this investigation will be of high relevance for the next generation of electronic devices based on organic semiconductors.

The MPhys student will use in-situ x-ray diffraction to assess the impact of temperature and trace gas concentration on small-molecule thin films relevant to organic photovoltaics and gas sensor devices. The student should have a strong interest in solid state physics. The project will also provide an opportunity to learn thermal deposition techniques for organic electronics and device physics, based on the student’s own interests. If you would like to discuss project details, feel free to contact us:

Supervisors: ***Dr J Martinez Hardigree*** and ***Dr M Riede***
Email: ***josue.martinezhardigree@physics.ox.ac.uk*** and ***moritz.riede@physics.ox.ac.uk***

CMP11 Photoluminescence from organo metal halide perovskites

Recently a new family of semiconducting material, the organometal halide perovskites, has been generating a huge amount of interest as a candidate for high performance next generation solar cells, able to deliver low cost renewable energy on a large scale. However, these materials are still at an early stage of development and their performance has not yet been optimised.

This project will use photoluminescence quantum efficiency (PLQE) and time-resolved photoluminescence spectroscopy to investigate the dynamics of the charge carriers in the perovskite. This will include the study of various surface treatments and their impact on charge lifetimes, thermal stability and solar cell device performance. The project will encompass several types of new and exciting perovskite materials, which are already showing promising solar cell device results. Specific details of the investigation may be discussed with the supervisor.

This is an experimental project, predominantly working with lasers using photoluminescence spectroscopy techniques. There could also be the opportunity to prepare samples in the laboratory, write Matlab code to analyse data and to use physical models to determine properties of the material, depending on the interests of the student and the development of the project.

Supervisor: ***Dr H Snaith***
Email: ***henry.snaith@physics.ox.ac.uk***

CMP12 Electronic structure of novel superconducting materials under applied strain

The iron-based superconductors containing represent new materials showing realistic potential towards their practical implementation. Among the different materials, FeSe, seems to be one of the simplest superconductor with intriguing electronic behaviour. Its superconducting properties can be enhanced either by applying hydrostatic pressure, by intercalating different alkali ions between its conducting layers or by the induced strain in its single-layer form.

This project is an experimental project which will consist in applying strain to superconducting FeSe and related materials to understand how it affects its normal and superconducting properties. Measurements will be performed also in high magnetic fields and at low temperatures. A suitable candidate for this project should have good knowledge of condensed matter courses, attention to details and good experimental skills. Strong computational skills would also be valuable to the project.

For further questions please email amalia.coldea@physics.ox.ac.uk

Emergence of the nematic electronic state in FeSe Phys. Rev. B 91 (2015)

Dichotomy between the Hole and Electron Behavior in Multiband Superconductor FeSe Probed by Ultrahigh Magnetic Fields Phys. Rev. Lett. 115, 027006 (2015)

Divergent Nematic Susceptibility in an Iron Arsenide Superconductor Science 10 August 2012, Vol. 337 no. 6095 pp. 710-712

Measurement of the elastoresistivity coefficients of the underdoped iron arsenide Ba(Fe0.975Co0.025)2As2 Phys. Rev. B 88, 085113 (2013)

Other useful links:

Wien2k allows electronic structure calculations of solids using density functional theory (DFT); BoltzTrap is a program for calculating the semi-classic transport coefficients.

Supervisor: ***Dr A Coldea***
Email: ***Amalia.Coldea@physics.ox.ac.uk***

CMP13 **Electronic structure of novel superconducting materials. Computational study of upper critical field in multiband superconductors**

A number of potentially relevant novel superconducting materials have complicated band structure with a large number of electron and hole bands. In order to understand the phase boundaries of these superconductors in magnetic field one needs to understand the contribution of the different bands to the upper critical field for two different orientations in magnetic field.

This project aims to predict the electronic properties of new candidate superconductors computationally in order to reveal the contributions of different bands to the upper critical field. A suitable candidate for this project should have good knowledge of condensed matter courses and theoretical physics and strong computation skills would be valuable to the project.

For further questions please email amalia.coldea@physics.ox.ac.uk

For further reading please see:

Upper critical field and the Fulde-Ferrel-Larkin-Ovchinnikov transition in multiband superconductors , A. Gurevich Phys. Rev. B 82, 184504 (2010)

Enhancement of the upper critical field by nonmagnetic impurities in dirty two-gap superconductors, A. Gurevich Phys. Rev. B 67, 184515 (2003)

Limits of the upper critical field in dirty two-gap superconductors Physica C: Superconductivity, Volume 456, Issues 1–2, 1 Pages 160–169 (2007)

Supervisor: ***Dr A Coldea***
Email: ***Amalia.Coldea@physics.ox.ac.uk***

CMP14 **Surface acoustic wave quantum devices**

Surface acoustic waves are mechanical waves that travel along the surfaces of crystals at a few km/s. On piezoelectric crystals, they are widely used in electronic devices (e.g filters in your mobile phone). We have recently made the first measurements of surface acoustic wave resonators in the single phonon regime (measured at 10 mK), paving the way for experiments integrating them into quantum circuits. This project will involve designing and measuring some new superconducting SAW devices in which we try to realise microwave frequency cavity optomechanics - physics that has so far mostly been realised with much lower frequency mechanics and higher frequency light. The devices may find applications in filtering of quantum signals in future quantum computers.

Supervisor: ***Dr P J Leek***
Email: ***peter.leek@physics.ox.ac.uk***

CMP15 **A new architecture for superconducting circuit quantum computing**

Superconducting electric circuits are proving to be a strong candidate for building the world's first useful universal quantum computer within the next decade. We are developing a new architecture that we think could be a strong candidate for scaling up to the 50-100 qubit level, at which calculations beyond classical computers could become possible.

This project may involve any of: CAD design, electromagnetic simulation, experimental control programming, measurements of multi-qubit circuits in our new architecture. Depending on progress it may involve benchmarking and optimisation of one and two-qubit logic gates.

Supervisor: ***Dr P J Leek***
Email: ***peter.leek@physics.ox.ac.uk***

CMP16 **Exploring the electronic properties of the topological Dirac materials. Searching for the chiral anomaly using angle dependent magnetotransport studies**

Topological insulators are electronic materials with strong spin-orbit interaction that have insulating bulk properties and topologically protected metallic surfaces on their surfaces or edges. In ordinary materials, backscattering, in which electrons take a turn back owing to collisions with crystal defects, effectively degrades the current flow and increases the resistance. On the surface of topological insulators, backscattering processes are completely suppressed (forbidden), so charge transport is in a low-dissipation state with exceptional transport mobility and reduced energy consumption, which due to their long life and low maintenance costs are extremely attractive for semiconductor devices. The superconductivity found in certain candidate topological insulators is predicted to have a significant effect on understand fundamental physics in particular in the search for Majorana fermions as well as from the applications point of view to pave the way towards designing novel dissipationless devices.

This project aims is to experimentally probe to electronic properties of novel Dirac materials using high magnetic fields and low temperatures. A suitable candidate for this project should have good knowledge of condensed matter courses. Strong experimental and computational skills would be valuable to the project.

For further questions please email amalia.coldea@physics.ox.ac.uk

For further reading please consult:

Giant negative magnetoresistance induced by the chiral anomaly in individual Cd3As2 nanowires arXiv:1504.07398

Linear magnetoresistance caused by mobility fluctuations in the n-doped Cd3As2 Phys. Rev. Lett. 114, 117201 (2015)

Topological insulators and superconductors, Rev. Mod. Phys. 83, 1057-1110 (2011) or http://arxiv.org/abs/1008.2026

Observation of a topological 3D Dirac semimetal phase in high-mobility Cd3As2 and related materials http://arxiv.org/abs/1211.6769

Other useful links:

Wien2k allows electronic structure calculations of solids using density functional theory (DFT); BoltzTrap is a program for calculating the semi-classic transport coefficients.

Supervisor: ***Dr A Coldea***
Email: ***Amalia.Coldea@physics.ox.ac.uk***

CMP17 **High fidelity single-shot readout of qubits in circuit QED**

One of the key requirements for operation of a quantum computer is to be able to carry out high fidelity (trustworthy) measurements of the states of the qubits at the end of quantum algorithms, or during, to enable reliable error correction. In superconducting circuits, this is commonly achieved by coupling electromagnetic resonators to qubits and observing how their frequencies shift with the qubit states via short pulses of radiation. At low pulse power, this process is very well understood and fits to a simple quantum mechanical model, but does not provide very high signal-to-noise. This project will involve experimentally investigating this so-called 'dispersive readout' at high pulse powers, and improving the measurement electronics and algorithms, to understand and optimise the qubit readout fidelity.

