Photo: Alan Segar

Trinity Term - 2017

Physics

MPhys Projects
Trinity Term
2017

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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 2017. 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 (available online) by the end of 6th week.

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

Prof. Hans Kraus, Head of the Physics Teaching Faculty

The information in this handbook is accurate as at 24 April 2017, 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 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 2017*, and infrequently a project may have to be withdrawn. All changes will be published at http://www2.physics.ox.ac.uk/students/undergraduates.

Project allocation

Projects are allocated by the Assistant Head of Teaching (Academic) using the student's choices on their ***MPhys Project Choices*** form which is circulated via WebLearn.

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 ten 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) 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).

(iv) 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;

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

Project Assessors are appointed 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 an expert (junior) and a non expert (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, lasting no more than 5 minutes. The rest of the meeting will consist of a question and answer period, which has the primary purpose of clarifying any issues that the Assessors have with the written report.

The meetings with the candidates are scheduled for 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 2017

Week 0 Publication of the *MPhys Projects Trinity Term 2017* **http://www2.physics.ox.ac.uk/students/undergraduates**

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 Complete the *Project Choice Form*
(Fri 3 pm) [On-line 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://www2.physics.ox.ac.uk/students/undergraduates**

Students read the introductory papers on their project

Michaelmas Term 2017

Week 0 Publication of the *MPhys Projects Guidance* **http://www2.physics.ox.ac.uk/students/undergraduates**
(Mon) [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 Project 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 2018

Weeks 1 - 8 MPhys project period continues

Week 6* '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 **http://www2.physics.ox.ac.uk/students/undergraduates**)

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 2018

Week 1 MPhys project reports handed in. **Examination Schools**
(Mon 12 noon) 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 2017

Week 1-8 Call for MPhys Projects starting in Michaelmas Term 2017 starts. **E-mail**

Trinity Term 2017

Week 0 Publication of the *MPhys Projects Trinity Term 2017*
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 2017

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 2018

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 **http://www2.physics.ox.ac.uk/students/undergraduates**)
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 2018

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 Functional analysis of X-ray spectroscopy data using machine learning

X-ray spectroscopy is an extremely information-rich diagnostic in plasma physics, and is one of the most important techniques used to study extreme states of matter found in astrophysical objects and fusion plasmas. But interpreting the complex and noisy experimental data, often measured as integrated over the time and space of emission, remains a significant challenge.

In this project, the student will investigate how machine learning techniques can be applied to the interpretation of X-ray emission data. This will involve applying a range of data reduction techniques to raw experimental and synthetic datasets, and building supervised machine learning algorithms to extract information on key parameters of the plasma systems such as their temperature, density, time evolution and spatial gradients. The project demands good analytical and programming skills (C/C++, Python, or similar).

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

A&L02 Designing bang-bang quantum control pulses with genetic algorithms

Quantum computers work by applying sequences of quantum logic gates to quantum bits. These quantum logic gates can be viewed mathematically as unitary transformations whose actions can be interpreted as logical operations, but it is also important to consider how these unitary operations can be implemented physically, given the constraints imposed by the actual physical system used to implement the quantum bit.

Typical implementations involve modulating the amplitude and phase of control Hamiltonians in the presence of a background Hamiltonian, but a particularly simple approach, known as bang-bang control, involves interspersing brief periods of intense control fields with longer periods of free evolution under the background Hamiltonian. Designing such control pulses can be challenging, but recent work suggests that genetic algorithms can be surprisingly effective in finding good approaches. This project will involve investigating the use of genetic algorithms to design control pulses for an NMR quantum computer.

This project requires some programming skills in Matlab.

Steering quantum dynamics via bang-bang control: Implementing optimal fixed-point quantum search algorithm, G. Bhole, V. S. Anjusha, and T. S. Mahesh, Phys. Rev. A 93, 042339 (2016)

Supervisor: ***Prof J A Jones***
Email: ***Jonathan.Jones@physics.ox.ac.uk***

A&L03 Quantum information with photons

Quantum physics promises to revolutionize a wide range of applications, such as measurement precision beyond the classical limit, secure communications, and exponentially fast information processing. At the heart of these quantum-enhanced technologies lies the concept of a quantum experiment. A quantum experiment can be divided into three stages: state preparation, processing, and measurement. To ensure the optimal performance of quantum-enhanced technologies requires the ability to accurately characterize each stage of a quantum experiment. Quantum state, process, and detector tomography respectively prescribe a procedure to completely characterize these stages. This is done by making multiple measurements on identically prepared quantum systems resulting in a set of probabilities for each possible outcome. These probabilities can be inverted to determine the mathematical representation of the state, process, or detector.

The aim of this project is to explore techniques to generate, manipulate and characterize individual light quanta (photons) for quantum technologies such as quantum communications and quantum-enhanced sensing. The student will gain working knowledge of state-of-the art quantum optical sources and detection techniques.

Thorough understanding of quantum mechanics is required. It will be helpful if the student has seen field quantization in terms of creation and annihilation operators. Basic knowledge of electronics will also be essential. Computer programming skills (LabVIEW and Matlab) to interface experimental equipment, acquire and analyze data will also be helpful.

Supervisors : ***Dr V Thiel*** and ***Prof B Smith***
Email: ***valerian.thiel@physics.ox.ac.uk***;
Brian.Smith@physics.ox.ac.uk

A&L04 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. The project demands good analytical and some programming skills (Python-numpy, Matlab, or similar, though this can be acquired during the project).

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

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

A&L05 The Zero Vector Potential Mechanism

Understanding laser-plasma interactions is important for a diverse range of physics applications, from particle acceleration, warm dense matter studies, plasma laboratory astrophysics, through to Inertial Confinement Fusion. While there are many well-known mechanisms that successfully describe energy absorption over a wide range of regimes, the Zero Vector Potential mechanism – which dominates in the limit of very high intensity and density and was, until recently, restricted to one dimension (T. Baeva et al. 2011 Phys. Plasmas 18, 056702) – has now been extended to three dimensions (A. Savin et al 2017 (in preparation)). The mechanism is associated with that point in time of the oscillating laser pulse when the vector potential passes through zero. At that precise instant, the ponderomotive pressure vanishes and the system is so severely disrupted that the suppressed relativistic skin layer is violently reconstructed. This allows the generation of fast electrons that co-propagate with the zeroes in the vector potential and results in attosecond-duration bursts of fast electrons, as well as similar duration coherent X-rays. The resulting accelerations experienced by the fast electrons are so large –1026 ms-2 – that it may be possible to explore the physics of black hole analogues in the laboratory. In this project, the student will explore the physics associated with the ZVP mechanism at even higher intensities than have been attempted to date and will investigate new avenues that exploit these extraordinary accelerations for fundamental physics.

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

A&L06 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, Phys. Rev. A 93, 042126 (2016)

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

Requirements: Very strong analytical background, good knowledge of harmonic oscillator states and of the second quantization

Mandatory: potential students should meet the supervisors for an informal project discussion before applying for the project

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

A&L07 Exclusion principle for hard-core bosons

One of the important questions in many-body physics is to understand the influence of the particle exchange symmetry in the reduced one- and two particle pictures. For fermions, it has recently been shown that the antisymmetry of the wave function implies (in contrast to the case of boson) constraints on the one-particle picture. These are the so-called generalized Pauli constraints (see e.g. [1]). In this project, we will interpolate between fermions and bosons in the form of hard-core bosons: Their wave function is symmetric under particle exchange, yet they are not allowed to sit at the same place. The main goal is to work out consequences of this rather exotic, mixed exchange behavior for the one-particle picture. This will mean to establish a generalized exclusion principle for hard-core bosons which would then allow scientists to efficiently determine ground states of systems of hard-core bosons. A very promising approach would be to work out the analogous hierarchy of N-representability constraints as Mazziotti did it for fermions (on the two-particle level) [2].

[1] F.Tennie, D.Ebler, V.Vedral, C.Schilling, Phys. Rev. A 93, 042126 (2016)

[2] D.A.Mazziotti, Phys. Rev. Lett. 108, 263002 (2012)

Requirements: Very strong analytical background, excellent knowledge of the formalism of second quantization and the concept of reduced density matrices

Mandatory: potential students should meet the supervisors for an informal project discussion before applying for the project

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

A&L08 Cavity Quantum Optomechanics (theory)

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&L09 Developing a functional theory based on occupation numbers

One of the most promising numerical approaches to many-body physics is `Reduced Density Matrix Functional Theory' (RDMFT) (see, e.g., the introductory talk [1]). There one seeks an `exact' functional of the one-particle reduced density matrix whose minimization will yield the correct ground state. Besides the problem of finding the correct functional the success of RDMFT is still significantly hampered due to computational problems: During the minimization process of the functional one needs to ensure that the eigenstates of the density matrix remain orthogonal. In this project, we will first observe that many lattice systems studied in many-body physics are translationally invariant. This has the important consequence that the eigenstates of the one particle density matrix are known from the very beginning (-> Bloch states) and do not need to be optimized anymore. We will then propose new functionals which depend on the occupation numbers, only. These functionals will be tested numerically for the most prominent lattice model systems. Furthermore, ideas should be developed for an extension to many-band lattice models.

[1] N.N.Lathiotakis, talk at `Pauli2016': https://podcasts.ox.ac.uk/people/nektarios-n-lathiotakis

requirements: Strong analytical background, basic programming skills, excellent knowledge of the concept of reduced density matrices

mandatory: potential students should meet the supervisors for an informal project discussion before applying for the project

Supervisors ***Dr C Schilling***
Email: ***Christian.Schilling@physics.ox.ac.uk***

A&L10 Entanglement analysis in an analytically solvable model

The study of ground states in many-body physics has tremendously benefited from new concepts inspired by quantum information theory. One prime example is the area law for entanglement. It states that for ground states of translationally invariant lattice models with local interaction the entanglement of a subsystem merely grows like the boundary area of the subregion [1]. In the proposed project we will study an analytically solvable model of particles in a harmonic trap with harmonic pair interactions to explore entanglement in continuous systems, and without translational symmetry. The hope is to establish an analogue of the area law for systems which are more relevant in quantum chemistry. While an analytic approach is preferable one may also resort to numerical tools to determine the mode-reduced density matrices for different spatial regions. Part of the project will also be to clarify more how to integrate out modes (see also [2]).

[1] J. Eisert, M. Cramer, M.B. Plenio, Rev. Mod. Phys. 82, 277 (2010)

[2] G.G. Amosov, S.N. Filippov, Quantum. Inf. Process. 16, 2 (2017)

requirements: Very strong analytical background, excellent knowledge of harmonic oscillator states and of the second quantization

mandatory: potential students should meet the supervisors for an informal project discussion before applying for the project

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

A&L11 Weak Collionsless Shocks in Laser Plasmas

The student will explore the theory describing laminar shock-like structures in a collisionless plasma and examine the parameter limits, in terms of the ion sound Mach number and the electron/ion temperature ratio, within which these structures exist. The essential feature is the inclusion of finite ion temperature with the result that some ions are reflected from a potential ramp. This destroys the symmetry between the regions up- and downstream of the shock that would otherwise give the well-known ion solitary wave solution. We have shown earlier (Cairns et al 2014 Phys. Plasmas 21 022112; Cairns et al 2015 Plasma Phys & Control. Fusion 57(4) 044008) that such structures may be relevant to problems such as the existence of strong, localized electric fields observed in laser compressed pellets and laser-driven acceleration of ions. The student will explore the physics of multiple reflections in the temporally separated shocks (analogous to Fermi acceleration) and help explore the extent of fusion fuel preheat and species separation in inertial fusion targets resulting from this process.

