MPhys Projects Trinity Term 2020

Physics Trinity Term - 2020

Contents

Contents Cont'd

Contents Cont'd

Foreword

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

You will start your Major Option Classes and your MPhys project Michaelmas Term 2020. 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 8th week.

Please do contact the Assistant Head of Teaching (Academic) carrie.leonard-mcintyre@physics.ox.ac.uk if you have any questions.

MPhys Industrial Projects

MPhys Industrial Projects

Industrial MPhys projects were introduced in 2018, following the success of the BA industrial project scheme. These projects are proposed and led by an external company, driven by physics-related problems. These problems will improve your employability and transferable skills in an increasingly competitive jobs market. Some of the companies are also actively looking to hire graduates.

You will be supervised mainly by the industrial supervisor, with additional support from an Oxford co-supervisor. You are expected to have regular (typically weekly) interactions with the industrial supervisor, just as if they were based in the Physics Department. Modest funding is available for visits to the company – there will clearly be some variation across projects, for example regular visits to a local company by bus are feasible, but if the company is further away less frequent visits are anticipated, or your supervisor may prefer to visit you. The Oxford co-supervisor will normally have more of an oversight role – they will, for example, prepare a risk assessment for experimental work, and you should talk to them if you have problems with your industrial supervisor.

In every other respect (allocation, reports, assessment) the industrial MPhys projects are identical to the MPhys projects offered from within Physics. Projects are allocated in the same way as, and alongside, the MPhys projects, so you can apply for a mixture of project types. If you would like to discuss a project before applying for it, please contact the Oxford supervisor in the first instance, who can make an introduction to the company. For projects where we have not yet allocated an Oxford supervisor, please contact Prof Moriz Riede, Moritz Riede (Physics) (moritz.riede@physics.ox.ac.uk)

The information in this handbook is accurate as at 22 May 2020, 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 this 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* 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 latest examination results, normally that of third year, Part B, ranking will also be used to assign students to projects. Exceptionally, second year, Part A, ranking will be used when Part B results are not available.

(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 .

(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 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

A number of prizes 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 2020

Week 4 Publication of the *MPhys Projects Trinity Term* **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 8 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 2020

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 Office**. 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 Office.** This progress report is for your College tutors.

Hilary Term 2021

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 2021

Week 1 MPhys project report submitted online
(Tues 12 noon) On line project submission with the Declaration of Authorship and SpLD (if appropraite) in pdf format.

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

Timetable for Supervisors

Hilary Term 2020

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

Trinity Term 2020

Week 4 Publication of the *MPhys Projects Trinity Term*
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 - September **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 2020

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 Office**. 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 2021

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 Office**, 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 2021

Week 1 MPhys Student submits their final report on-line.
Deadline for return of Supervisor's Report Form.

MPhys Project Descriptions

Atomic and Laser projects

_A&L01_ Designing robust trapped-ion quantum computers

Quantum computing is a new way processing information, exploiting quantum-mechanical phenomena such as superposition and entanglement to perform computation. Trapped-ion quantum processors have demonstrated, on a small number of qubits, all the building-blocks required to build a quantum computer with precision better than any competing technology.

In this project, the student will model and numerically investigate quantum entangling algorithms in a register of trapped-ion qubits. This will involve understanding experimental sources of error, and designing gate algorithms via guided searches that are maximally robust to the error environment. This project requires strong programming skills.

Supervisor: ***Dr C Ballance***
Email: ***chris.ballance@physics.ox.ac.uk***

_A&L02_ Rapid precision sensing with a quantum computer

Quantum computing is a new way processing information, exploiting quantum-mechanical phenomena such as superposition and entanglement to perform computation. Trapped-ion quantum processors have demonstrated, on a small number of qubits, all the building-blocks required to build a quantum computer with precision better than any competing technology.

In this project, the student will develop and experimentally test techniques to rapidly sense and adjust the environment of a register of qubits at the single-quantum level. This will involve developing algorithms to optimally measure the system using adaptive Bayesian estimation or machine learning. This project requires good programming and experimental skills.

Supervisor: ***Dr C Ballance***
Email: ***chris.ballance@physics.ox.ac.uk***

_A&L03_ A compact and efficient optically-heated atomic source for ion traps

The next generation of ion trap quantum computers will demand processor nodes that offer higher reliability, performance and scalability, as we aim to take experiments from the proof-of-principle stage to the scale where useful quantum algorithms can be performed.

Key to any ion trap system is a reliable source of ions, generally produced by photoionisation of a neutral atomic beam. Such atomic beams are typically generated via Joule heating of a small steel ‘oven’ filled with the source element, such as calcium or strontium, which emits an uncollimated beam from a small aperture directed towards the trap. However, the wires used to deliver the necessary current also act as a thermal sink, greatly increasing the heating power required and preventing close integration of the source with the trap chip.