Supervisor: ***Dr P J Leek***
Email: ***peter.leek@physics.ox.ac.uk***

CMP18 **A computational study of electronic band-structure of novel superconductors as determined from ARPES experiments**

Angle resolve photoemission spectroscopy (ARPES) is a powerful tool to extract information about the electronic structure of novel quantum materials. The ARPES measures the band dispersions and in order to extract their positions requires detailed analysis of the position of the bands in momentum space.

This project aims to develop of friendly GUI interface in Matlab in order to improve the visualization of the ARPES data using the second derivative method in tracking the position of extrema from experimental curves and to improve the localization of the band extrema for a better visualization of intensity image plots.

A suitable candidate for this project should have good knowledge of condensed matter courses and strong computation skills would be valuable to the project.

For further questions please email amalia.coldea@physics.ox.ac.uk

For further reading please see:

A precise method for visualizing dispersive features in image plots Rev. Sci. Instrum. 82, 043712 (2011)

Angle-resolved photoemission studies of the cuprate superconductors Rev. Mod. Phys. 75, 473 (2003)

Supervisor: ***Dr A Coldea***
Email: ***Amalia.Coldea@physics.ox.ac.uk***

CMP19 **Photoluminescence of single semiconductor nanowires investigated by confocal microscopy.**

Semiconductor nanowires may become a key part of nanotechnology, acting as building blocks for compact electronic and optoelectronic devices from photovoltaics to light emitting diodes. However, problematic are the potential structural and compositional fluctuations of such nanowires within an ensemble fabricated by modern growth epitaxy. In the proposed project, differences between semiconductor nanowires from a given ensemble will be studied through confocal photoluminescence microscopy. This technique will permit the systematic study of compositional fluctuations, doping and trap states in semiconductors nanowires ensembles.

Supervisors: ***Prof L Herz*** and ***Prof M Johnston***
Email: ***Laura.Herz@physics.ox.ac.uk, michael.johnston@physics.ox.ac.uk***

CMP20 **tbc**

More details from the supervisor.

Supervisors***: Prof P Radaelli*** and ***Dr R Johnson***
Email***: Paolo.Radaelli@physics.ox.ac.uk***

CMP21 **tbc**

More details from the supervisor.

Supervisor : ***Dr M Riede***
Email : ***moritz.riede@physics.ox.ac.uk***

CMP22 **tbc**

More details from the supervisor.

Supervisors***: Prof P Radaelli*** and ***Dr R Johnson***
Email***: Paolo.Radaelli@physics.ox.ac.uk***

CMP23 **tbc**

More details from the supervisors.

Supervisors: ***Prof A Boothroyd*** and ***Dr D Prabhakaran,***
Email: ***Andrew.Boothroyd@physics.ox.ac.uk, dharmalingam.prabhakaran@physics.ox.ac.uk***

CMP24 **tbc**

More details from the supervisors.

Supervisors: ***Prof A Boothroyd*** and ***Dr D Prabhakaran,***
Email: ***Andrew.Boothroyd@physics.ox.ac.uk, dharmalingam.prabhakaran@physics.ox.ac.uk***

Interdisciplinary projects

***INT01 & INT02* Very-high-energy gamma-ray astrophysics with the Cherenkov Telescope Array**

Very high-energy gamma-ray astrophysics is an exciting field spanning fundamental physics and extreme astrophysical processes. It will soon be revolutionized by the construction of the international Cherenkov Telescope Array (CTA; http://www.cta-observatory.org/). This will be the first open observatory for very-high energy gamma-ray astronomy, and will be sensitive to photon energies up to 10^15 eV. Its science goals are:

(1) Understanding the origin of cosmic rays and their role in the Universe.

(2) Understanding the natures and variety of particle acceleration around black holes.

(3) Searching for the ultimate nature of matter and physics beyond the Standard Model.

CTA will consist of up to one hundred imaging air Cherenkov telescopes using state-of-the-art Silicon Photomultiplier detectors and high-speed digital signal processing to detect and characterize the electromagnetic air shower caused when an astrophysical gamma-ray enters the Earth's atmosphere.

I expect to be able to take up to two M.Phys. students this year working on either experimental or theoretical aspects of the CTA programme. These would suit students taking either the Astrophysics or Particle Physics options.

In the lab, we work on the design and construction of the cameras for CTA's small-sized unit telescopes. These will have ~2k pixel SiPM detectors and front-end amplifiers which feed into custom electronics using ASICs and FPGAs. This gives a system that can image at a rate of a billion frames per second.

On the theoretical/observational side of the programme, recently we have developed new theoretical models for the broad-spectrum emission from steady-state jets (Potter & Cotter 2012, 2013a,b,c) that let us use the gamma-ray observations and those at other wavelengths to investigate the physical properties of the jet and the black hole at its base. We now propose to extend these models to look in particular at (i) rapid variability and flaring in jets and (ii) entrainment of heavy particles as the jets propagate through their host galaxy, and the resulting possibility of hadronic particle processes within the jets. We will investigate how CTA may be used to determine the physical conditions that lead to flaring and the presence, and extent, of emission from hadronic processes.

References

Actis et al. 2010, http://arxiv.org/abs/1008.3703

Potter & Cotter 2012, http://arxiv.org/abs/1203.3881

Potter & Cotter 2013a, http://arxiv.org/abs/1212.2632

Potter & Cotter 2013b, http://arxiv.org/abs/1303.1182

Potter & Cotter 2013c, http://arxiv.org/abs/1310.0462

Supervisor: ***Dr G Cotter***
Email: ***Garret.Cotter@physics.ox.ac.uk***

***INT03 & INT04* An Electronics Project**

Design, build and test a piece of electronic equipment of your choice. The project will take place on the Practical Course electronics laboratory.

Suggested Reading:

Horowitz and Hill

Any book on electronics.

Supervisor***: Dr R Nickerson***
Email***: richard.nickerson@physics.ox.ac.uk***

***INT05* The statistics of Galactic supernova remnants**

The explosion of a supernova launches a blast wave into the low density interstellar medium. There are 274 known supernova remnants (SNR) in the Galaxy. The 'sigma-D' relation between the radio brightness (sigma) and the diameter of the blast wave (D) shows that the radio luminosity decreases as the blast wave increases in diameter. The sigma-D statistics were analysed during the 2015-16 project and uncovered a surprisingly well-ordered number distribution in sigma. The aim in 2016-17 is to perform a Monte Carlo simulation to explore how a strong correlation might emerge from diverse data when supernova explosions are triggered randomly in the Galaxy with different energies in different environments. Programming skills are essential.

The student will need access to a desktop or laptop computer to write a computer program and display graphs.

Supervisor***: Prof T Bell***
Email***: Tony.Bell@physics.ox.ac.uk***

***INT06* Gamma-ray and electron-positron production by electrons in intense laser fields.**

A free electron oscillates relativistically (Lorentz factor ~ 100) in the electromagnetic fields of the most intense laser beam presently available. Due to strong acceleration during oscillation the electrons radiate gamma-rays. Very intense lasers are under construction and are being planned in which an electron may radiate away a large part of its energy during one laser period in a single gamma-ray photon which in turn has enough energy to interact with the laser fields to produce an electron-positron pair. The aim of the project is to write a computer program to calculate the stability/instability/chaos of electron trajectories and the generation of gamma-rays and electron-positron pairs. Programming skills are essential.

The student will need access to a desktop or laptop computer to write a computer program and display graphs.

Supervisor***: Prof T Bell***
Email: ***Tony.Bell@physics.ox.ac.uk***

***INT07* Laboratory studies of volcanic lightning on Venus and the early Earth**

Lightning may have been crucial in the development of life, as it enables key chemical reactions to occur. We cannot directly observe early Earth's hot, CO2-rich, atmosphere; however, similar conditions exist today on Venus, where there may be lightning. This project will involve laboratory experiments to investigate mechanisms that could generate electric fields that result in volcanic lightning under these environmental conditions. One of these mechanisms is known to be the electric charge released by fractoemission (rocks breaking up), which is responsible for some of the lightning we see in volcanic plumes on Earth. Fractoemission from a variety of rock samples, including Venus-analogue rocks (basalts), will be measured in a small chamber that can simulate the hot, high pressure atmosphere characteristic of Venus or the early Earth. The project will involve preparing and testing the chamber, and carrying out a sequence of measurements, essentially fragmenting rock samples using an automated rock collision apparatus and measuring the charge generated under a range of conditions. This is an interdisciplinary experimental project and will suit students with interests in atmospheric and planetary science or geophysics.