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

A&L12 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&L13 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&L14 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&L15 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***
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A&L16 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***
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A&L17 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.

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A&L18 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***
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A&L19 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***
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A&L20 Hyperfine Transitions in a Bose-Einstein Condensate

The aim of the project will be to construct a microwave antenna capable of driving transitions between hyperfine energy levels in two isotopes of rubidium. The student will research the advantages of many popular designs, such as a quarter-wavelength antenna or a patch antenna, and construct an device capable of delivering significant microwave power to a trapped Bose-Einstein condensate or dual-species mixture; a wide-band impedance matching circuit will also be considered. Once the antenna and supporting hardware has been assembled, the antenna will be used to investigate the hyperfine energy level structure of a quantum gas mixture and to produce atoms in superpositions of hyperfine states, investigating Rabi oscillations and dressed atoms.

Further reading: Coherent Manipulations of the Rubidium Atom Ground State, MSc thesis, Amir Waxman

[http://www.bgu.ac.il/atomchip/Theses/Amir_Waxman_MSc_2007.pdf]

Supervisor : ***Prof C Foot***
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A&L21 **Construction and Implementation of a Bragg Diffraction Apparatus**

Diffraction is most often encountered when a coherent light source scatters from a periodic array of atoms, for example a grating. However, the complementary effect, where atoms can scatter off a periodic array of light, has also shown to occur. The method of Bragg diffraction is a valuable tool to study the momentum distribution of a trapped quantum gas. Bragg diffraction is facilitated when an atom absorbs a photon from one incident laser beam whilst emitting coherently into another laser of a slightly different frequency, thus acquiring a kick in the process. This method has been recently demonstrated to investigate the momentum distribution of a interacting Bose-Einstein condensate [1]. We aim to extend this method in investigating a BEC trapped in a quasi-two-dimensional geometry. The student will design and assemble the optical and electronic hardware required for the apparatus. They will then align the two Bragg beams on to the Bose-Einstein condensate and perform measurements of the momentum distribution and the dependence on trap geometry and atomic density. [1] I. Gotlibovych, Phys. Rev. A 89, 061604 (2014)

Supervisor : ***Prof C Foot***
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A&L22 **tbc**

More details from the supervisor.

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Atmospheric, Oceanic and Planetary Physics projects

AO01 Understanding the variability in the link between atmospheric circulation patterns over the Pacific/North American and Euro-Atlantic regions

The Pacific North American (PNA) pattern and the North Atlantic Oscillation (NAO) are patterns of atmospheric circulation that dominate the wintertime temperature and precipitation variability over North America and Europe, respectively. For example, the winter of 2013/14 was characterised by the positive phase of the NAO and a large number of storms hit the UK resulting in widespread flooding, whereas, the winter of 2009/10 was characterised by the negative phase of the NAO with cold temperatures and snow across western Europe. These patterns arise from the fluid dynamics of atmospheric flow, in particular variations in the terms which make up the atmospheric momentum budget.

Some studies have shown that these two patterns are linked and that the PNA exerts an influence on the NAO[1]. However, this link seems to vary over the latter half of the 20th century[2]. In this project, we will analyse this relationship on a longer period using reanalysis datasets from latter half of the 19th century and in long simulations of coupled climate models. We will analyse the dynamics during periods when there is a strong or weak relationship between these two patterns.

This is a computer-based project but only limited programming experience is necessary.

[1] Drouard et al. 2015: The Link between the North Pacific Climate Variability and the North Atlantic Oscillation via Downstream Propagation of Synoptic Waves. J. Climate. 28: 3957-3976.

[2] Pinto et al. 2011: The variable link between PNA and the NAO in observations and in multi-century CGCM simulations. Climate Dyn. 36: 337-354.

Supervisors: ***Dr T Woollings***; ***Dr M Drouard*** and ***Dr C O'Reilly***
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AO02 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***
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AO03 Idealized models of the dynamics of outgassed planetary atmospheres

Many planetary atmospheres have their source in sublimation or evaporation of a volatile substance from a condensed solid or liquid reservoir, where the reservoir is heated by illumination by the planet's star. Such atmospheres include the SO2 atmosphere of Io, the nitrogen atmospheres of Triton and Pluto, and postulated sodium vapor atmospheres on tide-locked planets with a permanent dayside magma ocean. Such atmospheres can either take the form of global atmospheres with weak pressure gradients (in the case of weak heat loss and condensation) or local atmospheres in which the surface pressure goes to nearly zero some distance from the volatile source. Simple one-dimensional models of such atmospheres have been developed, but are missing certain crucial pieces of the physics, such as radiative cooling. The transient (time-dependent) behavior of such atmospheres also has not been explored. In this project, the student will implement and explore existing models of such atmospheres, extend the physics beyond what has been incorporated before, and explore both steady-state and transient behavior. Applications to magma-ocean planets will be of particular interest. Another possible variant of this project is to study the fluid dynamics of fully compressible (as opposed to hydrostatic) flow.

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***

AO04 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 CO2 molecules with 13C atoms compared to the normal 12C. Others, e.g. H2O, 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***
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AO05 Infrared Emissivity of the Earth's Surface

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.

The calculation is simpified if it is assumed that the earth's surface behaves as a black body, and over the oceans this seems to be a good approximation. However, over land, emissivity is much more variable.

The aim of this project is to assess the impact of different surface emissivity models on the retrieval of atmospheric parameters on a global scale. This will involve running both simulated and real retrievals using the existing Oxford code. 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***
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AO06 Taking the rough with the smooth: understanding the effects of random rough boundaries on fluid flows

Fluid flows over complex rough surfaces are ubiquitous in nature. A fundamental understanding of the effects of rough surfaces on fluid flows is crucial to the study of various phenomena in engineering, astrophysical, and geophysical settings. For example, the summer melting of Arctic sea ice depends crucially on the impact of turbulent ocean and atmospheric flows on heat transfer to the ice. Despite the importance, certain simple yet important questions remain unanswered. One such question is the following: Given a fluid flow over a random rough surface, what statistics of the rough surface fully quantify its effects on the flow? The goal of this project is to address this question in simple flow settings using numerical simulations and theoretical interpretation.

We will build fundamental insight by separately considering pressure-driven and convective flow in a channel between two boundaries of different temperature, and how the heat transfer and drag respond to changes in the boundary roughness. The simulations would be carried out with different realizations of rough walls in order to discern which statistical features of the roughness are most important for characterising the impact on the flow. This study would be the crucial first step towards understanding fluid flows in the atmospheric boundary layer and underneath Arctic sea ice.

The numerical simulations will exploit the Lattice Boltzmann Method, which is a computational tool derived from Boltzmann kinetic theory to solve fluid-flow problems, and has been shown to be particularly effective in dealing with arbitrary rough surfaces (e.g. see http://users.ox.ac.uk/~phys0881/RoughConvection.mov for a visualisation of scaled temperature in Rayleigh-Benard convection under a fractal sea ice boundary). There may also be an opportunity for an interested student to consider a complementary theoretical approach using techniques from non-equilibrium statistical physics to characterise the emergent behaviour.

This project provides an opportunity to learn and combine techniques from fluid mechanics, computational physics and non-equilibrium statistical physics, to solve a fundamental problem. The student will have the opportunity to develop experience in state-of-the art methods for computational simulation of fluid flows. 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.

Suggested background reading:

[1] A. Smits and I. Marusic, Wall Bounded Turbulence, Physics Today. 66 (9), 25 http://dx.doi.org/10.1063/PT.3.2114 (2013). [2] L. Kadanoff, Turbulent Heat Flow: Structures and Scaling, Physics Today. 54 (8), 34 http://dx.doi.org/10.1063/1.1404847 (2001). [3] R.S. Sayles and T.R. Thomas, Surface topography as a nonstationary random process, Nature 271, 431, http://dx.doi.org/10.1038/271431a0 (1978). [4] S. Toppaladoddi, S. Succi and J.S. Wettlaufer, Turbulent transport processes at rough surfaces with geophysical applications, Procedia IUTAM 15, 34, http://dx.doi.org/10.1016/j.piutam.2015.04.006 (2015).

Supervisor: ***Dr A Wells*** and ***Dr S Toppaladoddi***
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AO07 Geophysical/atmospheric applications of new techniques for detecting bifurcations.

The mathematical phenomenon called "bifurcation" refers to a situation in which, when a continuous parameter of a system is varied smoothly, the state of the system undergoes discontinuous changes at "bifurcation points" from one state to another. Detecting bifurcations in complex systems governed by nonlinear ordinary or partial differential equations can be challenging, but modern mathematical techniques have been developed to deal with such systems. This project will explore applications of these new methods the the fluid flow equations governing escape of a planet's atmosphere to space, specifically the bifurcation between hydrostatic, non-escaping flow and transonic escape states. The governing equations consist of a coupled system of nonlinear ordinary differential equations.

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***
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AO08 Understanding the Building Blocks of Primitive Asteroids

In September 2016 NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission was successfully launched to asteroid Bennu (1999 RQ36) with the aim of returning a sample to Earth in the early 2020s. Here in Oxford Physics we are helping to map the composition of the asteroid to help with sample site selection and this project will allow you to be involved in the mission as we get ready for the key survey phase in 2018. This project will focus on characterising the thermal infrared (TIR) signature of meteorite analogues in anticipation of remote TIR emissivity observations of primitive asteroid Bennu. Bennu is thought to be a parent body to carbonaceous chondrite meteorites, some of the most primitive material left over from the formation of the Solar System. Being able to interpret these remote observations of its 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 sample into context with other carbonaceous chondrite meteorite classes.

In this project, we will be inverting laboratory thermal infrared emissivity spectra of meteorites and meteorite analogues provided by the OSIRIS-REx Carbonaceous Meteorite Working Group to determine their modal mineral abundances. Additional studies of terrestrial samples known to be good analogues for meteorites will be investigated to understand the effects of varying particle size distributions and the abundance of low albedo materials. This analysis is vital for understanding the methods that will be used to make spectrally derived mineral maps of Bennu once OSIRIS-REx is in orbit about the asteroid. Specifically the project will entail:

(1) Characterise thermal infrared emissivity signatures of meteorites and meteorite analogues using facilities in our Planetary Spectroscopy Facility under Earth-like and asteroid-like conditions. (2) Develop a linear unmixing algorithm for estimating mineral abundances in meteorite samples, in particular placing weights across different wavelength ranges based on spectral features (3) Compare laboratory TIR emissivity measurements of primitive asteroid analogues to (a) previously measured laboratory TIR emissivity measurements of carbonaceous chondrite meteorites and (b) TIR telescopic observations of asteroids.