We recently demonstrated a variation on this design, using a laser to optically heat a more thermally isolated oven, reducing power requirements by an order of magnitude. We have since devised an even more efficient and scalable optically-heated source, based on a sub-mm scale fused-silica structure fabricated using laser-written etching, which would reduce power and response time by a further factor of ten while also improving the collimation. This would allow integration of the source into the ion trap chip itself and could be compatible with operation in cryogenic environments.

We are confident in the potential of the design, but it remains at the concept stage; the aim of this project would be to develop and optimise the source via Solidworks CAD and COMSOL simulation of the thermal and mechanical properties. Providing good progress is made in the early computational stages of the project, we would aim to produce the first prototype in HT 2021, and benchmark its performance via fluorescence spectroscopy of the emitted atomic beam. This is a challenging but potentially extremely rewarding project suited to a highly motivated student; no specific skills are essential, but prior experience with CAD software such as Solidworks would be very useful.

Supervisor: ***Dr J Goodwin***
Email: ***joseph.goodwin@physics.ox.ac.uk***

_A&L04_ Superresolution imaging via linear optics in the far-field regime

Rayleigh’s criterion defines the minimum resolvable distance between two incoherent point sources as the diffraction-limited spot size. Enhancing the resolution beyond this limit has been a crucial outstanding problem for many years. A number of solutions have been realized; however, all of them so far relied either on near-field or nonlinear-optical probing, which makes them invasive, expensive and not universally applicable. It would therefore be desirable to find an imaging technique that is both linear-optical and operational in the far-field regime. A recent theoretical breakthrough demonstrated that “Rayleigh’s curse” can be resolved by coherent detection the image in certain transverse electromagnetic modes, rather than implementing the traditional imaging procedure, which consists in measuring the incoherent intensity distribution over the image plane. To date, there exist proof-of-principle experimental results demonstrating the plausibility of this approach. The objective of the project is to test this approach in a variety of settings that are relevant for practical application, evaluate its advantages and limitations. If successful, it will result in a revolutionary imaging technology with a potential to change the faces of all fields of science and technology that involve optical imaging, including astronomy, biology, medicine and nanotechnology, as well as optomechanical industry.

The students will perform experiments in an optics lab and use advanced data processing techniques, including machine learning, to analyse the results. Affinity to experimental physics is required, as well as some programming skills (python preferred) and basic understanding of artificial neural networks.

Supervisor: ***Prof A Lvovsky***
Email: ***alex.lvovsky@physics.ox.ac.uk***

A&L05 Optical neural networks

The project is to implement artificial neural networks using optics rather than electronics. The training of neural network consists of linear operations (matrix multiplication) combined with nonlinear activation functions applied to individual units. Both these operations can be implemented optically using lenses, spatial light modulators and nonlinear optical techniques such as saturable absorption. However, one crucial element of the training procedure - so-called backpropagation - has so far remained elusive. Our group has developed an idea to overcome this obstacle and implement pure optical backpropagation in a neural network, thereby enabling the training that is practically electronics-free. We confirmed the viability of this approach by simulation. Our next goal – and the goal of this doctoral research project – is to set up an experiment and test the method in a practical setting.

The students will perform experiments in an optics lab and use advanced data processing techniques, including machine learning, to analyse the results. Affinity to experimental physics is required, as well as some programming skills (python preferred) and basic understanding of artificial neural networks.

Supervisor: ***Prof A Lvovsky***
Email: ***alex.lvovsky@physics.ox.ac.uk***

A&L06 Experimental Quantum Computing in Ion Traps

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

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

A&L07 Laser Cooling and Trapping of Neutral Atoms

Cooling and trapping of neutral atoms with laser light is a well established technique to prepare ultra-cold atomic samples in a large variety of experiments, ranging from dense degenerate quantum gases to fully controlled single atoms being used as stationary quantum bits in quantum computing applications.

In this project, the student will be given the opportunity to explore different ways of atom trapping and cooling, ranging from the magneto-optical trapping of rubidium in a pyramid-MOT over the use of an optical molasses to prepare certain atomic beam velocities to the implementation of tiny dipole-force traps, created by artificial holography using spatial light modulators. These activities are all element of a larger research project, and the precise task is going to depend strongly on the overall progress.

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

A&L08 Modelling of modulation transfer spectroscopy

Ultracold atoms provide a versatile platform for studying many-body quantum physics. The major technique for cooling atoms into the ultracold regime is laser cooling. This relies on very precise control of laser wavelength (around 1 part in a billion), to achieve this lasers are often referenced to atomic transitions using Doppler-free spectroscopy techniques. One such technique is modulation transfer spectroscopy (MTS) in which a phase-modulated pump beam and probe beam are passed through an atomic vapour. The non-linear medium of the vapour results in a wavelength dependent transfer of the modulation from the pump to the probe beam.

The aim of this project is to model the MTS process for particular transitions in erbium atoms. At first this will be done for a single applied laser excitation wavelength but will then be extended to the more complicated situation of the same atoms being simultaneously probed with two wavelengths. An improved understanding of MTS should enable the optimisation of the technique for stabilising the lasers required for cooling of erbium atoms.