Supervisors: ***Dr K Aplin*** and ***Dr M Airey***
Email: ***karen.aplin@physics.ox.ac.uk***

***INT08 & INT09* Statistical Mechanics of employment: how to predict your next job**

The current approach used in economics and social science to model country-wide employment and unemployment trends is based on a simple average picture: pools of unemployed apply to job vacancies in a random process with a given success rate, leading to an overall number of employed and unemployed. This picture ignores the many complexities of economic systems, in particular, the role played by individual companies which are different from one another in many ways such as their specialty, their size, geography, etc. A very recent model called the labour flow network, designed by the supervisors, deals with such complexities by organizing country-wide economies as networks of companies, and individuals move through their careers along the links of the network. Such networks are constructed from data, and are therefore capable of reproducing reality. This approach, similar to diffusion of the workforce in the steady state has been able to explain features of the economy not well understood. We are now studying the model for out-of-steady-state behavior, critical to understand economic crises, the introduction of tax or educational incentives for companies and the workforce, and other such dynamic behavior. The ultimate goal of this model is to forecast employment at a high resolution level. The student(s) interested is (are) expected to work on mathematical and computational approaches to random walks on graphs, and use linear algebra as part of the techniques. This project is well suited for theory option students, although accessible to all options.

Supervisors: ***Dr E Lopez, Dr O Guerrero,***
Email: ***eduardo.lopez@sbs.ox.ac.uk***

***INT10* Measuring Blood Flow Changes using Magnetic Resonance Imaging**

MRI can be used to image both structure and function in the human brain, but it can also be used to determine the health of the cerebrovasculature, by measuring the response of blood flow in the brain to inspired carbon dioxide. This blood flow effect is called the cerebrovascular reactivity (CVR). It is usually measured in terms of a relative change in blood flow caused by dynamic changes in inspired CO2. However, one of the main methods used to measure blood flow changes during tasks may not work for a physiological stimulus like CO2. The project would measure the changes in blood flow velocity in major arteries in the brain during the inhalation of CO2, and investigate how this change would impact the measurement of blood flow to the tissues. This project will take place at Oxford's Centre for Functional MRI of the Brain (FMRIB) and the student will be a member of the FMRIB Physics Group, comprising about 20 engineers and physicists. This project requires good computational skills and some knowledge of programming (both MATLAB and image analysis software be used in the project). In addition to analysing and interpreting data, the student will be involved in acquiring MR images and will have the opportunity to interact with basic and clinical neuroscientists at FMRIB who are interested in using this new technology.

Location: FMRIB Centre, John Radcliffe Hospital, (see http://www.fmrib.ox.ac.uk)

Supervisor: ***Dr D Bulte***
Email: ***daniel.bulte@ndcn.ox.ac.uk***

***INT11* A census and calibration of nuclear radiation doses**

Fears of the dangers of nuclear radiation abound in the popular media, yet a calibration and context for how real the dangers are is lacking.

Part of the problem is that lack of easily accessible sources for busy journalists and the public to get rapid feedback on likely doses (in easily understood units) from particular incidents or sources, and the true danger from such doses. Building on Oxford's expertise in ultra-low background environments gained from solar neutrino and dark matter experiments, we propose a well-researched and authorative website to fill this gap. In order to provide a proper context for what is and what is not dangerous, a census of actual, plausible doses from a wide cross-section of sources will be assembled. This will be from a combination of sifting through the scholarly literature and assessing the veracity of reported measurements, together with undertaking new measurements of very low signal sources in the ultra-low background environment of the bottom of the Boulby Mine over 1 km below the North East coast of England. Collation and curation of the assembled data and provenance thereof into an accessible and meaningful web-site will be a final goal.

Supervisors: ***Prof D Wark*** and ***Prof K Blundell***
Email: ***Katherine.Blundell@physics.ox.ac.uk***

***INT12* Computer Modelling of Muon Tomography**

There are about 200 million shipping containers moved around the world each year, the vast majority of which contain nothing more hazardous than new DVD players. Finding a handful of dangerous objects in this vast stream of goods is a significant challenge, however the ability to spot a single unexpected concentration of very dense material within a shipment could potentially avert a grave disaster. Muon tomography is one of the tools used to examine shipping containers, however its use is limited by the slow scan rate given the low flux of cosmic ray muons. An idea is being developed with the potential to greatly speed up scanning and expand the application of muon tomography. The project will use computer simulations to explore the advantages of the new method and demonstrate what maximum scanning rate could be achieved. Anyone interested in this project should have good computing skills. Knowledge of and some experience in C++ programming is required, knowledge of ROOT would be an advantage (asking for GEANT experience would really be pushing it!).

Supervisors: ***Prof D Wark*** and ***Prof K Blundell***
Email: ***david.wark@stfc.ac.uk***

***INT13* Using Magnetic Resonance and Ultrasonic Interferometry to investigate novel magnetic materials**

The project will use a combination of 4 different techniques to examine the properties of exotic novel magnetic materials in search of such phenomena as Jahn-Teller distortions, Spin-Ice behaviour, Enhanced Nuclear Magnetism etc. The three resonance techniques, ESR, NMR and NQR respectively probe the electronic magnetism, the nuclear magnetism and the nuclear quadrupole coupling to the surrounding crystal. Ultrasonic Interferometry is used to detect and characterise phase transitions by measuring changes of parts per million in the sample dimensions and the acoustic velocities. The technique works by growing thin film microwave acoustic transducers on the sample under study and carrying out microwave interferometry on the echo responses to a short acoustic excitation pulse. The measurements will be made over the temperature range from ambient down to 4 Kelvin.

Supervisors: ***Prof J Gregg, Dr A Princep*** and ***Dr A Karenowska***
Email: ***john.gregg@physics.ox.ac.uk***

***INT14* Making a tracking Proton Magnetometer to measure magnetic fields to an accuracy of parts per million**

The proton (Hydrogen nucleus) has spin 1/2 and a magnetic moment that resonates at 42.5759 MHz in a field of 1 Tesla. Finding the resonant frequency of protons in a magnetic field of unknown magnitude is thus a very precise way to measure the value of the field. In the course of an experiment to study a magnetic sample, it may be desirable to sweep the magnitude of the magnetic field applied whie simultaneously measuring its instantaneous value. This project aims to make a piece of equipment that performs this task by tracking the proton resonance in an aqueous sample that is held in the swept field adjacent to the magnetic sample under study. An ability to solder and an appreciation of analogue electronics would be an advantage when carrying out this work.

Supervisor: ***Prof J Gregg***
Email: ***john.gregg@physics.ox.ac.uk***

***INT15* Superconducting Parametric Amplifiers for Quantum Devices and Astronomical Receivers**

The best low noise microwave amplifiers currently available are based on high quality high electron mobility transistors (HEMTs). However, even the best HEMT devices reach noise temperatures at least an order of magnitude away from the ultimate quantum limit. To reach this limit, the new technology of superconducting parametric amplifiers is emerging.

Unlike the inherently dissipative transistor-based amplifier, a parametric amplifier relies purely on non-linear reactance to convert energy between different frequencies in a mixing process. Superconducting devices are ideally suited to this application, since a strong non-linearity can be easily realised in an intrinsically dissipation-free device. To reach high gain, the signal must interact strongly with the non-linearity and this can be realised by making a device with a very long propagation length – a travelling wave parametric amplifier (TWPA) – likely to be promising due to much larger bandwidth and higher dynamic range than recently developed resonator-based approaches.

At Oxford, we have just started a new area of research to develop parametric amplifies for astronomical detectors and qubit readout in quantum computing experiments. This project will explore a design of TWPA based on the kinetic inductance of high normal resistance superconducting transmission line [1], and their application in quantum technology and astronomical receivers. To predict the performance of the device, we need to develop software that solves the coupled differential equations [2] which governs the propagation of signals along the non-linear transmission lines and therefore calculates the magnitude of amplification. The student will start by reviewing the work done in this area, modify the standard equations to apply to our design and write the code to solve the coupled equations. The project will best suit a student with theoretical/computational interest.

[1] Eom, Byeong Ho, et al. "A wideband, low-noise superconducting amplifier with high dynamic range." Nature Physics 8.8 (2012): 623-627.

[2] Chaudhuri, Swarat, Jiansong Gao, and Kent Irwin. "Simulation and Analysis of Superconducting Traveling-Wave Parametric Amplifiers." Applied Superconductivity, IEEE Transactions on 25.3 (2015): 1-5.

Supervisors: ***Prof G Yassin*** and ***Dr B Tan***
Email :***ghassan.yassin@physics.ox.ac.uk***

***INT16* An electronics project: precise experimental control using an FPGA**

Suitable for someone with a strong interest in electronics. The project can be tailored to individual interest but we are aiming to produce a system to control various tasks in an experiment on ultracold atoms.

Supervisor : ***Prof C Foot***
Email: ***Christopher.Foot@physics.ox.ac.uk***

***INT17* Investigation of a low distortion oscillator**

More details from the supervisor.