Given the project description, the master's student will obtain a unique set of skills

(1) mineral sample handling and preparation,

(2) the use of analytical facilities like scanning electron microscope (SEM), electron microprobe (EMP), and X-ray diffraction (XRD),

(3) the use of Fourier Transform Infrared (FTIR) spectrometers,

(4) the analysis of reflectance and emissivity laboratory data sets, and

(5) comparing laboratory data sets with remote sensing observations.

Preferred skills: Software programming experience (MATLAB, Python, IDL, etc.) and laboratory experience

Suggested reading material: (1) Lauretta, D. S. et al. (2015), Meteoritics & Planetary Science, 50, 834-850. (2) Ramsey and Christensen (1998), Journal of Geophysical Research, 103, 577-596. (3) Donaldson Hanna et al. (2017), Icarus, 283, 326-342. (4) OSIRIS-REx website (http://www.asteroidmission.org/).

Supervisors: ***Dr K Donaldson Hanna*** and ***Prof N Bowles***
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AO09 Patterns in melting permafrost: pathways to enhanced methane emissions?

The frigid high latitudes harbour large reservoirs of methane that are currently trapped in frozen soils. Thawing of this permafrost can release methane into the atmosphere. Methane is a potent greenhouse gas, and it has been hypothesised that the nonlinear feedback between atmospheric warming, permafrost melt and methane emissions may have played a significant role in major climate warming episodes in the Earth's past. However, key details of the controls on the melting rates of permafrost remain under-constrained.

So-called thermokarst lakes are a common feature in regions of melting permafrost, and provide pathways for large methane fluxes to the atmosphere. Melting of ice in the pore space of the soil leads to fluid flow and localised subsidence, and collection of water into a surface lake. Each lake provides a region of enhanced solar and atmospheric heating, providing a feedback on the melting of the permafrost below the lake. This project will try to understand the physical mechanisms responsible for the formation of localised thermokarst lakes and their spatial distribution, by exploring the potential for a flow-induced instability during the melting of an initially uniform permafrost layer. The goal is to explore the hypothesis that the spatial patterns of thermokarst lakes can be understood as a result of nonlinear dynamics, instability, and pattern formation in thawing permafrost. The results will aim to build new understanding of the development of lakes in melting permafrost, with potential impact on predictions of methane emissions and long term climate dynamics.

This project provides an opportunity to learn and use techniques from theoretical analysis and computational methods to tackle a geophysical problem involving fluid mechanics and nonlinear dynamics. The student will have the opportunity to develop experience in computational methods for modelling fluid flows. 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***
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AO10 **A simple model of the Antarctic Circumpolar Current**

The Antarctic Circumpolar Current (ACC) transports 137 x 106 m3 s-1 of water around Antarctica, connects the different ocean basins and has a profound impact on climate. Despite this, we lack a convincing theory of the processes that set the volume transport of the ACC. The dominant mechanical forcing of the ACC is believed to come from surface wind forcing, though most of the wind work occurs north of the open latitude band of Drake Passage. In this project, the student will study a new approach to estimating the effective wind forcing of the ACC through a rotational-divergent decomposition of the surface wind stress. The project will involve a combination of pen and paper and computational work with a simple numerical model (doi:10.1016/j.ocemod.2015.11.010). The aim is to develop a simple conceptual understanding of how wind forcing sets the volume transport of the ACC.

Supervisor: ***Prof D Marshall***
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AO11 **Meteorological data and cosmic rays at Snowdon Summit**

A small weather and cosmic ray station has run at Snowdon Summit since 2005. The instruments at the station comprise a radiometer to measure down and up- welling visible and infra-red radiation in the atmosphere, and detectors for cosmic rays and natural radioactivity. This project will involve collation and analysis of the long-term data set. For example, the cosmic ray data should show signals from the 11-year solar cycle and space weather events. Another possible effect is the variation of natural radioactivity emitted from the ground with meteorological conditions, in particular snow cover, which can be identified with the radiometer data from the surface albedo. The site is likely to undergo considerable improvement and expansion in 2017-18, such as installation of additional instruments like a field mill to measure the atmospheric electric field. To support this, the student can carry out electromagnetic modelling to predict the geometric effects of the summit building and mountain itself on the atmospheric electric field, for effective comparison with other sites. This project is most closely linked to the atmospheric physics major option, with some particle physics overlap, though neither option is essential. The student should be competent, or willing to become competent, at writing code in a data analysis package such as R or IDL, and working with electrostatic modelling software. There may be also an opportunity to visit the site and/or become involved in outreach activities as part of the project.

Supervisor: ***Dr K Aplin***
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AO12 **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 charge-generating mechanisms that could result in volcanic lightning under these environmental conditions. One mechanism is 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 charge measurements resulting from the fragmentation of rock samples by an automated rock collision apparatus. Measurements of the charge generated will be collected in a variety of conditions including different atmospheric compositions, and at high pressures and temperatures, which will include Venus and early Earth 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 (***University of Reading)
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AO13 **Infra-red absorption of atmospheric ions in the laboratory**

Natural radioactivity and cosmic rays constantly ionise the air. The ions and electrons formed stabilise by clustering with other atmospheric molecules to make nanometre-sized cluster-ions. These charged clusters are hydrogen bonded to a central ion, and the bond rotations and vibrations absorb infra-red radiation (this principle is often used to spectrally identify gases). The infra-red absorption from the hydrogen bonds in cluster-ions has been detected both in the atmosphere and in laboratory experiments, but the sensitivity of the effect to the cluster-ion concentration is not yet well known. This project will involve setting up and running laboratory experiments to create ions with radioactive sources, measuring the associated infra-red absorption and how it varies with the ion concentration. The instrumentation used has already been developed but will need setting up in a new configuration; data analysis will also be required to understand the results. The theory behind this project is most closely linked to the atmospheric physics major option, with a small particle physics overlap, though neither option is essential.

Supervisor: ***Dr K Aplin***
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AO14 **The Impact of Festivals on Anthropogenic Climate Change**

Due to the steady rise of greenhouse gases emitted by anthropogenic activities global warming is expected to continue into the future. Tiny particles, known as aerosols, emitted with greenhouse gases in combustion are hypothesised to suppress precipitation and cool the climate. The amount of cooling is highly uncertain. Festivals such as the Chinese New Year, American Independence Day and Guy Fawkes/ Bonfire Night result in sharp localised increases in anthropogenic aerosol and poor air quality. These extreme localized events, provide an opportunity to determine whether anthropogenic aerosol perturbations are substantial enough to influence cloud properties and precipitation.

The goal of this project is to quantify the atmospheric impact of several national-scale festivals. The project will make use of multiple state-of-the-art satellite data sets. The retrieved quantities will be obtained from active (e.g. radar and lidar) and passive imaging satellite products in a comprehensive analysis, also including corroborating measurements from surface-based instruments. These products will be combined using the Community Intercomparison Suite (CIS). Statistical methodologies will need to be developed based on theoretical models describing aerosol-cloud interactions in order to the quantify climate impacts.

The student will have the opportunity to deepen their computer programming skills, learn about and develop the theory behind aerosol cloud interactions, and apply numerous integrated datasets together to determine the impact of aerosol from festivals. The project demands basic analytical and programming skills (preferably in IDL, Matlab, or Python).

Supervisors: ***Dr M Christensen*** and ***Prof P Stier***
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AO15 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***
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AO16 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***
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AO17 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***
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AO18 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 ***Prof N Bowles***
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AO19 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 ***Prof N Bowles***
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AO20 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***
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AO21 Exploring interactions between climate change and economic growth

Integrated assessment models (IAMs) are widely-used tools for climate change policy analysis, addressing questions such as determining the level of carbon tax required to stabilise temperatures at 2 degrees above pre-industrial (or, following the Paris Agreement, "well below 2 degrees"). Current IAMs include a rather limited representation of potentially non-linear feedbacks between climate change and the rate of economic growth. While there is a literature dating back decades on non-linear climate change and an entirely separate literature on non-linearity in macro-economics, much less has been written on possible non-linear interactions between the two. This project will begin from a simple linear climate model coupled to idealised representations of global damage and the global economy to explore how interactions between climate change and economic growth might result in interesting behaviour in IAMs, such as bifurcations (sometimes called "tipping points") between different climate policy regimes.

The student will have to be familiar with the chaos components of the B1 course. Having attended the S-25 option would be helpful, but not essential (notes are on weblearn). Familiarity with some form of mathematical programming language such as matlab or IDL would be helpful, and an interest in economics and interdisciplinary problems essential.

Background reading: The Climate Casino: Risk, Uncertainty, and Economics for a Warming World by William Nordhaus, and for a our starting point see Allen (2016), "Drivers of peak warming in a consumption-maximising world", Nature Climate Change, http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2977.html

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AO22 tbc

More details from the supervisor.

Supervisor: ***Prof P Read***
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AO23 Correction for atmospheric delays in the Interferometric Synthetic Aperture Radar (InSAR) data processing

Correcting for atmospheric delays is one of the largest challenges facing the interferometric synthetic aperture radar (InSAR) community (Hooper et al., 2013). In fact, tropospheric and ionospheric signals in InSAR data tend to mask smaller surface displacements due to geological phenomena (e.g., fault activity, landslide and subsidence; Rosen et al., 2000).

Tropospheric signals consist of a short-scale (few km) component, introduced by turbulent as well as coherent dynamics in the troposphere, a longer-scale (10s of km) component, introduced by lateral variation of pressure, temperature and humidity, and a topography correlated component due to changes of pressure, temperature, and relative humidity with height.

Until now the tropospheric correction in InSAR results have considered the use of one of the following methods: integration of weather models, GPS measurements, multi-spectral observations (e.g. from the Medium Resolution Imaging Spectrometer (MERIS) onboard the Envisat satellite; or the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites), or GPS in combinations with spectrometer data.

However, the different tropospheric correction techniques all have their own limitations, and are not always sensitive to the same component of the tropospheric delay and, therefore, none of them can be considered the best in reducing the tropospheric delays consistently over different regions and times (Bekaert et al., 2015).

In this project, the student will focus on the reduction of tropospheric (and eventually ionospheric) noise in InSAR data through the integration of different tropospheric correction methods.

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

Suggested reading:

Bekaert, D.P.S., Walters, R.J., Wright, T., Hooper, A.J., Parker, D.J., 2015. Statistical comparison of InSAR tropospheric correction techniques. Remote Sensing of Environment, 170 40–47. http://dx.doi.org/10.1016/j.rse.2015.08.035

Hooper, A., Pietrzak, J., Simons, W., Cui, H., Riva, R., Naeije, M. Socquet, A. (2013). Importance of horizontal seafloor motion on tsunami height for the 2011 Mw = 9.0 Tohoku-Oki earthquake. Earth and Planetary Science Letters, 361, 469–479. http://dx. doi.org/10.1016/j.epsl.2012.11.013

Rosen P.A., Hensley S., Joughin I.R., Li F.K., Madsen S.N., Rodríguez E., Goldstein R.M., 2000. Synthetic Aperture Radar Interferometry. Proceedings of the IEEE, 88, 333-382.