While a large part of this project will be theoretical/computational there will also be the opportunity to compare predicted results to experiments.

Supervisor: ***Dr R Smith***
Email: ***robert.smith@physics.ox.ac.uk***

A&L09 Simulations of a narrow-line magneto-optic trap

Ultracold atoms provide a versatile platform for studying many-body quantum physics. The starting point for producing ultracold atoms is a magneto-optic trap (MOT) which comprises counter-propagating laser beams combined with a quadrupole magnetic field to simultaneously cool and traps atoms.

The aim of this challenging project is to simulate this process for the case of erbium atoms.

While a large part of this project will be theoretical/computational (involving programming probably in C++ /Rust/ Python) there will also be the opportunity to compare predicted results to experiments.

Supervisor: ***Dr R Smith***
Email: ***robert.smith@physics.ox.ac.uk***

A&L10 Relativistic Molecular Dynamics Simulations

Modeling many-body systems is one of the core challenges of modern physics. The standard numerical approach consists of following each particle. The classical equations of motion are then solved by calculating the force produced by all other particles onto every single particle. This numerical technique is known as Molecular Dynamics. While Molecular Dynamics can be generalized to quantum systems by introducing appropriate interaction potentials, the extension to relativistic many-body systems has not been developed in details. In this project, we propose to extend the current Molecular Dynamics to relativistic systems by replacing the classical equations of motion with their fully relativistic counterparts, but with each particle interacting with non-relativistic potentials. This approach is viable for studying mildly relativistic systems, and it could be used to study electron-positron plasmas relevant in many astrophysical systems. The project demands good analytical and programming skills (C/C++, Python, or similar).

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

A&L11 Raman amplification in the UV regime

This project will look at the Raman amplification mechanism used for amplifying laser pulses to ultra-high intensities utilising stimulated Raman backscattering. The mechanism scatters photons from a pump pulse into a counter-propagating seed pulse via a plasma density perturbation (three-wave interaction). When entering the nonlinear amplification stage, the seed pulse normalised amplitude increases while the laser duration decreases. So far, Raman amplification has not been studied (theoretically or experimentally) in the ultraviolet regime where, in order to fulfil the matching conditions, the plasma density has to be increased (for sensible laser wavelengths of the third harmonic). This leads to the necessity of using collisions in the code. This project will consist of using large-scale particle-in-cell simulations to find the optimal parameter space for Raman amplification in the ultraviolet regime. Resting window simulations will be compared with moving window simulations to validate recent updates to the code OSIRIS.

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

A&L12 Wakefield acceleration in the a cluster plasma

Laser-driven wakefield accelerators have proven to be very effective tools to accelerate particles to high energies. If the wakefield is driven in a plasma of nanometer-scale clusters rather than a uniform plasma, the trapping mechanism for electrons changes. The project will look at how the cluster expansion due to the laser electric field in combination with the shape of the "ion-bubble" created by the ponderomotive force will introduce a lower threshold for self-injection into the wakefield. To this end, the rate of change of the size of the bubble will have to be looked at using particle-in-cell simulations and analytic models.

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

A&L13 An investigation of flying focii

If a short laser pulse is focused with a conventional mirror then all the frequencies are focused to the same point. Recently there has been considerable interest in the "flying focus" which can generate a focal region which moves forwards - or even backwards - at arbitrary velocity.

A flying focus is generated by focusing a frequency-chirped pulse with a hypergeometric lens (related to a zone plate). With a hypergeometric lens each frequency component is focused to a different longitudinal position, and hence by controlling the chirp of the incident pulse it is possible for the focused pulse to move forwards or backwards.

Related to this idea is simultaneous spatial and temporal focusing (SSTF). Here a spatially-chirped beam (one in which the frequency varies with transverse position) is focused by a conventional optic; all frequencies are focused to the same point, but since it is only at the focus that all frequencies are present, the duration of the pulse increases with distance away from the focus. As such the region of high intensity is more strongly localized than in the absence of SSTFC.

These ideas have considerable potential in applications of laser-plasma interactions, such as laser-driven plasma accelerators, photon accelerators, and x-ray generation. In this project the student will investigate - analytically and numerically - the flying focus and SSTF systems. The objective will be to establish a framework which can describe both effects, and to investigate how these can be used to enable complete control of the spatial and temporal distributions of the focused pulse. The project will require a good understanding of modern optics and food analytical and programming skills (Matlab, Python, or similar).