Supervisor: ***Dr G Peskett***
Email: ***guy.peskett@physics.ox.ac.uk***

Particle and Nuclear Physics projects

***PP01* Algorithms for longitudinal profile image reconstruction of femtosecond electron bunches**

Imaging of longitudinal femtosecond electron bunch profile is a key to successful implementation of next generation of state-of-the-art accelerators and their application for generation of coherent THz and X-ray radiation. A number of imaging technique based on spectral analysis of coherent radiation generated by the electron bunches are available. However the problem of uniqueness of the reconstruction and its stability is still not resolved, especially for a bunch of complex shape. The project proposed will be based on development of numerical algorithms based on Kramers-Kroening and Bubble-Wrap techniques. It will involve the research based on both analytical and numerical studies as well as analysis of the spectral data observed at FACET, SLAC (Stanford University, USA) and Diamond light Source, (Harwell Science Park, UK). It is expected that at the end of the project a sophisticated spectral analysis tools based on novel algorithm will be developed. The knowledge of programming techniques and mathematical methods is essential for this project.

Supervisors: ***Dr R Bartolini, Dr I Konoplev*** and ***Dr G Doucas***
Email: ***Riccardo.Bartolini@physics.ox.ac.uk***

***PP02* A Flexible Algorithm for Online Optimisation of Particle Accelerator Performance**

The overall performance of the electron storage ring is critically dependant on a large number of machine parameters. This performance can be characterised in a number of different ways, such as by measuring electron beam lifetime, transverse stability, injection efficiency, injection transients, instability thresholds and so on. However, it is frequently the case that improving one parameter comes at the cost of harming another. Similarly, given the large number of variables involved in optimising the ring performance, the true, global optimum solution may be difficult to identify using simple parameter scans.

In order to address this problem, flexible optimisation tools are required. These tools should be capable of optimising several parameters at once, using an arbitrary number of variables to achieve this goal (typically the strength of various magnets). It should be possible to apply the tools to any online optimisation problem, and not tied to any particular set of optimisation variables. The tool should also be able to cope with measurement noise on the parameters to be optimised.

The programme involves extensive numerical simulations and the application of the techniques developed to the Diamond Light Source with possible machine shifts at the facility.

Supervisor: ***Dr R Bartolini***
Email: ***Riccardo.Bartolini@physics.ox.ac.uk***

***PP03* Evaluation of HV-CMOS sensors**

The High Luminosity LHC (HL-LHC) project will require the replacement of the all ATLAS tracker. Research and development is currently taking place to develop the optimal sensor technology for this project. The candidate will work on High-voltage particle detectors in commercial CMOS technologies that open up the possibility of incorporating read-out electronics into the sensing element. This development is generating large interest in particle physics since it could provide low-cost, thin and radiation-tolerant detectors with a high time resolution. The candidate will evaluate the performance of these sensors, denoted as HV-CMOS, before and after irradiation in a laboratory setting using lasers and radioactive sources.

Supervisor: ***Prof D Bortoletto***
Email: ***Daniela.Bortoletto@physics.ox.ac.uk***

***PP04* Theoretical and experimental studies of multi-cell asymmetric cavity for Energy Recovery Linac**

High-brightness, intense sources of coherent X-ray radiation are extremely useful tools in science and used to probe matter of different kinds and in different states. These radiation sources are usually driven by particle accelerators such as synchrotrons and free electron lasers, vital tools which exist at only a few national laboratories around the globe. The size and energy consumption of such particle accelerators are key reasons for the restricted number of facilities and there are number of projects undergoing to develop more compact and affordable electron beam drivers.

This project is a part of a larger initiative to develop compact, superconducting, RF driven, high current energy recovery linear accelerator (LINAC). Such a LINAC can be used to generate high intensity X-Ray of properties comparable with radiation observed at large synchrotron or FEL facilities. The one of the main challenges of the project is to control and suppress high order modes inside accelerating/decelerating structures, which will be excited by the high current beam. These modes could interfere with the energy recovery and could potentially interrupt the beam transportation through the system. The main tasks will be development of a numerical model using CST microwave studio and experimental mapping of the field inside the cavity using equipment available in the RF laboratory.

The outcome of the project will contribute to the current UH-FLUX research program on development of compact source of coherent radiation. It is expected that the student who will take on this project is familiar with computer codding (MATLAB, C, Python) and EM theory. The researcher will be working in team with senior colleagues and good communication skills are expected. If the project is successful it may lead to a publication and good writing skills will be beneficial.

Supervisors***: Dr I Konoplev, Prof A Seryi*** and ***Dr A Lancaster***
Email***: Ivan.Konoplev@physics.ox.ac.uk, Andrei.Seryi@adams-institute.ac.uk, Andrew.Lancaster@physics.ox.ac.uk***

_PP05_ The Higgs as probe for new physics

In 2012 the Higgs boson was discovered in collisions of the Large Hadron Collider at CERN. Run 2 of the LHC will start this year and will allow more detailed studies of the properties of this particle. The measurement of the "off shell" production of at high invariant mass is sensitive to the Higgs boson total decay width and to new physics. In particular, it is generally sensitive to new particles that affect the Higgs boson mass and thus offer a solution to the so-called "hierarchy problem". The candidate for this project will use MADGRAPH, a Monte Carlo which includes SM and the MSSM effects in the determination of the Higgs gluon fusion cross section, to investigate the sensitivity of the transverse mass distribution to new physics.

Supervisor: ***Prof D Bortoletto***
Email: ***Daniela.Bortoletto@physics.ox.ac.uk***

_PP06_ Studies of H->bb and the Higgs self coupling

In 2012 the Higgs boson was discovered in collisions of the Large Hadron Collider at CERN. Nonetheless the decay of the Higgs boson to bottom quarks, H->bb, has not yet been measured. The candidate for this project will work with our team to study the impact of new advanced statistical learning tools for improving the analysis of this decay mode that suffers from poor signal to background. The long term goal will be to apply these techniques also to the study of dihiggs production in final states that include 4 b-quarks and can be used to test the Higgs self coupling.

Supervisor: ***Prof D Bortoletto***
Email: ***Daniela.Bortoletto@physics.ox.ac.uk***

_PP07_ What can the LHC tell us about supersymmetric Dark Matter

The ATLAS collaboration at the CERN LHC has performed a range of searches for supersymmetric particles. This project examines a wide range of theoretical models, each consistent with the observed relic density of dark matter, and explores the extent to which each of them has been ruled out, or not, by the measurements performed at the LHC. The student may also wish to propose additional, novel, searches for new particles. Knowledge of the python and/or c++ programming languages would be an advantage. It is anticipated that the student would be taking the fourth-year particle physics option.

Supervisor: ***Prof A Barr***
Email: ***Alan.Barr@physics.ox.ac.uk***

_PP08_ A CP-violation analysis of charged B-mesons

The student will explore the large CP-violation effects in B→DK(*) decays using Run 1 data of LHCb.

The project will be based on ntuple data files and the student will writing a 2D fitting algorithm that can exploit the full information about the B and D meson mass distribution.

This will be the first time this technique has been attempted with these modes for the LHCb dataset and thus the project will be an interesting feasibility study for the LHCb group.

Prior use of python and C++ in a Linux environment is important.

Supervisor: ***Dr M John***
Email: ***Malcolm.John@physics.ox.ac.uk***

_PP09_ Novel polarization states in fibre lasers for particle acceleration

Recent experiments have shown that it is possible to directly accelerate electrons by tightly focusing radially polarised laser beams. These are usually created with expensive specialist optics that produce imperfectly polarised beams. The aim of this project is to work on generating these polarisation states directly from fibre lasers by a novel method of combining higher order spatial modes in fibre amplifiers and investigate numerically and experimentally the focusing properties of these modes. This project is predominantly experimental and would suit a student who is interested in lab work, but the project will also involve the theory and numerical modelling of these polarisation states and their properties.

Supervisor: ***Dr L Corner***
Email: ***Laura.Corner@physics.ox.ac.uk***

_PP10_ Optimisation of algorithm for longitudinal profile image reconstruction of femtosecond electron bunches

Imaging of the longitudinal profile of femtosecond electron bunches is key to successful implementation of the next generation of state-of-the-art accelerators and their application for generation of coherent X-ray radiation. There are number of imaging techniques based on spectral analysis of coherent radiation generated by the electron bunches, but difficulties with the stability of the solutions (i.e. the uniqueness of final 1D image) are still present, especially for a bunches with complex shapes.

The project will develop a method to optimise the number of observations and their target frequencies to enable measurement of the longitudinal beam profile to a specific accuracy. The studies will be conducted using analytical and numerical models as well as spectral data observed at FACET, SLAC (Stanford University, USA). The proof of algorithm validity will be important part of this research project, as will the optimisation of the relevant numerical models.