Supervisors: ***Dr A Novellino*** and ***Dr C Wilson***
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AO24 Retrieval of H2SO4 from IASI measurements

Sulphuric acid (H_2SO_4) aerosols are important modifiers of climate because they reflect solar radiation. The principal source of H_2SO_4 aerosols is volcano-emitted sulphur dioxide that is oxidised to H_2SO_4 (gas) before condensation into particles.

Satellite infrared spectrometers (such as IASI) are used to detect and retrieve different atmospheric constituents, e.g. aerosol and gases. Measurements of SO_2 and H_2SO_4 can be particularly important to quantify climatic effects of volcanic plumes that reach the stratosphere - such as Nabro (2011), Kelut (2014) and Calbuco (2014) - where the volcanic aerosols affect the atmosphere for months after the eruption.

In this project the student will:

(i) add the H_2SO_4 droplet optical properties to the present IASI aerosol retrieval scheme;

(ii) apply the retrieval to obtain H_2SO_4 optical depth and effective radius and the mass of erupted H_2SO_4;

(iii) study the information content and perform an error analysis of the retrieved H_2SO_4.

The focus of this work will be on the Calbuco eruption (April 2015) where preliminary work shows an H_2SO_4 signal that persists for more the 10 days together with an SO_2 plume. If time permits, the existing SO_2 amounts and the H_2SO_4 retrievals will be used to quantify the rate of conversion of SO_2 into H_2SO_4.

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Astrophysics projects

AS01 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.

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AS02 Dissecting galaxies using cosmic telescopes - strong gravitational lenses

Gravitational lenses are remarkable phenomena – a striking visual demonstration of Einstein's theory of General Relativity – where the light from a distant galaxy is bent by the gravity field of an intervening massive foreground galaxy or group of galaxies lying along the line of sight. This results in an amplified, magnified and distorted image of the distant background galaxy often resulting in multiple images or complete and partial rings. The separation and distortion of lensed images is entirely determined by the total matter distribution in the intervening 'lens', this includes both luminous (i.e. stars) and elusive dark matter. Therefore lensing is one of the only means to "weigh" galaxies, and to constrain dark matter providing one of the most direct pieces of evidence for its existence. However, finding gravitational lenses remains a difficult task with large numbers of false positives (configurations that mimic lenses) requiring significant effort in visually inspecting the candidates. Strong gravitational lenses have a variety of astrophysical and cosmological applications, including mapping dark matter and constraining cosmological parameters. In this MPhys project we focus on understanding the distribution of mass in the lenses, and the nature of the distant (high-redshift) lensed galaxies. The lenses studied in this project were discovered by citizen scientists taking part of the Galaxy Zoo and Space Warps (spacewarps.org) Zooniverse projects. The work will be centred on analysing spectroscopic data already in hand to determine the nature of the lens and place constraints on the lens model, mass and distribution of dark matter. The student will be guided through existing data reduction and analysis software packages. Therefore candidates should be comfortable with basic programming, and some experience with IRAF would be advantageous, but not essential. There will also be opportunity to liaise with lensing enthusiasts participating in Space Warps

More information

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AS03 Modeling the near-IR emission of star-forming regions and active black holes

The two main processes that control the evolution of galaxies are the formation of stars and the growth of the central super-massive black hole (BH). Therefore, to understand how galaxies evolve across cosmic times, we need methods to distinguish between galaxies dominated by star-formation (SF) and those dominated by an accreting BH.

Several diagnostic diagrams exist. However, most of them use the optical spectral range which is unreliable in the dusty obscured environments where most of the SF and BH accretion in the Universe take place. For this reason, alternative diagnostic diagrams using wavelengths less affected by dust extinction, like the near-infrared (1 to 2.5 micron), are necessary.

In this project, we will model the intensities of the near-IR atomic transitions as a function of the energy source (young stars vs. BH accretion) and compare these predictions with observations of nearby galaxies. To do so, we will use the spectral synthesis code Cloudy (www.nublado.org). Basic knowledge of Python or IDL is required.

Supervisor: ***Dr M Pereira Santaella***
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AS04 The mass dependence of radio-loud active galactic nuclei

The growth and evolution of super-massive black holes in active galactic nuclei (AGN) is clearly linked to galaxy evolution, but we do not yet know all of the details of how this happens. A small fraction of AGN have jets of relativistic plasma that emits synchrotron emission, which is observable at radio wavelengths. These 'radio-loud' jets are thought to be fed via two different accretion processes, which divide the population into 'high-excitation' and 'low-excitation' radio galaxies. In this project, you will use catalogues from the VISTA Deep Extragalactic Observations (VIDEO) survey, which has been cross-matched to a radio survey, and study the redshift evolution of both types of radio-loud AGN, and compare the evolution of the two populations with each other. This will improve on current studies, which are limited in field of view and depth.

Requirements: This project is computational and will involve manipulating large catalogues, making plots, etc. Any experience in this would be helpful, but should not put off anyone interested in the project.

Supervisors: ***Dr L Morabito*** and ***Prof M Jarvis***
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AS05 Black holes in gravity with a Higgs mechanism

Abstract: It has been suggested that gravity can support a Higgs mechanism for Newton's constant (or the Planck mass). In this scenario, gravity "switches off" at high curvatures. There are a few proposals of how to modify General Relativity to make this work. In this project we will explore the consequences for black holes: their existence, stability and formation. The student will have to have a good knowledge of GR (and know, for example, how to derive the Schwarzschild solution) and the ability to write code, preferably in Python, fortran or C (although these skill can be aquired during the project).

Supervisor: ***Prof P G Ferreira***
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AS06 Detection of transiting exoplanets with K2 and TESS

The Transiting Exoplanet Survey Satellite, TESS, will commence operations in 2018, scanning almost the entire sky for planets transiting across bright stars. It will spend between one month and one year observing any given portion of the sky, with one observation every minute for the brightest 200000 stars. Simulations of TESS's planet yield suggest it will discover thousands of new exoplanets, including several dozens of terrestrial planets. Here at Oxford we have developed tools to detect and model planetary transits in the context of previous space missions CoRoT and Kepler, which we are now using to analyse data from K2 (the refurbished Kepler mission), and we want to be ready for TESS data when it becomes available. The project will consist in simulating TESS data and using it to test our transit search and validation code. Depending on progress, the student will also have the opportunity to contribute to our ongoing search for planets in new data from K2 that will be released during the course of the academic year - and thus could be involved in the discovery of brand new exoplanets.

The project will suit a student interested in exoplanets, with a good statistical background and programming skills (ideally some experience of Python). The student will work both with existing code (to detect and model transits) and write their own (to simulate TESS data).

Supervisor: ***Prof S Aigrain***
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AS07 Characterising Asteroids with Spectroscopy on the PWT

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 extend a previous successful MPhys project to make the classification a semi-automatic long term programme from Oxford.

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. A previous MPhys project (2015) demonstrated the potential for using the PWT to spectroscopically classify asteroids, but only managed a handful of objects (though in enough detail to warrant a potential publication currently in progress).

This project aims to extend that basic work and develop an automatic process to fully exploit the telescope's robotic control system.

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; automating the software technique to extract the spectra from the data and 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***
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AS08 Understanding the mass assembly of bright galaxies in the early Universe

Studying the build-up of massive galaxies in the early stage of the Universe is crucial to constrain our galaxy evolution model and the impact of galaxies on re-ionization. The drivers of mass assembly (smooth gas accretion and in-situ star-formation or galaxy interactions and mergers) are still actively debated, especially because galaxy observations at these redshifts are challenging, and statistical measurements from these observations show currently no clear agreement with simulations. In this context, HST (Hubble Space Telescope) imaging of extremely high redshift galaxies offers a material of choice to extract both morphological and photometric informations which are required to constrain the scenario of the galaxy build-up. In order to disentangle the possible formation mechanisms leading to these observations, we can rely on cosmological simulations, which provide a way to implement our current knowledge about galaxy evolution and to confront it with observations.

The student will first make use of an existing code to create realistic photometric images of high redshift galaxies in the state-of-the-art Horizon-AGN simulation. He will compare them to existing HST images of identified bright high-redshift galaxies (Bowler+17). In a second step, the student will connect the simulated galaxies with their current and past star formation histories in order to provide a framework to interpret the HST observations. Depending on the progress of the project, the student will finally compute the UV luminosity function of the simulated high-redshift galaxies and compare it with the observed one.

The project requires some programming skills.

Supervisor: ***Dr C Laigle***
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AS09 Instrumentation on the Philip Wetton Telescope

The Philip Wetton telescope here in Oxford is used for a range of undergraduate projects, some research, and of course public outreach. The telescope is fully automated (robotic), and takes data for a range of projects every clear night. Currently, the only instrument available is a standard CCD camera with a range of colour filters. This project aims to expand the instrumentation capabilites of the observatory by developing some new instruments for spectroscopy or adaptive-optics. A range of possible options is listed below, but interested students are strongly recommended to discuss options with the supervisors before the application deadline -- there is scope to tailor the project to the student's aims. These projects would suit a student with an interest in the more practical side of astronomy.

Potential instrumentation projects include;

+ Automating the existing slit spectrograph to allow robotic operation

The observatory has an existing spectrograph, but it is little used as it is not compatible with robotic operation. This project will involve adding components (e.g. servo motors + controllers) to the spectrograph, and developing control software to allow it to be used remotely. Depending on how the project develops, we will also look at integrating the spectrograph into the existing observatory control software to allow fully robotic spectroscopy for the first time. This project should suit a student with an instrumentation and coding; exploiting the spectrograph to its full will require some significant code development.

+ Designing a new spectrograph for an integral field unit

We have an fibre integral field unit (to allow spectroscopy of extended objects such as planets or galaxies), which was built as an MPhys project several years ago. Unforuntately the existing spectrograph is not good enough work efficiently with the IFU, so we need to design a new more suitable spectrograph. This project will involve investigating different optical design options, and then developing a mechanical design around them. Depending on how the project develops, we will attempt to build a first version of the spectrograph in the lab. This project would suit a student with an interest in optical/mechanical design.

+ Characterising a new cheap fast camera for wavefront sensing

We have recently bought a small fast camera based on new CMOS technology, which seems to offer good potential as a wavefront sensing camera -- the first step in building a potential adaptive optics system for the PWT. This project will involve characterising the true performance of the camera in the lab and then on the telescope. Developing an AO system is beyond the scope of this project, but we will attempt to use the camera to characterise the atmosphere above Oxford as input to any future designs. This will involve developing some simple instrumentation and taking large runs of data with the camera. This project would suit a student with an interest in software and data processing/analysis.

Special Requirements

As the instrumentation projects are quite specialised, students must speak to the supervisors before applying for the projects. Code for the projects will be mainly based in Python, so experience in this is useful but not necessary. Some of the projects, particularly the wavefront sensing project, will require night-time working to take data.