Reading

[1] A. Sainte-Marie, O. Gobert, and F. Quéré, Optica 4, 1298 (2017). DOI: https://doi.org/10.1364/OPTICA.4.001298

[2] D. H. Froula, D. Turnbull, A. S. Davies, T. J. Kessler, D. Haberberger, J. P. Palastro, S.-W. Bahk, I. A. Begishev, R. Boni, S. Bucht, J. Katz, and J. L. Shaw, Nature Photon 12, 262 (2018). DOI: https://doi.org/10.1038/s41566-018-0121-8

[3] D. H. Froula, J. P. Palastro, D. Turnbull, A. Davies, L. Nguyen, A. Howard, D. Ramsey, P. Franke, S. W. Bahk, I. A. Begishev, R. Boni, J. Bromage, S. Bucht, R. K. Follett, D. Haberberger, G. W. Jenkins, J. Katz, T. J. Kessler, J. L. Shaw, and J. Vieira, Phys. Plasmas 26, 032109 (2019). DOI: https://doi.org/10.1063/1.5086308

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

A&L14 Wakefield acceleration driven by a flying focus

In a laser-driven plasma accelerator an intense laser pulse propagates through a plasma and drives a trailing plasma wave. The electric fields formed within the plasma wave can be one thousand times greater than those used to accelerate particles in a conventional radio-frequency accelerator, which allows the length of the accelerator to be shrunk by the same factor.

There are two key issues in laser-driven plasma accelerators. First, the electrons to be accelerated have to be injected into, and trapped within, the plasma wave before they can be accelerated. Second, when they reach high energies the electrons outrun the plasma wave, which travels at the group velocity of the laser (< c) - this phenomenon is known as "de-phasing".

A so-called "flying focus" may offer novel ways of overcoming these issues. In this approach the large spectral bandwidth of a short laser pulse is used in conjunction with a chromatic focusing element to generate a focused pulse which moves forwards - or even backwards - at arbitrary velocity. This approach could be used to reduce the speed of the driving laser pulse, which would aid electron injection, or to increase the speed to that of light in vacuo, which would overcome electron dephasing.

In this project the prospects of using flying foci to control electron injection and/or overcome dephasing will be explored through numerical simulations. The project will require a good understanding of modern optics and good analytical and programming skills (Matlab, Python, or similar).

Reading

[1] S. M. Hooker, Nature Photon 7, 775 (2013). DOI: https://doi.org/10.1038/nphoton.2013.234

[2] A. Sainte-Marie, O. Gobert, and F. Quéré, Optica 4, 1298

(2017). DOI: https://doi.org/10.1364/OPTICA.4.001298

[3] D. H. Froula, D. Turnbull, A. S. Davies, T. J. Kessler, D. Haberberger, J. P. Palastro, S.-W. Bahk, I. A. Begishev, R. Boni, S. Bucht, J. Katz, and J. L. Shaw, Nature Photon 12, 262 (2018). DOI: https://doi.org/10.1038/s41566-018-0121-8

[4] D. H. Froula, J. P. Palastro, D. Turnbull, A. Davies, L. Nguyen, A. Howard, D. Ramsey, P. Franke, S. W. Bahk, I. A. Begishev, R. Boni, J. Bromage, S. Bucht, R. K. Follett, D. Haberberger, G. W. Jenkins, J. Katz, T. J. Kessler, J. L. Shaw, and J. Vieira, Phys. Plasmas 26, 032109 (2019). DOI: https://doi.org/10.1063/1.5086308

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

A&L15 Quantum simulation of a dipolar spin glass

The nature of magnetic order in dilute lattice systems with dipole-dipole interactions is a long-standing question in condensed-matter physics. For instance, the interplay of ferro- and antiferro-magnetic interactions with disorder can cause the system to freeze into a disordered, spin-glass phase at low temperatures, which seems to exist in the rare-earth dipolar system LiHoF_4 when Ho ions are substituted by non-magnetic Y ions [1].

The goal of the project is to analyse some simple spin models including disorder to determine the phase diagram of the system, and to explore the potential to quantum-simulate these models using dilute Rydberg-atom or polar-molecule gases trapped in optical lattices [2].

Suggested reading:

[1] M. Schechter and N. Laflorencie, Phys. Rev. Lett. 97, 137204 (2006); J. A. Quilliam et al., “Evidence of spin glass dynamics in dilute LiHo{x}Y{1−x}F{4}”, Phys. Rev. Lett. 101, 187204 (2008).

[2] W. Lechner and P. Zoller, Phys. Rev. Lett. 111, 185306 (2013); I. Lesanovsky and J.P. Garrahan, Phys. Rev. Lett. 111, 215305 (2013); Blackmore et al., Quantum Sci. Technol. 4, 014010 (2019).

Requirements:

This project will suit a student with an excellent grounding in quantum mechanics and a keen interest in theoretical aspects of physics, including condensed-matter physics and statistical mechanics. This project will require a combination of analytical and numerical techniques; hence, good programming skills will be an advantage.

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

A&L16 Nonlinear quantum optical processes enabled by classical driving

In the interaction between light and matter, processes that do not conserve the total number of excitations seldom occur, since energy is not conserved. However, when the light-matter coupling rate is comparable to the frequency of the bare modes, the rotating wave approximation breaks down and these processes become relevant (this is the so-called ultra-strong coupling regime). This gives rise to a family of quantum nonlinear processes that can be used to generate non-classical states of light and to mediate exotic interactions between qubits.