The knowledge of programming techniques (MATLAB, Python, C) and mathematical methods (Fourier analysis, Complex function) is desirable for this project. The researcher will be working in team and it is expected to have a good communicational skills. It is expected that if the project is successful it will potentially lead to publication in one of the physics journals.

Supervisor***s: Dr I Konoplev*** and ***Dr A Lancaster***
Email***: Ivan.Konoplev@physics.ox.ac.uk, Andrew.Lancaster@physics.ox.ac.uk***

_PP11_ Photon recognition algorithms for dark matter searches

Dark Matter Searches based on detection of WIMP scattering in noble liquids, such as xenon for example, rely on efficient algorithms for extracting single photons from PMT data. This project aims to develop such algorithms and test them against real data and simulation. The project requires proficiency in C++ and ROOT, both of which can be learnt as the project progresses and the specific knowledge on ROOT is not very demanding. Some experience in digital signal processing would be useful but is not strictly required.

Supervisor: ***Prof H Kraus***
Email: ***hans.kraus@physics.ox.ac.uk***

_PP12_ Simulation of background sources on dark matter experiments

This project will build a model (in GEANT) of a simple dark matter detector and explore the effects various types of radioactive impurities in materials have on the final result. Experience in GEANT4 would be useful, but can be acquired quickly with sufficient background in C++ programming.

Supervisor: ***Prof H Kraus***
Email: ***hans.kraus@physics.ox.ac.uk***

_PP13_ Combining real time differential and absolute distance interferometry

We wish to combine two distance measurement techniques in the same optical setup. One of the methods will be FSI as described in #1 which can measure distances for short times (shots) at high frequency but not continuously and not with low latency. We therefore wish to combine this method with more conventional methods of differential interferometry that can be used in fast (order of kHz) feedback loops for position control. For this purpose we seek to set up a new interferometer head on an optical table that can combine the two methods and use them simultaneously or sequentially with low dead time. The project will entail the design and setup of the head and the analysis of the data from verification experiments. We hope to achieve a real time measurement of a moving target with low latency and high repetition rate.

Required skills:

Very good command of spoken and written English, must be able to work with laser and as such has to have vision on both eyes (we can provide safety training),knowledge of optics and interferometry principles, practical skills in a laboratory, preferably with optics setups, ability to extend existing computer based analysis algorithms using Java.

Desired skills:

Familiarity with some data analysis package, basic ideas of electronics, interest in optics simulation

Supervisor: ***Prof A Reichold***
Email: ***a.reichold@physics.ox.ac.uk***

_PP14_ Study of the impact of cosmic-ray tagger systems for the SBND experiment

Liquid Argon (LAr) detectors offer exquisite resolution images of particle interactions and provide great background rejections. They are therefore optimal detectors for neutrino physics. It is believed that the resolution is good enough to reject any event induced by cosmic rays. However some particular cosmic-ray interaction could mimic signal events and contaminate signal samples. The SBND detector will face the challenge of running on the surface and it was decided that a system of cosmic-ray tagger would greatly reduce the cosmic-ray background. This project will require the use of the SBND analysis software (ROOT-based, i.e. C++) to study the cosmic-ray background and the impact of the tagger system. This study is extremely relevant to all future neutrino LAr detectors.

Computing requirements: Knowledge of C++ language (knowledge of ROOT is an advantage)

Supervisor: ***Dr R Guenette***
Email: ***Roxanne.Guenette@physics.ox.ac.uk***

_PP15_ Frequency referencing for with gas absorption cells and frequency combs

In 2015 Prof Reichold visited the German national institute of metrology (PTB) and compared their state of the art frequency combs to the absorption spectra of a variety of gas absorption cells that form the metrological core of each FSI system. These measurements should provide a much improved knowledge of the absorption frequencies and line width. The project will seek to analyse the data taken in 2015, characterise the gas cell and use this knowledge in the analysis of a set of length comparison measurements also performed at PTB with the same gas cells.

Required skills:

Very good command of spoken and written English, good knowledge of Java, Fourier transform mathematics, data analysis techniques in general, knowledge of basic optics principles and interferometry,

Desired skills:

Familiarity with general programming languages and matlab, some concepts of parallel computing, basic concepts of CUDA programming

Supervisor: ***Prof A Reichold***
Email: ***a.reichold@physics.ox.ac.uk***

_PP16_ Detector calibration measurements using tagged cosmic muons for MicroBooNE

The MicroBooNE detector, a 170t Liquid Argon Time Projection Chamber at Fermilab started to collect data last October. MicroBooNE has placed a small muon counter system external to the detector to obtain a sample of known cosmic-rays. The tagged data set can be used for detector calibration measurement such as electron life-time measurements or electron recombination studies. This project will use MicroBooNE data to study the detector properties.

Computing requirements: Knowledge of C++ language (knowledge of ROOT is an advantage)

Supervisor: ***Dr R Guenette***
Email: ***Roxanne.Guenette@physics.ox.ac.uk***

_PP17_ Search for new physics in di-Higgs final state

Searches for new physics in di-Higgs final states are an active and important field of research at the Large Hadron Collider (LHC). This project will allow the student to search for new heavy states of matter in the ATLAS data in final states with two Higgs bosons, where at least one of them decays into two b-quarks. Important areas of research are the improvements to the b-quark identification, jet mass calibration and the utilization of novel jet algorithms which adjust their features to the momentum of the Higgs bosons and neural network analysis techniques. Depending on the interest of the student it could also involve phenomenological studies on the Higgs self-coupling measurement which the di-Higgs process is sensitive to.

Required skills are: Programming in C++, basic understanding of ROOT (https://root.cern.ch/root/htmldoc/guides/primer/ROOTPrimer.pdf) and Linux/Unix.

Supervisor: ***Prof C Issever***
Email: ***Cigdem.Issever@physics.ox.ac.uk***

PP18 The Intense Beam Experiment (IBEX)

The Intense Beam Experiment (IBEX) is under construction at the Rutherford Appleton Laboratory in collaboration with the University of Hiroshima, Japan. It aims to use an experimental system to 'simulate' important intensity-dependent effects in particle accelerators, but in the lab frame. The experiment will be used investigate the dynamics of particle beams in machines such as ISIS neutron source, future upgrades to the LHC and next generation proton accelerators. To do this, it relies on a non-neutral Argon plasma in a device called a linear Paul Trap. The experiment is about to enter commissioning phase, so you will have a unique opportunity to help get this experiment up and running, be involved in first data taking and have the chance to contribute to our understanding of the experiment through simulation work. Some experience with computer programming is desirable, but not essential. Any travel expenses for experimental work at RAL will be covered.

Supervisor: ***Dr S Sheehy***
Email: ***suzie.sheehy@physics.ox.ac.uk***

PP19 Search for neutrinoless double beta decay at SNO+

SNO+ is an experiment designed to look for neutrinoless double beta decay, which would indicate that neutrinos are their own anti-particles, could help explain why neutrino masses are so small, and shed light on possible dark matter candidates and other non-Standard Model physics. The experiment will use about a tonne of Tellurium dispersed in 1000 tonnes of liquid scintillator in order to pick up faint traces of light which result from this decay. Possible specific projects include the refinement of algorithms to recognize these faint traces, and to investigate the effect of low energy radioactive backgrounds on the experiment's sensitivity. Some familiarity with C++ and Linux would be an advantage.

Supervisors: ***Prof S Biller, Prof A Reichold*** and ***Prof J Tseng***
Email: ***Steven.Biller@physics.ox.ac.uk,***
Armin.Reichold@physics.ox.ac.uk,
Jeff.Tseng@physics.ox.ac.uk

PP20 Improving Strong Gravity Generator BlackMax

Theories of quantum gravity may have LHC-energy manifestations in the form of rapidly decaying microscopic black holes, especially in the context of extra spatial and other exotic types of physical dimensions.

The BlackMax Monte Carlo generator (Phys.Rev. D77:076007,2008, http://arxiv.org/abs/0711.3012) simulates experimental signatures of these black holes, and has been used in a number of LHC-based searches for new physics. This MPhys project aims to update the BlackMax generator for the new LHC run with new models and features. The project requires good knowledge of object-oriented programming, preferably with C++, and an interest in numerical techniques and software development. More information about the generator can be found at https://blackmax.hepforge.org/

Supervisors: ***Prof C Issever*** and ***Prof J Tseng***
Email: ***Cigdem.Issever@physics.ox.ac.uk,***
Jeff.Tseng@physics.ox.ac.uk

PP21 Analysis of two-phase flow properties in thin evaporators

The state-of-the-art method of cooling silicon detector tracking systems in particle physics experiments is evaporative cooling. Due to the push to minimize material in the system the geometries of the evaporators are optimized for small size and mass flows. To understand the performance of the evaporative cooling within these constraints the pressure drops and heat transfer properties in the thin tubes need to be accurately understood.