Supervisors: ***Dr F Clarke*** and ***Dr R Barnsley***
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AS10 The cosmic star formation rate to high-redshifts from emission line galaxies

Recently star-forming galaxies show strong emission lines emitted from the ionized regions near young stars. Using measurements of the strength of these lines from spectroscopy it is possible to measure the cosmic star-formation rate density and typical specific star-formation rate and how this varies with time. The disadvantage of such spectroscopic samples however, is that they are typically small and can be biased to nearby or highly star-forming galaxies. An alternative to spectroscopy is to use deep imaging data, using both narrow and broad-filters, which can pick out galaxies with a range of a range of underlying masses, luminosities and to higher redshifts. In this project, you will select a sample of emission line galaxies from several deep photometric imaging datasets. By fitting the multi-band photometry available in these fields, it will be possible to determine their underlying physical properties and their redshifts, and in doing so make a new measurement of the cosmic star-formation rate density and typical galaxy specific star-formation rate, and hence constrain the peak of galaxy formation. An alternative would be to use a recent machine learning code developed by our group, to learn the relationship between emission line luminosity and the multi-band photometry. Depending on the interests of the student either or both methods could be employed.

Requirements

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 put off anyone interested in the project.

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

AS11 Outlier detection with citizen science

As astronomical datasets grow in size, classification and sorting becomes an increasingly intractable problem. This project will make use of two complementary techniques - firstly, the involvement of large numbers of classifiers recruited via the Zooniverse citizen science platform and secondly cutting edge machine learning to investigate the behaviour of a hybrid system capable of identifying interesting outliers. This might involve using data from Galaxy Zoo, to investigate galaxy morphology, or from Zooniverse projects aimed at detection of transients such as supernovae. This would suit a student who is comfortable with code, or who wants to learn techniques with broad applicability for future work.

Supervisor: ***Prof C Lintott***
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AS12 Strategies for finding high-redshift radio galaxies

Many high-redshift radio galaxies have been found by selecting radio galaxies with ultra-steep spectral energy distributions (SED) at radio wavelengths, and following up with optical observations to determine the redshift. High-redshift radio galaxies are indicative of dense environments in the distant Universe, and are thought to evolve into the most massive galaxies we see today. They are therefore an interesting link in studying the evolution of massive galaxies. Recent work has shown that simply selecting based on radio SEDs will bias high-redshift samples towards only extreme galaxies. In order to select a more representative sample of candidate high-redshift radio galaxies, it is necessary to consider other indicators like compact size. New low-frequency radio surveys with unprecedented sensitivity and resolution offer the possibility to select samples of more "normal" high-redshift radio galaxies. This project will involve (1) determining a strategy based on the available data to select a complete sample of high-redshift galaxy candidates and (2) applying the strategy to low-frequency radio surveys.

Requirements: This project is computational and will involve manipulating large catalogues, making plots, etc. Any experience in this would be helpful, but should not put off anyone interested in the project.

Supervisors: ***Prof M Jarvis***; ***Dr L Morabito*** and ***Dr R Bowler***
Email: ***Matt.Jarvis@physics.ox.ac.uk***;
leah.morabito@physics.ox.ac.uk;
rebecca.bowler@physics.ox.ac.uk

AS13 & AS14 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 would suit students with an interest in astrophysics. Some computing skill is desirable.

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

AS15 Comparing optical and infrared morphologies

The shape of a galaxy - its morphology - is a record of its dynamical history, recording star formation and interactions over many billions of years. The Galaxy Zoo project has enlisted citizen scientists to provide reliable classifications of morphology across the largest surveys available. This project will make use of recent Galaxy Zoo data from the UKIDSS survey, providing classifications of infrared morphology, to investigate the differences between infrared and optical morphologies; the two measurements should trace different timescales and so we will focus on galaxies with different morphology in the two bands. The project requires moderate programming, and would also suit those with an interest in outreach.

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

AS16 Shape twisting of galaxies and halos in the Horizon simulation

The shapes and orientation of galaxies are aligned throughout the large-scale structure. These alignments are typically well measured in observations and simulations, and are thought to arise due to the interaction of galaxies with the tidal field of the universe. This interaction can stretch a galaxy, and it can also rotate its axis in a preferential direction. These alignments can be a function of the region of the galaxy being probed. Inner regions might display less alignment than outer regions, since stars are less gravitationally bound in the outskirts and can be influenced more strongly by the tidal field. A similar effect can be expected for dark matter halos, in which galaxies are typically embedded. I propose an exploration of this effect using the Horizon-AGNcosmological hydro-dynamical simulation. The results of this project will aid us in the improvement of our physical understanding of the origin of these intrinsic alignments and their modelling as a contaminant to weak gravitational lensing cosmology.

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 A Slyz***; ***Dr J Devriendt*** and ***Dr S Codis(CITA)*** & ***Horizon simulation collaborators***
Email: ***elisa.chisari@physics.ox.ac.uk***

AS17 & AS18 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***

AS19 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***

AS20 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.

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

AS21 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***

***AS23* 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***

***AS24* 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***

***AS25* 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***

***AS26* 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***

***AS27* 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***

AS28 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***

AS29 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***

AS30 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***

AS31 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***

AS32 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***

AS33 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***

AS34 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***

AS35 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***
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AS36 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***

AS37 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***

AS38 tbc

More details from the supervisor.

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

AS39 tbc

More details from the supervisor.

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

AS40 Seeing Star Forming Galaxies in 3D in an era when the Universe was most active

We have identified many star forming galaxies at around a redshift of one (when the Universe was half its current age), through observations with the Wide Field Camera 3 on the Hubble Space Telescope (the WISPS collaboration), using a mode where the light is dispersed by a prism to take low-dispersion spectra. We detect emission lines, powered by the ultraviolet ionizing photons produced by the most massive, hottest, shortest-lived stars. It appears that this era in history is when the most intense star formation took place, and we want now to study how this star formation is distributed within individual galaxies. To do this, we have taken spectra with the Very Large Telescopes in Chile, using the KMOS instrument that Oxford was involved in building. KMOS is an integral field spectrograph working in the near infrared, taking a spectrum at each point over a 2D area.

The wavelength provides a third dimension, which can map the rotation of galaxies through the Doppler shift (and hence estimate their masses). This project will be to reduce and analyse the KMOS integral field spectra, and use this to determine the star formation rates and the distribution of star formation within these galaxies, and to measure the velocity spread and velocity shifts as a way to estimate the mass of the galaxies. The project will be computer based, using some pre-written software but also developing new analysis software tools. Experience in a language such as Python or IDL will be an advantage, and the student will be expected to be doing the fourth year astrophysics C-paper, or to have taken the third year S26 "Stars and Galaxies" short option last year.

Supervisor: ***Prof A Bunker***
Email: ***Andy.Bunker@physics.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: ***Prof S Tucker***
Email: ***stephen.tucker@physics.ox.ac.uk***

***BIO04* A Method for the Recording and Analysis of Electrochemical Potentials and 'Bioelectricity'**

All living cells are electrically active. 'Bioelectricity' results from the electrochemical gradients generated by the selective permeability of biological membranes to different charged ions such as Na+ and K+. In this project the student will design and construct a simple apparatus for the measurement and analysis of electrochemical potentials. The aim is to produce a piece of equipment suitable for a new biophysics practical in the third year teaching laboratories. In addition to the equipment itself, the project will also involve producing easy to follow protocols. Finally, parts of the overall practical may involve use of 'ready to use' equipment such as that provided by https://backyardbrains.com/ . The project will therefore also investigate suitable options for the recording and analysis of nerve activity within an undergraduate practical setting. Considerable background research has already been done. The project requires no previous experience and would be extremely suitable for those wishing to get hands-on experience of equipment design/construction and scientific communication.

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

***BIO05* 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***

***BIO06* 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, improving resolution from ~200 nm to ~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 for single biological cells, and applied them to many organisms ranging from living 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.

This project 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***

***BIO07* *P*hysics 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***

BIO08 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 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***

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 of Magnetic Skyrmions

Nowadays, condensed matter physicists become more and more aware of the fundamental implications of a material's topological properties. The largely unexplored magnetic skyrmions carry rich topological physics and hold the promise of future applications in information technology. Skyrmion physics concerns nonlinear many-body system, which shows non-trivial spin structures, phase transitions, and dynamics. Therefore, theoretical calculations are of great importance in understanding the skyrmion-carrying systems.

This simulation project is dedicated to the exploration of skyrmion dynamics in low-dimensional systems. It is part of the UK-wide, EPSRC-funded national research program into Skyrmionics, designed to achieve a step-change in our understanding of skyrmions in magnetic materials and engineer them towards application. A detailed description of the research topics and institutions involved can be found at http://www.skyrmions.ac.uk. Computer simulations of the detailed position- and time-dependent magnetisation ("micromagnetism") describe these phenomena well.

This project will involve modelling of micromagnetic systems using NIST's Object Oriented Micromagnetic Framework (OOMMF, see Donahue, MJ and Porter, DG "OOMMF User's Guide, Version 1.0" NIST inter-agency report).

Further Reading:

[1] Zhang, S. L.; Bauer, A.; Berger, H.; et al., Resonant elastic x-ray scattering from the skyrmion lattice in Cu2OSeO3, Phys. Rev. B 93, 214420 (2016)

[2] Zhang, Shilei; Baker, Alexander A.; Komineas, Stavros; et al., Topological computation based on direct magnetic logic communication, Sci. Rep. 5, 15773 (2015)

Special skills required:

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

Supervisors***: Dr T Hesjedal*** and ***Dr S Zhang***
Email***: Thorsten.Hesjedal@physics.ox.ac.uk***

CMP02 Synthesis of Skyrmion-carrying thin films

Topological insulators are a very exciting new class of Nowadays, condensed matter physicists become more and more aware of the fundamental implications of a material's topological properties. The largely unexplored magnetic skyrmions carry rich topological physics and hold the promise of future applications in information technology. Being distinct from the well-known magnetic orders (e.g., ferromagnetic, antiferromagnetic, ferromagnetic), magnetic skyrmions emerge as a new ordered state that exhibits as a topologically-protected spin swirl structure, leading to a series of novel magneto-electrical effects.

This is an experimental project dedicated to the exploration and study of novel, low-dimensional skyrmion-carrying materials. It is part of the UK-wide, EPSRC-funded national research program into Skyrmionics, designed to achieve a step-change in our understanding of skyrmions in magnetic materials and engineer them towards application. A detailed description of the research topics and institutions involved can be found at http://www.skyrmions.ac.uk. The ultimate goal of the project is the synthesis of room-temperature, skyrmion-carrying thin film materials, which enable device applications in the future. The main tool for the growth of the thin film systems is magnetron sputtering, and X-ray diffraction and SQUID magnetometry will be used for their characterisation.