In this theoretical project, the student will investigate how a classical driving field can enable the same kind of nonlinear processes in systems that are not necessarily on the ultra-strong coupling regime. We will explore this approach in order to generate exotic quantum states of light and matter in different platforms described by the same underlying physics, such as quantum cavity electrodynamics or quantum acoustics. For this computer-based project, the student is required to have a good knowledge of basic quantum mechanics and programmings skills in Mathematica, Python or similar.

Supervisors: ***Dr C Sánchez Muñoz*** and ***Prof D Jaksch***
Email: ***carlos.sanchezmunoz@physics.ox.ac.uk***

A&L17 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 proportionally to 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 [2] 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 how to “integrate out modes” (see also [3]).

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

[2] C.Schilling, Phys. Rev. A 88, 042105 (2013)

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

Requirements: 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

Supervisor: ***Prof V Vedral***
Email: ***vlatko.vedral@qubit.org***

A&L18 An electronics project

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***
Email: ***Christopher.Foot@physics.ox.ac.uk***

A&L19 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., Refs. [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 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 an experimental setup shall be proposed allowing one 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: 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

Supervisor: ***Prof V Vedral***
Email: ***vlatko.vedral@qubit.org***

A&L20 Applying the principles of machine learning to optimise quantum-matter experiments

The applicant will apply optimal control and machine learning routines to an experimental apparatus that produces a quantum gas at temperatures below 1 microkelvin. This will automate the optimisation procedures that we regularly carry out 'by hand' (and brain) to improve the efficiency of the experiment. Techniques such as the Bayesian 'search and find' routine or gradient descent can locate fine features or establish global optima in high-dimensional parameter spaces. This has been demonstrated to work elsewhere [1]. The applicant should be able to program effectively in Matlab, which will speed up integration with current experimental control software.

[1] Fast machine-learning online optimization of ultra-cold-atom experiments. P. Wigley et al. Scientific Reports volume 6, Article number: 25890 (2016)

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

A&L21 tbc

More details from the supervisor.

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

A&L22 Interpretation of inelastic X-ray scattering measurements using machine learning

X-ray inelastic (Thomson) scattering is a popular and information-rich diagnostic in plasma physics, commonly used to study the temperature and density conditions of extreme states of matter similar to those found in astrophysical objects and fusion plasmas. But interpreting the complex and noisy experimental data, normally measured integrating over the time and space of emission, remains a significant theoretical challenge.

In this project, the student will investigate how machine learning techniques can be applied to the robust interpretation of X-ray scattering data, and will deploy algorithms to evaluate the uncertainties in data published in the literature. This work will be used to both validate current results and conclusions, but also to inform future experimental setups and investigations.

The project demands good analytical and programming skills (C/C++, Python, or similar).

Computer-based project, requires computer usage

Supervisors: ***Dr S M Vinko*** and ***Prof G Gregori***
Email: ***Sam.Vinko@physics.ox.ac.uk***

A&L23 Coherent X-ray microscopy for nano-imaging

The development of bright, coherent x-ray pulses from free-electron laser (FEL) sources is revolutionising x-ray science, allowing advances across a diverse range of fields ranging from non-linear x-ray optics and biomolecular imaging to the investigation of matter in extreme conditions. Many experiments require stringent control over the parameters of the x-ray pulses interacting with the studied samples, but the single-shot characterisation of femtosecond FEL pulses still poses significant practical challenges.

In this project, the student will perform Fourier analysis on interferometric data obtained at the Coherent X-ray Imaging endstation (CXI) of the LCLS x-ray FEL at SLAC (https://lcls.slac.stanford.edu), using a newly developed two-frequency shearing method. The results of the analysis will yield the full phase and intensity profile of the nano-focused x-ray beam at CXI, for a single ultra-short x-ray pulse. The aberrations of the beam and the quality of the nano focus vs. the alignment of the focussing mirrors will be investigated, and the developed algorithms fielded at the LCLS.

The project demands good analytical and programming skills (C/C++, Python, or similar).

Computer-based project, requires computer usage

Reading: Schropp et al., Scientific Reports 3, 1633 (2013), DOI: 10.1038/srep01633

Supervisors: ***Dr S M Vinko*** and ***Dr B Nagler*** (SLAC/LCLS)
Email: ***Sam.Vinko@physics.ox.ac.uk***

Atmospheric, Oceanic and Planetary Physics projects

AO01 Mushy gravity currents: modelling brine flows into ice shelves and snow on sea ice.

In the polar oceans, there are multiple settings where saline seawater intrudes into snow on floating ice. This often occurs via buoyancy-driven fluid flow through the porous snow. Such brine has been observed in a thin layer extending tens of kilometres horizontally into the snow on floating ice shelves [1], which can impact ice shelf break up and bias remote sensing estimates of ice thickness. The same process leads to flooding of sea ice, when the weight of snow on floating ice pushes the ice freeboard below sea level and allows an inflow of saline seawater [2]. This source of salty brine has important implications for polar biogeochemistry and impacts the sea-ice structure during later freezing, leading to snow-ice formation. The lateral spread of intruding brine depends on fluid flow driven by buoyancy-differences between seawater and air, and the thermodynamic interaction between the seawater and porous snow matrix.