This project will take data taken with realistic evaporator geometries using evaporative CO2 cooling and analyse the pressure drops and heat transfer coefficient, and compare the results to different models of 2-phase flow and boiling. The project will require programming skills (C++ and use of the data analysis package ROOT).

Supervisors: ***Dr G Viehhauser***
Email: ***Georg.Viehhauser@physics.ox.ac.uk***

P22 Using a Neural Net to optimize a "Jump Multiplicity" B-meson tagger in Ultra-high Energy jets

The Large Hadron collider (LHC) collides protons head-on with a centre of mass energy of 13 TeV. When this happens it is not uncommon for jets of particles to have over 1 TeV of energy. There are future colliders on the books where these energies will only increase.

The goal of most of these machines is to look for new physics that we, as yet, do not understand. Often though, in many theories, the final states involve the production of b-quarks which eventually appear as B mesons or B baryons in the final state. B particles get a large fraction of the total jet energy, live for about 1 ps, and then decay. But because B particles in > 1 TeV jets have so much energy, they can actually traverse some of the inner layers of the ATLAS detector before they decay.

In this project we will be using neural net techniques to try to optimise the properties of a "jump multiplicity counter" which simply means counting the hits in a simulated detector in B jets and comparing this to light quark jets. If a B meson decays between two layers it makes many additional charged particles that were not present before hand, by counting the additional hits in the detector layers and adjusting the size of the jets as a function of energy, we aim to improve the efficiency and purity of this technique.

The simulation uses C++ as the main computing language and is stand-alone code. The neural net has not been developed and most of the project will be around building and running the neural net and comparing its results to more traditional cut methods.

Supervisor: ***Prof T Huffman***
E-mail: ***todd.huffman@physics.ox.ac.uk***

PP23 Understanding the efficiency and performance of prototype Particle Physics pixel detectors

More details from the supervisor.

Supervisor: ***Prof T Huffman***
E-mail: ***todd.huffman@physics.ox.ac.uk***

PP24 ATLAS Physics

The world's highest energy particle accelerator, the Large Hadron Collider (LHC) at CERN, started operation at the high-energy frontier in 2009. Constructed in a 27 km long circular tunnel, 100 meters underground, it accelerates two counter-rotating proton beams and brings them into collision at center-of-mass energies of up to 14 TeV. By pushing the energy frontier by an order of magnitude above that previously accessible, it offers unprecedented opportunities to explore the fundamental constituents of the universe.

The ATLAS and CMS experiments have observed a new boson, and this opens up a new research area with the aim of understanding if this particle is a Higgs boson and, if so, whether it a Standard Model (SM) Higgs boson or a more exotic version. Studies can be carried out with the existing data to begin to address these issues, such as determining the spin of the boson. Even if the new particle turns out to be compatible with a SM Higgs, there are many remaining problems in the SM, many of which point to the existence of exotic physics in the LHC energy range. Hence a primary goal of ATLAS is to explore SM physics in new energy regimes and to discover new physics signatures beyond the SM. Possibilities include Supersymmetry (SUSY) as well as models which posit the existence of additional spatial dimensions beyond our normal experience.

In addition, the LHC is a "factory" for W and Z bosons and top quarks, enabling not only systematic studies of their properties but also their use as precision tools to probe the deep structure of the proton and to guide searches for physics beyond the Standard Model.

PP2401 Using LHC measurements of precision ratios to search for new physics

According to astronomical observations, ordinary baryonic matter only accounts for about 15% of the matter content of the Universe with the rest being due to "dark matter". However laboratory experiments are essential to pin down the nature of this dark matter. In many models, the dark matter is in the form of Weakly Interacting Massive Particles (WIMPS) which can be produced at the LHC. Although WIMPS would not be directly detected in an LHC experiment like ATLAS, their presence could be inferred from the apparent missing transverse momentum. This project will explore the phenomenology of the search for dark matter at the LHC.

The project will focus on measurements of the ratios $R_{jets}=\sigma(W+jets)/\sigma(Z+jets)$ and $R_{inv} = \sigma(Z+jets, Z\rightarrow\nu\nu)/\sigma(Z+jets, Z\rightarrow l^+ l^-)$. Both these ratios benefit from the cancelations of many systematic errors such as luminosity and can therefore be measured precisely. The values of these ratios would be affected by new physics processes such as the production of dark matter. This project will study the phenomenology in order to determine how to minimise the theoretical uncertainties and hence maximise the sensitivity to new physics. If time permits some of the ideas developed would be applied to real ATLAS data.

Supervisor: ***Dr T Weidberg***
Email: ***tony.weidberg@physics.ox.ac.uk***

PP2402 Precise measurement of the W boson mass

Prior to the discovery of the Higgs boson, its mass was predicted by precision measurements of electroweak parameters, including the W boson mass. The knowledge of this mass provides a key constraint in determining what might lie beyond the Higgs boson. Future measurements of the W boson mass with ATLAS and CDF data will significantly reduce the current uncertainty on this quantity and further constrain the properties of new particles (or suggest their existence). This project will focus on reducing the important uncertainties in the measurements.

Supervisor: ***Dr C Hays***
Email: ***chris.hays@physics.ox.ac.uk***

PP2403 Measurement of Higgs boson production in decays to W bosons

The 2012 observation of a new resonance with properties consistent with that of a Higgs boson provides the first step in understanding the source of particle mass. Further measurements of the Higgs boson couplings to SM particles will determine if the Higgs is the sole source of this mass. An important coupling is that of the Higgs boson to W-boson pairs, which is tightly constrained by measurements of the W boson mass. Precisely measuring the Higgs-to-WW coupling will provide a standard against which other coupling measurements can be compared. This project will focus on the many theoretical uncertainties in this measurement.

Supervisor: ***Dr C Hays***
Email: ***chris.hays@physics.ox.ac.uk***

PP25 Reactor anti-neutrino measurements with the Solid experiment

The Solid experiment will probe the observed deficit of neutrinos close to nuclear reactors. In 2015 the collaboration deployed a 288 kg detector module 5 m from the core of the BR2 reactor at SCK-CEN in Mol, Belgium. Towards the end of 2016 the collaboration will be deploying a 1.5 tonne detector at the experimental site. The group at Oxford are heavily involved in developing the technology to record data from this new type of neutrino detector. We are looking for an MPhys student who will help analyse the first data collected by the full scale detector, with a focus on understanding how well the data acquisition system is performing. The project will involve writing data analysis programs, and so experience in programming in C/C++ and/or Python would be helpful.

Supervisors: ***Dr N Ryder*** and ***Prof A Weber***
Email: ***nick.ryder@physics.ox.ac.uk***

PP26 **Improved understanding of the structure of the proton using LHC data**

The Large Hadron Collider (LHC) has recently started its second Run, with an increased centre-of-mass energy of 13 TeV. This opens up new prospects for the discovery of physics beyond the Standard Model. One of the dominant uncertainties, which can limit the ability to discover new physics, is an imprecise knowledge of the structure of the proton. This project will investigate the prospects for existing LHC data to constrain and improve our knowledge of proton structure. A set of proton parton distribution functions (PDFs) will be extracted using LHC data taken at 7 and 8 TeV, and possibly 13 TeV data, if available. The impact of any improvements on the prospects for new physics discovery will be investigated. This is a computing project. Some prior experience of C++ would be an advantage.

Supervisor: ***Dr C Gwenlan***
Email: ***Claire.Gwenlan@physics.ox.ac.uk***

PP27 **Development of particle reconstruction and identification algorithms for the DUNE near detector**

DUNE is an international effort to build a next-generation long-baseline oscillation experiment between Fermilab (Illinois), where a new neutrino beamline will be built, and a 40-kt liquid argon far detector located at the Sanford Underground Research Facility (South Dakota), about 1300 km away. A near detector will be installed several hundred meters downstream of the neutrino production point with the primary role of constraining the systematic uncertainties in the DUNE oscillation measurements by characterising the energy spectrum and composition of the neutrino beam as well as performing precision measurements of neutrino cross sections. Several technologies are being considered for the DUNE near detector; among them, a pressurized argon gas time projection chamber (GArTPC). Such a detector, thanks to the low density and low detection thresholds of the active target, would allow the detailed measurement of nuclear effects at the interaction vertex using the same material of that of the far detector. The technology also enables efficient particle identification and the measurement of the momenta and charge of outgoing particles using a magnetic field.

In this project, the student will work on the development and optimisation of algorithms for the reconstruction and identification of the various particles emitted in neutrino interactions using data generated with the detector simulation of the DUNE GArTPC. The performance of the near detector (and thus the final sensitivity of DUNE) depends to a great extent on the quality of such algorithms.