Reading list (recent group publications):

[1] Zhang, S. L.; Bauer, A.; Burn, D. M.; et al, Multidomain Skyrmion Lattice State in Cu2OSeO3, Nano Lett. 16, 3285-3291 (2016)

[2] Zhang, S. L.; Chalasani, R.; Baker, A. A.; et al., Engineering helimagnetism in MnSi thin films, AIP Adv. 6, 015217 (2016)

[3] Lancaster, T.; Xiao, F.; Salman, Z.; et al., Transverse field muon-spin rotation measurement of the topological anomaly in a thin film of MnSi, Phys. Rev. B 93, 140412 (2016)

Required skills: strong interest in quantum materials, their synthesis and characterisation, strong work ethics.

Supervisors***: Dr T Hesjedal*** and ***Dr S Zhang***
Email***: Thorsten.Hesjedal@physics.ox.ac.uk***

CMP03 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***

CMP04 Computational study of critical currents in novel superconductors

Superconductivity has a very large number of practical applications from superconducting magnets used in MRI scanners to levitating trains and its ultimate use is for reduction of the energy consumption as superconductors have zero resistance. To test realistic materials for potential applications one needs to know their phase diagrams, in particular of the critical current and the critical magnetic field. This project is a computational study to explore the critical current as determined from magnetization measurements as well as from direct transport studies in high magnetic fields and at very low temperatures. The project aims to be able to predict superconducting phase diagrams of new superconductors based on the input parameters of different materials. A suitable candidate for this project should have good knowledge of condensed matter courses and strong computation skills (Matlab, Phyton) would be valuable to the project. This project will take place in the Oxford Centre for Applied Superconductivity (www.cfas.ox.ac.uk). For further questions please email amalia.coldea@physics.ox.ac.uk. For further reading please read:

1. Critical-state magnetization of type-II superconductors in rectangular slab and cylinder geometries http://dx.doi.org/10.1063/1.358576

2. Magnetization of Hard Superconductors, https://doi.org/10.1103/PhysRevLett.8.250

3. Critical current and critical magnetic field in hard superconductors, http://jetp.ac.ru/cgi-bin/dn/e_018_05_1368.pdf

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

CMP05 Electronic bandstructure of quantum materials as determined from ARPES experiments.

Angle resolved 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. The student to look at real ARPES data collected at Diamond Light Source and extract useful information about the electronic structure.

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***

CMP06 The effect of applied strain on the magnetotransport behaviour in superconducting and Dirac materials

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***

CMP07 Fermi surface topography of iron-based superconductors

In order to develop new models for superconductivity as well as to predict superconductivity at high temperatures one needs to be able to understand all the essential ingredients of the electronic structure and the details of the pairing interaction that lead to the creation of Copper pairs. This project is a computational and analytic study of the electronic structure of FeSe in order to determine the exact topography of its Fermi surface. The student will use and develop methods to predict the angular dependence of the Fermi surface and compare to available quantum oscillations data. Once the Fermi surface is fully determined the project can be extended to include predictions about the magnetotransport behaviour. A suitable candidate for this project should have good knowledge of condensed matter courses and strong computation skills (Matlab, Phyton) would be valuable to the project. For further questions please email amalia.coldea@physics.ox.ac.uk. For further reading please read:

Emergence of the nematic electronic state in FeSe, Phys. Rev. B 91, 155106 (2015), 10.1103/PhysRevB.91.155106

Detailed Topography of the Fermi Surface of Sr2RuO4, Phys. Rev. Lett. 84, 2662 (2000), https://doi.org/10.1103/PhysRevLett.84.2662

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

CMP08 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 nanowiresarXiv: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***

CMP09 Upscaling of evaporated perovskite solar cell

Perovskite solar cells have emerged as most promising semiconductor devices for next generation photovoltaics. The power conversion efficiency of single junction solar cells has reached >22% within 6 years. Efficient tandem solar cells based on perovskites have also been achieved. However, almost all reported high efficiency devices have small active areas, typically around 0.1 cm2. Upscaling of single junction and tandem perovskite solar cells are required for successful manufacturing and commercialisation. In the proposed project large-area perovskite solar cells will be designed based on our recent understanding of perovskite opto-electronics and device physics. Photon absorption within a complex multilayer (tandem) devices will be optimized using a transfer matrix approach and the effect of parasitic resistance (sheet and shunt resistance) will be modelled prior to fabricating real devices. Large-area perovskite cells will be fabricated by thermal co-evaporation, which offers uniform perovskite films with few pin-holes and shows the potential for solar cell manufacturing.

Supervisors: ***Prof L Herz***; ***Prof M Johnston*** and ***Dr Q Lin***
Email: ***Laura.Herz@physics.ox.ac.uk***;
michael.johnston@physics.ox.ac.uk

CMP10 Beyond Energy Harvesting: Metal Halide Perovskite Resistive Memories

Following an unprecedented rise in power conversion efficiencies within the past five years, metal halide perovskites (MHPs) have surged as a new class of photovoltaic materials and hold great promise to revolutionise the solar industry. Their extraordinary electrical and optical properties are currently undergoing extensive studies and being explored for further optoelectronic applications beyond solar PV.[1-2] More importantly, the abundance of raw materials, the simplicity of synthetic routes and the versatility of fabrication process make MHPs suitable for cost-effective, high-volume and large-area manufacturing.

Looking away from energy harvesting, the aim of this project is to explore the applications of MHPs in resistive memory. The latter is a technology for next-generation memory storage via changing the device conductivity/resistivity.[3-4] Apart from the material processing advantages, the unique electronic properties of MHPs allow their conductivity to be adjusted using voltage bias, hence making MHPs a highly-suitable material for large-area resistive memories. In this study, various types of MHPs will be used for fabricating resistive memories in the configuration of conductor-perovskite-conductor.[5] By performing simple current-voltage measurement, we will be able to examine the functionality of MHP resistive memories as well as to further optimise the material design for next-generation high-performance memories.

Reference & Note

[1] W. Zhang, G. E. Eperon, H. J. Snaith, Nat. Energy 2016, 1, 16048.

[2] S. D. Stranks, H. J. Snaith, Nat. Nanotechnol. 2015, 10, 391-402.

[3] D. B. Strukov, G. S. Snider, D. R. Stewart, R. S. Williams, Nature 2008, 453, 80-83.

[4] W.-P. Lin, S.-J. Liu, T. Gong, Q. Zhao, W. Huang, Adv. Mater. 2014, 26, 570-606.

[5] The project activity will NOT include any device fabrication.

Supervisors: ***Dr Y Lin*** and ***Dr H Snaith***
Email: ***yen-hung.lin@physics.ox.ac.uk***;
henry.snaith@physics.ox.ac.uk

***CMP11* Surface acoustic wave quantum devices on diamond**

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 mobile phones). We have recently made the first working quantum devices in which superconducting qubits are coupled to surface acoustic wave resonators, enabling a new range of 'quantum acoustic' devices to be built. The devices may find applications for example in filtering of quantum signals in future quantum computers. This project will involve design and measurement of a new range of such devices on diamond crystals, in which the coupling can be stronger, and the devices may be used to reach interesting new regimes of quantum optical physics (with microwave phonons instead of optical photons, and superconducting qubits instead of atoms). The project may involve any of: CAD design, electromagnetic simulation, analytic and numerical quantum mechanics simulations, measurements and data analysis. Note that this and other projects in the group are subject to change due to the rapid rate of progress in research. We will always endeavour to find a project that is interesting, new and a good match for your particular interests & skills.

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

***CMP12* Multilayer coaxial superconducting circuits for 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 have developed a new architecture based on coaxial circuit elements and 3D wiring in which rapid progress can be made with scaling up towards the 50-100 qubit level, at which calculations beyond classical computers could become possible. This project will involve looking at novel extensions of the architecture to multiple layer circuits which could further enhance their power. The project may involve any of: CAD design, electromagnetic simulation, experimental control programming, measurements of multi-qubit circuits, quantum logic gates, characterising entangled states. Note that this and other projects in the group are subject to change due to the rapid rate of progress in research. We will always endeavour to find a project that is interesting, new and a good match for your particular interests & skills.

Supervisors: ***Dr P J Leek*** and ***Dr G Tancredi***
Email: ***peter.leek@physics.ox.ac.uk, giovanna.tancredi@physics.ox.ac.uk***

***CMP13* High power response in circuit quantum electrodynamics**

In circuit QED (a circuit equivalent of cavity QED), an electrical resonator is strongly coupled to a superconducting qubit. At low energy, this system is very well understood and is the foundation of much of the rapid progress in recent years in superconducting quantum computing. However, when the system is subjected to strong coherent driving, it can display extremely rich and less well understood behaviour, in particular often involving bifurcation of the states of the resonator and qubit. This project will involve investigation of this high power regime of circuit QED, and its potential use in high fidelity readout of qubits. The project may involve any of: CAD design & electromagnetic simulation of new devices to probe the above physics, software and/or hardware programming, measurements and data analysis. Note that this and other projects in the group are subject to change due to the rapid rate of progress in research. We will always endeavour to find a project that is interesting, new and a good match for your particular interests & skills.

Supervisors: ***Dr G Tancredi*** and ***Dr P J Leek***
Email: ***giovanna.tancredi@physics.ox.ac.uk, peter.leek@physics.ox.ac.uk,***

***CMP14* Hexaferrite crystals: Candidate materials for future oxide electronics**

In many key areas of information technology, such as magnetic data storage, the physical processes exploited in the functional component of a device rely on the flow of electrical currents. If this requirement for electrical currents could be circumvented, and electric fields used instead, huge gains in device efficiency would be achieved. A promising route is found in the use of insulating multifunctional oxides. For example, in a multiferroic magneto-electric material, the magnetic state may be manipulated by an applied electric field, which could be exploited in a memory device. Materials with these characteristics have been realised, yet none have been directly applicable to device construction. Y-type hexaferrites, of nominal composition Ba2Mg2Fe12O22, have been shown to exhibit the greatest level of room temperature magneto-electric functionality observed to date. They exhibit a plethora of exotic magnetic phases, many of which allow the control of magnetic order by electric fields. Several new hexaferrites with different elemental composition have been grown at the Clarendon Laboratory, and initial characterisation has shown promising evidence of high temperature magneto-electric phases with technological potential. This experimental project will use measurements of the dielectric constant and magnetisation to investigate the magneto-electric properties of a new Y-type hexaferrite composition, with the aim of determining the suitably of these materials for future devices.

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

***CMP15* 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***

CMP16 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: ***Blundell, Prof Stephen***

CMP17 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***

CMP18 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***

CMP19 tbc

More details from the supervisor.

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

CMP20 Preparation and physical properties of a new candidate Weyl semi-metal

In recent years there has been great interest in materials whose electronic structure has topologically non-trivial features. Weyl semi-metals have two linearly dispersing electron bands which cross at points called Weyl nodes which lie at the Fermi energy. The electronic quasiparticles are massless chiral fermions, similar to those in graphene, but in Weyl semi-metals the nodes are robust against small perturbations in the structure. Only a small handful of real materials are known to behave as Weyl semi-metals. In this project you will investigate a new phase, TaIrTe4, which has been predicted to be a new type of Weyl semi-metal. You will perform measurements on single crystals of TaIrTe4 to establish its physical properties. You will also synthesize a series of related compounds RIrTe4, where R = a rare-earth ion. The R ions have a magnetic moment, and you will explore whether the moments order at low temperature. Magnetic order would perturb the Weyl fermions and could influence the electrical properties. The measurements as a function of temperature will be performed with a SQUID magnetometer and an electrical transport probe.