The goal of this project is to develop a fluid-mechanical and thermodynamic model to describe a gravity current of dense brine spreading horizontally through a mushy snow layer. The approach will initially adapt theories for fluid flows in shallow layers [3] to include the thermodynamics of ice and saltwater mixtures [4], and hence derive a simplified theoretical model to characterise the varying thickness of the spreading gravity current. Computational methods for nonlinear partial differential equations will be used to solve the resulting model. The project aims to build a physical understanding of the characteristic timescales, thermal, and chemical properties of the brine intrusions that have been observed in the polar regions.

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 thermodynamics. The student will have the opportunity to develop experience in computational methods for modelling nonlinear PDEs involving fluid flows. Whilst prior experience with a programming language such as MATLAB/Python/etc. would be an advantage, there is potential for students to learn the necessary skills during the project.

Suggested background reading:

[1] Cook et al (2018) Widespread potential for seawater infiltration on Antarctic ice shelves. Cryosphere, 12, p3853, 2018 https://doi.org/10.5194/tc-12-3853-2018

[2] Provost et al (2017), Observations of flooding and snow-ice formation in a thinner Arctic sea-ice regime during the N-ICE2015 campaign: Influence of basal ice melt and storms, J. Geophys. Res. Oceans, 122, 7115, https://doi.org/10.1002/2016JC012011

[3] Huppert & Woods (1995) Gravity-driven flows in porous layers. J. Fluid Mech. 292, p55. https://doi.org/10.1017/S0022112095001431 [4] Wells et al (2019) Mushy-layer growth and convection, with application to sea ice. Phil. Trans. R. Soc. A 377 : 20180165. http://dx.doi.org/10.1098/rsta.2018.0165

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

AO02 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/Python/etc. would be an advantage, there is potential for students to learn the necessary skills during the project.

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

AO03 Understanding the Physics of Particle Scattering in the Search for Past Life on Mars with The Rosalind Franklin ExoMars Rover

The ExoMars Rosalind Franklin rover is due to land on Mars in 2022. The main goal of the ExoMars mission is to look for evidence of past habitability in the minerals and rocks on Mars. Its main instrumentation are two visible\ near infrared radiometers called PanCam and ISEM. High priority rock samples have been identified, which if found on Mars could indicate past life. Their spectral have been measured in the laboratory under standard viewing angles. However, on Mars PanCam and ISEM will measure rocks on the surface at many different viewing angles and the scattering from the surface will need to be accounted for. Mathematical models exist that attempt to predict how a surface will scatter light at different wavelengths (given the optical properties of a material and its surface roughness), but more laboratory data is required to test these models. We have a unique lab facility know as a goniometer, which can measure how light is scattered at multiple viewing angles from a powdered rock sample.

This project will involve measuring the scattering behaviour of some of the high priority target samples for ExoMars to test the established scattering models.

Reading: Coates et al 2017 – "The PanCam Instrument for the ExoMars Rover" and Cousins et al 2012 – "Selecting the geology filter wavelengths for the ExoMars Panoramic Camera instrument".

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. Some programming experience maybe useful, although the modelling could be done in excel.

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

AO04 Understanding the Heat Flow around the Lunar Surface for Mission Planning

Several remote sensing missions have shown measurements that suggest surface and buried subsurface water ice almost certainly exist mixed in with the soil at the South and North pole of the Moon. PROSPECT is an ESA instrument that will land at the Lunar south pole onboard the Russian Luna27 lander in the next decade. Its primary mission goal is to drill and directly sample the water present there. The primary dataset for its landing site selection is thermal infrared models coupled with a diffusion model which highlight regions where temperatures are low enough for water to remain stable over billions of years. Some regions have incredibly low surface temperatures < 30K – the coldest natural places in the solar system. These are in places on the Moon known as permanently shadowed regions – since due to constant low solar angles and topography – they are always in shadow. In these regions the only source of heat transfer is from scattered radiation from nearby terrain.

We have a thermal model that can simulate the Lunar surface temperature, but would like to update some of the functions incorporated inside this model biased on new laboratory studies. Using the newly updated model we can then re-simulate potential landing sites for PROSPECT to check if water ice is still predicted to be present. Depending on the student (if they are interested in laboratory work) we could also complete some laboratory experiments to test key assumptions in the models.

Reading : King and Warren 2020 – "The Oxford 3D Thermophysical Model with application to PROSPECT/Luna 27 Study Landing Sites"

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. For the computer-based elements programming experience is useful.

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

AO05 Investigating the YORP effect in the Laboratory

The YORP and Yarkovsky effects change the rotation and orbit of an asteroid over time by thermal infrared emissions from the surface. It is only relatively recently that the YORP and Yarkovsky effects have been directly measured on a near earth asteroid. The problem is to fully model these effects we need accurate (~100 m spatially resolved) topographic information about the surface of asteroids as well as accurate spatial surface maps of albedo and emissivity. These datasets are only available for very few asteroids limiting our ability to test our models and understanding.