Required skills: Some knowledge of C/C++ and/or Python

Supervisors: ***Dr J Martin-Albo*** and ***Prof A Weber***
Email: ***justo.martin-albo@physics.ox.ac.uk***

Theoretical Physics projects

TP01 **Locomotion of microorganisms in biological fluids**

The locomotion of microorganisms such as bacteria, sperm cells or algae, is mainly determined by physical principals based on fluid mechanics and Brownian motion. While we already have a good understanding how microorganisms swim in Newtonian fluids such as water, much less is known about how they move in more complex fluids -- which are of great biological relevance.

In this project swimming of a simple spherical model microorganism is investigated. It moves in a complex fluid which consists of water and polymers. The swimming velocity and stochastic motion of this microswimmer, and the flow field it creates, is investigated numerically by means of computer simulations.

Reading:

http://www.damtp.cam.ac.uk/user/gold/pdfs/teaching/FDSE/LaugaPowers09.pdf

Supervisors: ***Dr A Zöttl*** and ***Prof J Yeomans***
E-mail: ***andreas.zoettl@physics.ox.ac.uk***

TP02 **Mechanics of Cell Fate**

Our group works on theoretical and computational modelling of soft and biological materials including cultures of cells, bacteria suspensions and microtubule bundles. This project will focus on cell mechanics:

Recent advances in studying living cells have revealed important functions for mechanical factors in cellular processes such as morphogenesis, wound healing and cancer invasion[1]. We have recently developed a model of cell division, identifying the division process as a source of active stress in cell monolayers[2] and suggesting its role in the morphology of growing colonies of living cells[3] . In addition to cell division, the density variation of a cellular monolayer is controlled by cell death (apoptosis). The balance between cell division and cell death plays a pivotal role in regularising the tissue integrity and in preventing cancer metastasis [4,5].

The project aims at exploring the competitive roles of cell division and cell death on the dynamics and morphological changes of growing cell cultures. There are two possible directions for the project, depending on the interests of the student. The first would extend our current codes to study the cell mechanics for different division and death rates. Alternatively, an analytical approach could be used to determine conformational and hydrodynamic instabilities induced by cell division and apoptosis.

The project will introduce students to the hydrodynamics of life at the cellular scale and to physical aspects of cellular processes at the interface of physics and biology. The outcomes of the project will substantiate the mechanics of cell fate due to cell division and death with potential impact on tissue spreading and cancer invasion.

The project will introduce students to the hydrodynamics of life at the cellular scale and to physical aspects of cellular processes at the interface of physics and biology. The outcomes of the project will substantiate the mechanics of cell fate due to cell division and death with potential impact on tissue spreading and cancer invasion.

[1] X. Trepat and J. J. Fredberg, Trends in Cell Biology, 2011.

[2] A. Doostmohammadi et al., Soft Matter, 2015.

[3] A. Doostmohammadi, S. P. Thampi, and J. M. Yeomans, In preparation, 2016.

[4] G. M. Slattum and J. Rosenblatt, Nature Review Cancer, 2014.

[5] M. Suzanne and H. Steller, Cell Death & Differentiation, 2013

Supervisors: ***Dr A Doostmohammadi*** and ***Prof J Yeomans***
E-mail: ***Amin.Doostmohammadi@physics.ox.ac.uk***

TP03 **Triple Higgs production at a future 100 TeV hadron collider**

The measurement of Higgs pair production will be a cornerstone of the LHC program in the coming years. Double Higgs production provides a crucial window upon the mechanism of electroweak symmetry breaking and has a unique sensitivity to the Higgs trilinear coupling. However, triple Higgs production, which allows to probe the Higgs quartic coupling, is beyond the LHC reach, and can only be accessed at higher-energy colliders such as the proposed Future Circular Collider with a center-of-mass energy of 100 TeV. In this project, the feasibility of triple Higgs production at a 100 TeV hadron collider in the final state with six bottom quarks, and the associated sensitivity to the Higgs quartic coupling, will be studied."

Requirements: a solid background in computational techniques, in particular in C++ programming, would be beneficial, though certainly not essential. From the syllabus point of view, students that have followed the Subatomic physics options, advanced QM etc would be better prepared.

Supervisor: ***Dr J Rojo***
Email: ***Juan.Rojo@physics.ox.ac.uk***

TP04 **Mapping orbits in almost Keplerian potentials**

The Kepler potential is the zeroth-order approximation for motion in planetary systems and in stellar systems dominated by a central black hole. This project will investigate the phase-space structure of orbits in the Kepler Hamiltonian perturbed by, e.g., the potential due to a surrounding stellar cluster or an externally imposed tidal field.

A good understanding of the material in the "Classical mechanics"short option (S7) is essential.

Supervisor: ***Dr J Magorrian***
Email: ***John.Magorrian@physics.ox.ac.uk***

TP05 The origin of streams in our solar neighbourhood

Several collections of stars exist in the vicinity of our Sun that cluster in position and velocity space. A key probe for distentangling between scenarios for the origin of these streams is their chemical composition. Unlike the motion and positions of stars, which change over their lifetime, their chemistry is primarily fixed by the properties of the initial gas cloud that collapsed to form them.

This project will make use of exciting new data on positions and velocities of stars from the European Space Agency's cornerstone Gaia mission, combined with information on their chemical composition from high-resolution spectra. The student can develop the project along several avenues, ranging from a phenomenological characterisation of the streams in terms of their positions, velocities and chemistry, to a dynamical prescription of their behaviour. Familiarity with C++ and Python would be beneficial, but the required skills can be developed throughout the project.

Supervisor: ***Dr P Das***
Email: ***Payel.Das@physics.ox.ac.uk***

TP06 Dirac Equation and electrons in solids

The Dirac equation is famous as the result of Dirac's effort to unite the ideas of quantum mechanics and special relativity.

The same equation also provides a description of electrons in solids, in a variety of situa- tions where the electron dispersion relation near the Fermi energy matches the Dirac form. Examples include graphene, high-temperature superconductors and topological insulators. These systems have been a focus of research over the last few years and some surprising and beautiful features have been discovered, involving for example deep connections between bulk and surface properties.

The aim of this project will be to learn about some of the basic quantum physics of Dirac electrons in solids, and to do calculations to illustrate the ideas that are involved. While some purely analytical calculations are possible, simple numerical work will also be involved, for example using Matlab to diagonalise tight-binding Hamiltonians.

The project is suitable for a mathematically able student who is interested in theoretical physics and should provide an opportunity to learn about an area of active contemporary research. The necessary condensed matter physics background is covered in B2. Knowledge from the theory option (C6) is not essential.

A review of the subject is given in: O. Vafek and A. Vishwanath, Annual Review of Condensed Matter Physics Vol. 5: 83-112 (2014), available in open-source form as http://arxiv.org/abs/1306.2272.

Supervisor: ***Prof J Chalker***
Email: ***John.Chalker@physics.ox.ac.uk***

TP07 Anyons and Topological Quantum Computing

One typically learns in quantum mechanics books that identical particles must be either bosons or fermions. While this statement is true in our three dimensional world, if we lived in two dimensions, more general types of particles known as "anyons" could exist. While this sounds like just a mathematical flight of fancy, in fact, when we restrict particles to move only within two dimensions, such exotic particles can (and sometimes do) emerge as low energy excitations of condensed matter systems, and various experiments have claimed to observe this behavior. It has been proposed that such anyons could be uniquely suited for building a so-called "quantum computer" — a computer that could in principle use the unique properties of quantum mechanics to perform certain types of calculations exponen- tially faster than any computer built to date.

The first objective of this project is to learn about the properties of anyons, where these particles exist, and how these particles might be used to build a computing device. A few toy model calculations will start the student in the direction of modern research.

The project is suitable for a mathematically strong student taking the Theoretical Physics option. This work will involve analytical calculations, abstract mathematics, and probably some computing based on Matlab or Mathematica.

Some background reading: Wikipedia Article on Anyons; Wikipedia Article on Topological Quantum Computing; Steven Simon (2010) "Physics World: Quantum Computing with a Twist" (see my home page for link); Ady Stern (2008), "Anyons and the quantum Hall effect

— A pedagogical review". Annals of Physics 323: 204; Chetan Nayak, Steven Simon, Ady Stern, Michael Freedman, Sankar Das Sarma (2008), "Non-Abelian anyons and topological quantum computation," Reviews of Modern Physics 80 (3): 1083.

Supervisor: ***Prof S Simon***
Email: ***steven.simon@physics.ox.ac.uk***

TP08 Topological Statistical Mechanics

Exactly solvable models have taught us an enormous amount about statistical physics and phase transitions. A new class of (classical) stat-mech models was recently proposed which can be solved exactly due to their having a special "crossing" symmetry. The simplest example of such a problem is counting the number of nets (branching tree structures) without ends on the honeycomb.