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

CMP21 **Investigation of the phase diagrams of doped spin ice**

A spin ice is compound with many possible ground states having almost the same energy, which owing to its crystal structure is analogous to the arrangement of hydrogen atoms in water ice. The best known examples are Dy2Ti2O7 and Ho2Ti2O7. Spin ices have very interesting statistical mechanics. In particular, there are low energy excited states that behave like magnetic monopoles. The statistical properties are changed when different ions are substituted randomly for Dy or Ti, and this has been the subject on recent interest. In this project you will investigate what happens when some of the Ti4+ is replaced by Sc3+. The different charge states of these ions results in changes in the local structure and magnetism and, eventually, a change in the global crystal structure. This is an experimental project in which you will synthesize samples of Sc-doped Dy2Ti2O7 and Ho2Ti2O7 and make a systematic study of their crystal structure and magnetization as a function of Sc concentration by X-ray diffraction and SQUID magnetometry. There will also be an opportunity to perform electrostatic calculations of the crystal field in order to model the magnetic data.

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

CMP22 **tbc**

More details from the supervisor.

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

Interdisciplinary projects

INT01 & INT02 **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***

INT03 **Low-temperature measurements of the inverse spin Hall effect. Investigating the spin pumping and inverse spin Hall effects at low temperatures**

The field of magnonics is the area of magnetics dedicated to the science of quasi-particles known as magnons. In certain magnetic systems, magnons are able to play the role of microscopic tokens which can carry 'spin' — the quantum mechanical currency of magnetism — over relatively long distances (up to centimetres), and at high speed (many tens of kilometres per second). Our group develops low-temperature microwave magnetic circuits to probe the physics of magnonic systems at the quantum level.

This project will involve designing and carrying out a low-temperature experiment to make an inverse spin Hall effect based measurement of a magnon-driven spin current pumped through a magnetic insulator/non-magnetic metal interface. Measurements will be made in a dilution refrigerator. The work will contribute to our group's investigations into how magnons — the quasi-particles associated with excitations of the electronic spin-lattices of ferro- and ferrimagnetically ordered materials — might be used in new types of quantum measurement and information processing device. This is a project suitable for anyone who enjoys challenging practical work and has a strong interest in magnetic dynamics and low-temperature experimental techniques.

Supervisor: ***Dr A Karenowska***
Email: ***Alexy.Karenowska@physics.ox.ac.uk***

INT04 **Investigating the physics of coupled magnonic resonators at millikelvin temperatures**

The field of magnonics is the area of magnetics dedicated to the science of quasi-particles known as magnons. In certain magnetic systems, magnons are able to play the role of microscopic tokens which can carry 'spin' — the quantum mechanical currency of magnetism — over relatively long distances (up to centimetres), and at high speed (many tens of kilometres per second). Our group develops low-temperature microwave magnetic circuits to probe the physics of magnonic systems at the quantum level.

This project will involve designing and carrying out an experiment in which microwave-frequency magnon modes in two lumped magnetic samples are controllably coupled. Measurements will be made in a dilution refrigerator. The work will contribute to our group's investigations into how magnons — the quasi-particles associated with excitations of the electronic spin-lattices of ferro- and ferrimagnetically ordered materials — might be used in new types of quantum measurement and information processing device. This is a project suitable for anyone who enjoys challenging practical work and has a strong interest in magnetic dynamics and low-temperature experimental techniques.

Supervisor: ***Dr A Karenowska***
Email: ***Alexy.Karenowska@physics.ox.ac.uk***

INT05 **X-ray based tools for reading ancient texts**

Over the last decade, tremendous progress has been made in "reading the unreadable" — deciphering ancient texts which are inaccessible to the human eye. A key step here has been the development of methodologies for the digital unwrapping of ancient paper, papyrus, and parchment documents which are too fragile to be manually unwrapped or unrolled. In collaboration with the leading group in this area — that of Prof. Brent Seales at the University of Kentucky —and colleagues at the Diamond Light Source, this project will contribute to the development of new X-ray based tools which, through their ability to detect ancient inks which are invisible to existing techniques, will significantly broaden the range of ancient texts which can be accessed using these methods.

Supervisor: ***Dr A Karenowska***
Email: ***Alexy.Karenowska@physics.ox.ac.uk***

INT06 **Portable Reflectance Transformation Imaging (RTI) apparatus for mapping the surface textures of ancient objects and inscriptions**

Reflectance Transformation Imaging is a well-established tool for investigation of ancient materials. RTI is used to uncover eroded inscriptions or fine surface textures that cannot be easily seen with the human eye. Though easy to optimize in a laboratory setting, traditional RTI hardware does not lend itself to use in the field — particularly in environments where space is limited or lighting conditions are difficult to control.

This project, which is extremely practical in nature, will involve completing an existing design of a fully portable RTI apparatus, constructing it, and evaluating its performance.

Supervisor: ***Dr A Karenowska***
Email: ***Alexy.Karenowska@physics.ox.ac.uk***

INT07 **Towards radiofrequency intelligent tomography of conductive surfaces**

This is a practical project involving the design of part of a prototype instrument which combines (1) high-resolution textural mapping and (2) compositional analysis of electrically conducting materials. Such an instrument has important applications in the study and identification of — among other things — ancient coins and other metal objects.

Two projects are offered in connection with this work. One involves the construction of the electronic and mechanical part of the instrument (using an existing circuit design and pre-manufactured mechanical components), the other focuses on the construction of a software-based tool for data capture and analysis.

Supervisor: ***Dr A Karenowska***
Email: ***Alexy.Karenowska@physics.ox.ac.uk***

INT08 Constructing a pulsed NMR spectrometer for hydrocarbon characterisation

More information from the supervisor.

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

INT09 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 this year 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. al.

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***

INT10 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***

INT11 & INT12 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***

INT13 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***

INT14 & INT15 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***

INT16 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***

INT17 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***

INT18 Ultra Sensitive Noise Temperature Measurement of a Superconducting Quantum Mixer

Superconductor-Insulator-Superconductor (SIS) mixers are the most sensitive quantum detectors for astronomical observations below 1 THz. They are now routinely used in various millimetre and sub-millimetre telescopes that require quantum-limited sensitivity for detection of weak spectral lines emitted by astronomical sources. The sensitivity of an SIS mixer is experimentally determined, in the laboratory, by measuring its equivalent noise temperature. This is done by comparing the difference in output power, when the mixer is illuminated by either a hot (room temperature) or a cold (liquid nitrogen) load.

The aim of this project is to design, build and test a setup that can measure the sensitivity of an SIS device rapidly and accurately. This involves replacing the manually operating hot/cold system used in our laboratory by an automatic system comprising a chopping wheel, and an electronic/software interface that syncs the timing of load changes with the readout system to measure the noise temperature instantaneously. The student will start by learning how to use a cryogenic system to test a 230 GHz SIS mixer using an existing system before working on the design of the automatic system. The new setup can then be used to test the same mixer for comparison.

The project is suitable for students who are interested in experimental works, and also requires some programming skills e.g., LabView code to sync the chopping wheel and the readout system. The student will be working in a team including the supervisors, an experienced technician and a D.Phil student who is investigating the performance of a 230 GHz SIS mixer..

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

INT19 **A Horn-Reflector Feed for Superconducting Detectors.**

Superconductor-Insulator-Superconductor (SIS) mixers are the most sensitive quantum coherent detectors for astronomical observations below 1 THz.

The principle of detection is based on down-converting the high frequency of the incoming signal (RF) into a much lower *intermediate* frequency (IF) which can be amplified and detected by standard electronics. Frequency down-conversion is obtained when the mixer is fed by both the astronomical signal of frequency ν_S and another high frequency signal that is generated by a Local Oscillator in the receiver (LO) of frequency ν_{LO}. An output signal is then generated at an intermediate frequency $\nu_{IF} = \nu_{LO}-\nu_S$ which can be handled by standard electronics. The non-linear device responsible for the frequency conversion is the superconducting tunnel junction which has an area of approximately $1\mu m^2$ fabricated in a planar circuit chip mounted in a block which is cooled below the transition temperature of the tunnel junction material (4 Kin our case). The electromagnetic signals (RF signal and LO signals) are received by an electromagnetic horn, mounted on the detector block and then coupled to the planar chip via a waveguide.

For efficient power coupling we aim to match the curvature of the wave-front of the local oscillator to the wave-front curvature of the signal that can potentially be emitted or received by the detector block horn. This is usually done by designing an optical system consisting of several curved mirrors between the local oscillator source and the detector. A much more compact system is obtained however if the detector block horn is replaced by a horn-reflector combination (H-R antenna) which is fabricated as a single optical unit that is optimized to receive (of emit) plane waves. In that case only a single curved mirror would be needed between the detector horn and the local oscillator horn. The aim of this project therefore is to design and test a Horn-Reflector antenna that is optimized to receive plane waves efficiently at 700 GHz. The horn is a conical section that emits spherical waves originating at the “phase centre” located at the axis of the cone. If the cone is mounted in such a way that the phase centre coincides with the focal pint of an offset parabolic reflector, the emerging wave will have a plane wave-front.

To calculate the fields at the aperture of the horn the student will use commercial electromagnetic software that simulates guided waves propagation. To calculate the radiated waves in the near and far field, the student will use a commercial “Physical Optics” software package called “GRASP” which is used in most modern optical designs in astronomy. The design can then be fabricated at Oxford Physics workshop and tested in one of our cryogenic systems.

The project will suit a student who likes to be involved in both experimental and computational work. There is also a scope for theoretical work as the student may choose to calculate the field at the aperture of the antenna analytically. The Oxford “THz Detectors” group has many years experience in the development of quantum limited detectors and optical components for astronomical receives at millimetre and submillimetre wavelengths. The student will have access to a state of the art detector laboratory, commercial and local software and powerful computing cluster.

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

INT20 **Investigation of a low distortion oscillator**

More details from the supervisor.

Supervisor: ***Dr G Peskett***
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Particle and Nuclear Physics projects

PP01 Measuring the W boson mass

Our current understanding of the fundamental constituents of matter, and the forces between them, is encapsulated in the Standard Model theory. It provides a remarkable resemblance of the behaviour that we observe in particle physics experiments. Yet it is known to be at best a low energy approximation of a more complete theory. The CERN LHC is intended to uncover the next layer of fundamental physics. A promising approach is to make ultra precise measurements that can be compared to the predictions of the Standard Model. For example the Standard Model asserts a relationship between the masses of the W boson, Higgs boson, and top quark, which results from Quantum loop effects. A measured deviation from this prediction could indicate Quantum loops involving heavy new particles from beyond the Standard Model. The sensitivity of this fundamental test is mostly limited by the precision with which we have been able to directly measure the mass of the W boson.