We want to re-create this effect in the laboratory to allow us to test to the YORP effect under controlled laboratory conditions. Some preliminary design work has been done and we can 3D print a custom asteroid shape, paint it in well characterised high emissivity paint and then place it into a vacuum chamber. Inside the vacuum chamber we can illuminate the asteroid shape in such a way as to induce the asteroid to rotate from stationary via the YORP effect. We can then compare these results to models of the YORP effect to test our understanding.

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. For the computer-based elements programming experience maybe useful. This project will involve 3D printing – but this can be learnt in an afternoon.

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

AO06 Measuring the global temperature of the Earth since 2010 from the Moon

The Lunar Diviner Radiometer Experiment, has been in orbit around the Moon as part of NASA's Lunar Reconnaissance Orbiter since 2010. Although the instrument spends most of its time producing thermal and compositional maps of the Moon, occasionally once every few lunar orbits, the instrument scans across the Earth. These thermal infrared measurements are unique; Diviner is currently the only instrument making measurements of the Earth from lunar orbit and covers a very wide part of the visible and infrared spectrum albeit at very low spatial resolution.

This project will investigate the types of information that can be derived from Diviner's low spatial resolution but very broadband spectral coverage, including application to possible future characterisation of exoplanets. The project will use radiative transfer models of the Earth's atmosphere to model the data from Diviner, and example questions include: Can we see a decade of global warming in the dataset? Can we see the seasonal changes we expect in each hemisphere? How does the shortwave energy input from the Sun match the long wave thermal energy emitted by the Earth? How do measurements made by Diviner compare with traditional Earth observation satellite in low and geostationary Earth orbit? What rotation rate do we derive for the Earth in each of Diviner's spectral channels and are they the same?

Skills: Coursework covering the fundamentals of radiative transfer e.g. from Atmos or Astro major options. For the computer-based elements programming experience is useful.

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

AO07 Atmospheric Pollution in Siberia

Northern Russia is remote, sparsely populated and consists of vast stretches of taiga (boreal forests) and tundra, all reasons to expect good air quality. However, satellite observations reveal frequent pollution events probably associated with forest fires or industrial activity.

The aim of this project is to use measurements of atmospheric composition made by the Infrared Atmospheric Sounding Interferometer (IASI) over recent years to characterise such events in terms of which pollutants are present, whether these are regular or sporadic events, and if they can be associated with particular sources.

The project requires some knowledge of infrared radiative transfer and so would be most suited to students taking the C5 option. The project is entirely computer-based so some knowledge of scientific computing and/or linux would also be useful.

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

AO08 Viewing Clouds with IASI

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. These spectra show absorption lines from various atmospheric molecules with characteristic signatures and from these it is possible to retrieve the absorber concentrations.

However, the spectra represent the integrated radiance from a field-of-view of diameter 12 km and so most pixels, particularly over areas such as the UK, will have at least some cloud within the FOV. The situation is helped by having a high spatial resolution (1km) imager, AVHRR, on the same satellites, which can be used to quantify the cloudiness of each IASI pixel.

The aims of the project are

1) To examine the consistency of the clouds represented in various IASI operational products with the co-located AVHRR data

2) To improve our current simple method of modelling the cloud contribution within IASI measurements.

A basic knowledge of infrared radiative transfer would be useful.

Also, since the project is entirely computer-based, some familiarity with scientific computing (eg python) in a linux environment is also desirable.

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

AO09 Measuring atmospheric temperature, relative humidity, cloud and wind profiles with weather balloons.

In this project, a simple weather balloon system and novel cloud detector (based on a commercial smoke detector) will be tested to determine the system's ability to measure the vertical dependence of temperature, relative humidity, wind and cloud in Earth's lower atmosphere. The project would entail conducting several balloon launch tests, analyzing the results, and assessing the quality of the observations with regards to local area forecasts and other determinations. The project would also involve some laboratory simulation to test the sensitivity of the cloud detector combined with radiative transfer analysis to understand better how the device might be applied.

The experiment would be ideally suited to students with excellent practical, analytical and problem-solving skills. Familiarity with computers and interfacing computers to the real world would also be an advantage.

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

AO10 Evolution and dynamics of Jupiter's cloudy atmosphere

The arrival of NASA's Juno spacecraft in orbit about Jupiter in July 2016 has heralded a new age of Jupiter atmospheric analysis. In addition to the Juno observations themselves, a coordinated programme of ground-based observations is being conducted to make observations at the same time as Juno's close flybys to set the Juno observations (which have rather narrow 'ground-tracks') into a global context. One such set of observations is being conducted by our group using the MUSE instrument at ESO's Very Large Telescope in Chile. MUSE is an integral field unit spectrometer that records visible/near-infrared images where each individual pixel contains a complete spectrum covering the wavelength range 490 – 930 nm, forming image 'cubes'. The visible/near-infrared spectrum of Jupiter is formed by the reflection of sunlight from its cloud layers, modulated mostly by the absorption of gaseous methane and ammonia and also Rayleigh scattering at blue wavelengths. At wavelengths of low absorption sunlight can penetrate to, and be reflected from, the deepest cloud layers, while at wavelengths of high absorption only sunlight reflected from the upper layers can be observed. Hence, such spectra can be inverted to 'retrieve' the cloud structure and reflectivity as a function of location and altitude, and also the variable abundance of ammonia.