The objective of this project is to use the exact solvabiltiy of these models as a stepping off point for the analysis of models which are nearly, but not exactly, solvable. I.e., we will perturb these models with small terms that slightly ruin the crossing symmetry. We will use several tools to come to an understanding on the statistical physics of these systems — these tools include numerical simulation of several types, analytical perturbation theory, and renormalization group approaches.

The project is suitable for a mathematically strong student taking the Theoretical Physics option. This work will involve analytical calculations, and a large component of computer programming. Working knowledge of a computational programming language such as C, C++, or fortran will be required.

Some background reading: Steven H. Simon, Paul Fendley; J. Phys. A 46, 105002 (2013). M. Hermanns and S. Trebst http://arxiv.org/abs/1309.3793.

Supervisor: ***Prof S Simon***
Email: ***steven.simon@physics.ox.ac.uk***

TP09 Fractional Quantum Hall Effect

One of the most spectacular experimental discoveries of condensed matter physics is the fractional quantum Hall effect — an effect that occurs to electrons at low temperature in two dimensional semiconductor devices in high magnetic fields. Under these extreme conditions, electrons can fractionalize to form quasiparticles having only part of the elementary electron charge.

What is perhaps even more remarkable about this effect is how well we understand it. The basics of the effect can all be summarized by one delightfully simple analytic wavefunction which, although approximate, very accurately describes the real systems. Numerical calculations involving this type of trial wavefunctions are possible and are viewed as extremely reliable.

The objective of this project is to learn about fractional quantum Hall physics and to begin performing monte-carlo style calculations that will make predictions for real experi- ments.

The project is suitable for a mathematically strong student taking the Theoretical Physics option. This work will involve a great deal of background reading and a large component of computer programming. Working knowledge of a computational program- ming language such as C, C++, or fortran will be required.

Some background material: Wikipedia article on Fractional Quantum Hall Effect; Article by Steve Girvin http://www.bourbaphy.fr/girvin.pdf ; arxiv.org/pdf/cond-mat/9907002 ; Book by R. Prange and S. Girvin, "The Quantum Hall Effect" (do yourself a favor and skip the chapter by Pruisken) Book by Tapash Chakraborty and Pekka Pietilainen, "The Quantum Hall Effects".

Supervisor: ***Prof S Simon***
Email: ***steven.simon@physics.ox.ac.uk***

TP10 Topics in Geometry and Gauge/String Theories

We present the student with a manageable (appropriate for a mathematically and theoretically inclined fourth-year), self-contained project in a specific problem in the realm of the interaction of geometry and gauge/string theory.

Topics have included finite graphs and field theory, Calabi-Yau manifolds and compactification, as well as modern geometrical aspects of the standard model from string theory.

The project will provide an opportunity for the student to some rudiments of, for example, differential geometry, field/string theory and advanced algebra.

Some programming experience (with C and mathematica/maple) most welcome.

Supervisor: ***Prof Y-H He***
Email: ***hey@maths.ox.ac.uk***

TP11 Theoretical Biological Physics

An MPhys project will be available on **either**: Using Ox-DNA to model self-assembling DNA nanostructures **or** to understand biologically active DNA conformation. More details on our research page. You may want to look at the following papers:

Structural and thermodynamic properties of a coarse-grained model of DNA, Thomas E. Ouldridge, Ard A. Louis, Jonathan P.K. Doye, J. Chem. Phys. 134, 085101 (2011)

Coarse-graining DNA for simulations of DNA nanotechnology, Jonathan P.K. Doye, Thomas E. Ouldridge, Ard A. Louis, Flavio Romano, Petr Sulc, Christian Matek, Benedict E.K. Snodin, Lorenzo Rovigatti, John S. Schreck, Ryan M. Harrison, William P.J. Smith, Phys. Chem. Chem. Phys. 15 20395 (2013)

or Modelling evolution on genotype-phenotype maps. More details on ourresearch page. You may want to look at the following papers:

The structure of the genotype-phenotype map strongly constrains the evolution of non-coding RNA, Kamaludin Dingle, Steffen Schaper, and Ard A. Louis, Interface Focus 5: 20150053 (2015)

Good analytic and computational skills are desirable.

Supervisors: ***Prof A A Louis***
Email: ***Ard.Louis@physics.ox.ac.uk***

TP12 Chemical evolution of the Milky Way and Satellite Galaxies

As kinematics, i.e. the motion of stars, change over their lifetime, the only information we have about the origin of a star, is its chemical composition together with some information on its age. This chemical composition is inherited from the gas cloud that collapses into the star, with very minor alterations afterwards. Understanding this information is key to quantify the history and dynamics of any stellar system, e.g. the components of our Galaxy or the evolution of dwarf galaxies.

The project will make use of an existing model of detailed chemical evolution of several elements, which is also capable of predicting kinematic information and modelling observations we compare to. Depending on the progress of the project and the interests of the student, we will then try to explore the enrichment of dwarf galaxies and the Galactic halo. This can be done in light of stochastic enrichment and/or trying to quantify the halo metallicity distribution and its dependence on stellar kinematics and positions.

The project demands good analytical and some programming skills (preferably in C++, though this can be acquired during the project).

Supervisor: ***Dr R Schoenrich***
Email: ***Ralph.Schoenrich@physics.ox.ac.uk***

TP13 Chemodynamics of the Milky Way Disk

The history and dynamics of the Milky Way disk can explored by comparing stellar ages and abundances, which act like a chemical footprint tagging the origin of stellar populations, with their motions and positions today. This way one can learn how the system re-distributes its stars through phase space and what the detailed history of the disc was. We have several different surveys that map out these distributions and are still in the process of understanding these data. The student is invited to partake in this analysis and to concentrate on detailed questions, like tracking the impact of past spiral wave, or a merging satellite on the observables.

Good analytic and programming skills are essential for this project, familiarity with C++ and Hamiltonian mechanics would be beneficial

Supervisor: ***Dr R Schoenrich***
Email: ***Ralph.Schoenrich@physics.ox.ac.uk***

TP14 Probabilistic Parameter Determinations of Stars or Galaxies

Until now, spectral analysis is more of an artwork than a quantitative science. Typically a spetroscopist will try to fit the spectral lines of a star by hand, in order to obtain its physical parameters like temperature, metallicity, surface gravity, etc. However, with the advent of larger spectroscopic surveys, we need to quantify the errors on stellar parameters (which are key to quantitative comparisons with Galaxy models) in a more objective way and need strategies for the automatic assessment of stellar parameters. Similarly we need the full probability distribution functions in parameter space to combine the spectroscopic information with other sources, like photometry or astroseismology. Our group has created a fully integrated C++-based pipeline that performs this analysis and have successfully applied it to data from several surveys.

The student can choose to work on different aspects of this pipeline, from implementing astroseismic information and improvements on the Bayesian framework to studying details of algorithms underlying the spectroscopic analysis.

The project demands good analytical and good programming skills in C++, though this may be acquired during the project. The student might (depending on their choices) need to deal with astronomical .fits files and large datasets.

Supervisor: ***Dr R Schoenrich***
Email: ***Ralph.Schoenrich@physics.ox.ac.uk***

TP15 Spiral structure using perturbation particles

Conventional N-body simulations of stellar systems are severely limited by Poisson noise. The method of perturbation particles (MNRAS 262, 1013) overcomes this limitation by using particle to represent only the difference between a perturbed model and an analytic equilibrium. To date this technique has been little used for lack of appropriate analytic models. In this project perturbations of models similar to those described in arXiv1402.2512 will be followed by perturbation particles.

An ability to program in C++ will be a distinct advantage.

Supervisor: ***Prof J Binney***
Email: ***james.binney@physics.ox.ac.uk***

TP16 tbc

More details from the supervisor.

Supervisor: ***Prof R Golestanian***
Email: ***ramin.golestanian@physics.ox.ac.uk***

Index

Appendix A

Project Allocation: CHOICE FORM

Please make your 8 project choices. It is important that you list your choices in order of preference, 1 being the highest and 8 lowest. Each project is listed using its own unique project number, e.g. **AS01**.

If you wish to add any further information to assist in the allocation process please add a **brief** comment to the back of this form. **You will be contacted by e-mail if you are required to make further choices.**

Are you doing Physics and Philosophy?..

I'm doing the following Major Options: ....

Return the form to the Physics Teaching Faculty, Clarendon Laboratory
Deadline: Friday 6th week, 3.00 pm of Trinity Term 2016

Name: ....

College: ....

MPhys Project

1. First Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

2. Second Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

3. Third Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

4. Fourth Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

5. Fifth Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

6. Sixth Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

7. Seventh Choice
Project Title: ....

.... Project Number: .... Supervisor: ....

8. Eighth Choice
Project Title: ....

.... Project Number: .... Supervisor: ....