This project will develop a method with which to measure the W boson mass using data from the LHCb experiment. The students will devise methods which allow the W boson mass to be determined with the highest possible precision, by comparing real LHC collision data with theoretical simulations. They will develop computer software to perform this analysis. Reduced datasets for this purpose have been prepared at CERN, and stored on a local computer cluster in Oxford.

This project requires programming skills (C++ required, python desirable).

Supervisors: ***Dr M Vesterinen*** and ***Dr M John***
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malcolm.john@physics.ox.ac.uk

PP02 Evaluation of HV-CMOS sensors

The High Luminosity LHC (HL-LHC) project will require the replacement of the 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 the Oxford Physics Microstructure Detector facility (OPMD) using lasers and radioactive sources.

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

PP03 A measurement of direct CP violation in two-body decays of charged D mesons

A charged D+ meson is a bound state containing a charm and down quark; the charm quark has zero isospin and the down quark has isospin, I=1/2. The final state pi+pi0 is part of the I=2 (pipi) multiplet thus the change of isospin in this decay is Delta-I=3/2. This standard model of particle physics can explain this transition with simply a tree-level weak transition where the charm quark turns into a down quark (Delta-I=1/2) and a up-down pair Delta-I=1 is radiated by a virtual W-boson. The weak decay is known to violate isospin symmetry so this transition is allowed. One can also imagine a loop process where the charm turns into a up-quark (Delta-I=1/2 transition) and radiates a gluon (I=0) which turns into a pi0. However, the strong force strictly conserves isospin and thus does not generate the additional Delta-I=1 as in the tree amplitude. This simple isospin argument means that the gluonic loop process should not contribute to the decay of charged D+ mesons, which is thus dominated by the singular tree diagram. This fact means this decay mode is a theoretically clean place to look for new physics amplitudes by looking for CP violation effects (unequal number of D- and D+ decays) because such interference is the hallmark of at least two contributing amplitudes.

In this project the student will take a sample of data from the LHCb detector and write an algorithm to extract the D-meson signal from the data and measure the CP violation (if any). The student will be responsible for assessing the statistical and systematic uncertainties and executing the cross-checks of the final result. The data sample will be preprepared by a a doctorate student working in this area. A performant, responsible project student could have the opportunity to to present their work to the LHCb collaboration's charm physics working group. The project demands curiosity, interest and tenacity; some programming skills being a helpful.

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

PP04 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***

_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_ 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***

_PP08_ Absolute distance interferometry using a frequency comb

Frequency scanning interferometry is a technique for absolute distance measurements. In the incarnation referred to as dynamic FSI, developed at Oxford physics, it relies on the ability to measure the frequency of scanning laser using absorption spectroscopy on molecular excitations of gases such as acetylene or hydrogen cyanide.

In 2015 FSI measurements were made at the German national institute of standards (PTB) in Braunschweig in which in addition to multiple gas absorption cells and a precision reference interferometer an state of the art, high precision frequency comb was used to record beat patterns of the scanning lasers with the comb laser. This data has not been analysed yet and could lead to new methods for improving the spectroscopic methods used in FSI and hence improve the distance measurement accuracy.

The projects purpose is to analyse the data using either extensions of existing JAVA codes and/or new MATLAB codes in a variety of ways among which could be:

1. Fitting the beat signals of the scanning lasers with the comb to obtain a highly precise frequency axis.

2. Fitting the positions and widths of the peaks in the absorption spectra with Voigt functions instead of the simpler Gaussian functions used so far.

3. Potentially performing the fits from 2. using a total chi-squared method in which errors in both axes can be considered.

4. Comparing the results of the above fits to see how accurately the Gaussian fraction of the width of the peaks can be fit and hence how accurately the pressure of the gas cell can be determined.

5. Comparing the results of the above fits to measure the relative spacing of the gas cell peaks

6. Using these results to improve the distance measurement results.

The project is open ended and the data has not been analysed before. How many of the above points can be dealt with depends on the student and on the data.

The project is entirely analysis based and demands good analytical skills and good programming skills with some experience in Java preferred because the majority of existing analysis code is in Java.

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

_PP09_ Constraints on Supersymmetric Dark Matter from recent LHC measurements

The make-up of dark matter is one of the outstanding problems of physics today. The world's highest-energy collisions at the LHC have the potential to produce dark matter in the laboratory for the first time. This project will use very recent results from the LHC to constrain the parameters of leading models of Dark Matter. The methodology involves Monte Carlo simulation, high-performance computing and statistical interpretation. Working knowledge of the c++ and/or python computing languages would be useful.

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

_PP10_ Improved understanding of the structure of the proton using LHC data

The Large Hadron Collider (LHC) at CERN is currently in its second Run, operating at a centre-of-mass energy of 13 TeV. This has opened 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 measurements.

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++ or FORTRAN would be an advantage.

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

_PP11 & PP12_ Higgs Self-Coupling and Search for New Physics with di-Higgs to final states with the ATLAS detector

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* energy and 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.

*jets are collimated sprays of particles, which are initiated by quarks.

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

_PP13_ 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***

_PP14_ 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***

_PP15_ Early high-voltage breakdown warning system for dark matter detectors

Dark matter detectors have progressed to unprecedented sensitivity in probing dark matter particle models. The challenge is the identification of any signal that is not associated with the interaction of dark matter but is caused by natural backgrounds or spurious electronics effects so that one can be sure that whatever is left after having removed (vetoed) all such possible contributions to the signal can be attributed to dark matter interaction. The detectors probing the smallest WIMP-nucleon interaction cross sections, and thus exhibiting the highest sensitivity are based on large time projection chambers filled with liquefied noble gases. Their operation involves the presence of high voltage in the detector and thus a detector system is necessary that is capable of identifying local or partial temporary discharges or breakdowns at a level that would not be detected by the existing safety systems but could still cause spurious signals in the detector's data. This project involves the modelling of an existing loop antenna system and its electronic readout system with the aim of maximizing its sensitivity. A thorough understanding of electromagnetism and circuits will be required as well as programming skills in C/C++.

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

_PP16_ 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***

PP17 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.

Supervisor*s: **Dr I Konoplev*** and ***Prof A Seryi***
Email***: Ivan.Konoplev@physics.ox.ac.uk;***
Andrei.Seryi@adams-institute.ac.uk

PP18 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***: Dr I Konoplev***
Email***: Ivan.Konoplev@physics.ox.ac.uk,***

PP19 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***

PP20 B Meson Tagging

The B0 meson is bound state of the bottom quark and the down quark. These mesons are produced at the Fermilab Tevatron in generous amounts. Our understanding of quantum mechanics indicates that the neutral B meson will spontaneously change into its anti-particle and then change back as it travels through space before it decays. This effect is called 'mixing' and has already been observed in the neutral kaon system and in the neutral B0 mesons. It has only recently been observed in the BS meson.

BS mixing occurs quite rapidly. Current experimental measurements on BS mixing indicate that the BS changes into the anti-BS on average 17 times before decaying. This is astonishing when one realizes that the BS lifetime is just a little over one picosecond. B0 meson mixing, however, takes place at a more stately pace, requiring approximately 5 lifetimes of the meson for one complete mixing oscillation.

Before one can measure mixing however we need to know whether the meson started out life as a particle or an antiparticle. The meson needs to be 'tagged' as either one or the other.

The goal of this project is to explore various tagging techniques on neutral B mesons using the CDF data taken at 2.0 TeV centre of mass energy. The student will attempt to measure the efficiency and dilution of tagging methods in these two cases in CDF data and compare these to the measured rates for charged hadrons and also MC simulations.

Specialized equipment needed: Computer Access

Knowledge of Computer programming required: Yes, C++ programming is be

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

PP21 **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***

PP22 **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***

PP23 **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.

PP2301 **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 Rjets=σ(W+jets)/σ(Z+jets) and Rinv = σ(Z+jets, Z$\rightarrow\nu\nu$/ σ(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***

PP2302 **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***

PP2303 **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***

PP24 **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***

PP26 **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***

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 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***

TP02 Bouncing on superhydrophobic surfaces

When patterned with micron or nano-scale posts a surface coated with a hydrophobic material can become superhydrophobic. Drops of fluid remain on top of the posts with an air layer trapped beneath. Contact angles can be very close to 180o and minimal contact angle hysteresis leads to easy run-off. The aim of this project is to investigate how drops bounce on inclined superhydrophobic surfaces.

The project would suit students keen on theoretical or computational physics who enjoyed the Fluids paper and who like to link theory to applications.

Reading:

Non-sticking drops, D. Quere, Reports on Progress in Physics 68 2495 (2005).

Pancake bouncing on superhydrophobic surfaces, Y. Liu et al., Nature Physics 10 515 (2014).

Supervisor: ***Prof J Yeomans***
E-mail: ***Julia.Yeomans@physics.ox.ac.uk***

TP03 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***

TP04 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***

TP05 Active systems

Active systems, such as cells, bacteria, molecular motors and active colloids, take energy from their environment and transform it into motion on an individual particle level. Hence dense assemblies of active particles provide an experimental testing ground for non-equilibrium statistical physics. They often form chaotic patterns, termed 'active turbulence' where topological defects are continually created and destroyed. Surprisingly topological defects have now been identified in cell layers, and the theories of active systems are being used to model collective cell dynamics

Details of the project will be settled nearer the time but two possibilities are:

(i) to investigate the spontaneous flow of active systems in channels and compare to experiments on confined, dividing cell colonies.

(ii) to couple the equations for Turing patterns to those of the active systems, of relevance to embryogenesis.

Reading:

Active turbulence in active nematics, S.P. Thampi and J.M. Yeomans, J. Eur. Phys. J. Spec. Top. 225 651 (2016).

Stabilization of active matter by flow-vortex lattices and defect ordering Nature Communications 7 10557 (2016)

Supervisor: ***Prof J Yeomans***
E-mail: ***Julia.Yeomans@physics.ox.ac.uk***

TP06 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***

TP07 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***

TP08 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***

TP09 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***

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, number theory and gauge/string theory.

Topics in the past 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/algebraic geometry, quantum field theory, supersymmetry, as well as number theory and advanced algebra.

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

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

TP11 Chemical Evolution of the Milky Way 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 analysis can be applied to data sets for stars in the Milky Way's halo, or its satellite galaxies. The student can also choose to examine halo star kinematics with action based distribution functions, or simpler estimators.

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

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TP12 Chemistry and Dynamics of the Milky Way Disk

With the advent of Gaia satellite data (kinematics and positions of stars throughout the disc) and their follow-up high-resolution spectroscopic surveys (giving us precise stellar abundances and ages), we can for the first time examine in detail the history and dynamics of the Milky Way.

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. Depending on their interests, the student can choose from a range of project options: From orbit calculations in idealised potential to examine the behaviour around resonances, to working out better descriptions of angular momentum changes and disc heating by spiral structure, to fitting those prescriptions to the available data with analytical chemodynamical models.

Good analytic skills are essential for this project, familiarity with programming (best C++) and Hamiltonian mechanics would be beneficial, but can be taught during the project.

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TP13 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, as well as analysing spectroscopic data from e.g. SEGUE, RAVE or Gaia-ESO.

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.

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TP14 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.

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