In this project, the most recent MUSE observations will be reduced and analysed with our radiative transfer and retrieval tool, NEMESIS, to map the distribution of cloud, ammonia and cloud-colouring agent (known as 'chromophore') in Jupiter's stormy atmosphere, to look for temporal changes and to help better interpret the Juno observations.

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

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

AO11 Study of clouds and gas abundances in Neptune's turbulent atmosphere

In this project, new observations of the turbulent atmosphere of Neptune made with the MUSE and SINFONI instruments at ESO's Very Large Telescope in Chile will be analysed. Both MUSE and SINFONI are integral field unit spectrometers that record images where each individual pixel is in fact a complete spectrum covering the wavelength range 490 – 930 nm for MUSE and 1500 – 2500 nm for SINFONI, returning 'cubes' of data that contain an incredible amount of information. The visible/near-infrared spectrum of Neptune is formed by the reflection of sunlight from its cloud layers, modulated mostly by the absorption of gaseous methane and also Rayleigh scattering at blue wavelengths. At wavelengths of low absorption sunlight can penetrate to, and be reflected from, the deepest cloud layers, while at wavelengths of high absorption only sunlight reflected from the upper layers can be observed. Hence, such spectra can be inverted to 'retrieve' the cloud structure and reflectivity as a function of location and altitude, provided we know the vertical and latitudinal distribution of methane. For many years it was assumed that the vertical profiles of methane observed by Voyager 2 in 1986 could be used at all locations. However, HST/STIS observations of Uranus, recorded in 2002, revealed that the abundance of methane varies with latitude. Fortunately, the MUSE wavelength range covers spectral features that allow variation in cloud height to be discriminated from variations in methane abundance, allowing both quantities to be determined reliably. Meanwhile, the SINFONI wavelength range allows us to detect and measure the abundance of hydrogen sulphide in Neptune's (and also Uranus's) atmosphere, allowing our research group to confirm, recently, and for the first time, that both planets really do smell of rotten eggs!

In this project, these VLT observations will be reduced and analysed with our radiative transfer and retrieval tool, NEMESIS, to map the distribution of cloud, and update and refine our determinations of the latitudinal variation in the abundance of methane and hydrogen sulphide in Neptune's stormy atmosphere.

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

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

AO12 The fractal dimension of clouds

Recent years have seen an increase in the production of global convection-resolving (or at least convection-permitting) atmospheric simulations. These simulations are very realistic when compared to observations. A good example of this can be seen in images of simulated cloud condensate fields, rendered in such a way that they can be directly compared to satellite images of the Earth (Fig. 2: Stevens et al, 2019). While it can be difficult at first glance to distinguish between model and observed data, on closer inspection, the satellite image can be identified. The fractal nature of the clouds, degree of convective organisation, and spatial distribution of clouds all differ subtly between different models and between models and observations.

This project will systematically compare ultra-high-resolution climate model data with observational datasets to quantify the ways in which simulated clouds differ from those observed. The project can be extended in a number of directions depending on the interests of the student. For example, do the statistics change with time, as the models drift away from initialisation towards their respective attractors?

A key goal of producing such high-resolution climate model simulations is that we can use them as a proxy for the true atmosphere to understand atmospheric processes and predictability. Such datasets have several advantages over using observations, including good spatial and temporal coverage, their high resolution, and the availability of a range of variables that are difficult to directly observe. However, if they are poor representations of the true atmosphere, their use is limited. Only by quantifying the difference between models and observations, as in this project, can we assess the degree to which a model can 'stand in' for observations to help us understand the real atmosphere.

Prerequisites: This project is best suited for someone with experience coding in Python or Matlab, and someone who took the short option on Chaos, Random Processes and Predictability.

References:

Stevens, B., Satoh, M., Auger, L. et al. DYAMOND: the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains. Prog Earth Planet Sci 6, 61 (2019). https://doi.org/10.1186/s40645-019-0304-z

The DYAMOND project website https://www.esiwace.eu/services/dyamond

Supervisor: ***Dr H Christensen***
Email: ***Hannah.christensen@physics.ox.ac.uk***

AO13 How predictable are Euro-Atlantic weather regimes?

Weather over the North Atlantic and Europe (the Euro-Atlantic) in wintertime (December, January and February) has been shown to be heavily influenced by the existence of so-called weather regimes. These can be thought of as a small number of large-scale circulation patterns which the atmosphere has a strong preference for manifesting and which tend to persist for many days before transitioning to a different regime. Because the consequence of being `stuck' in particular regimes for extended periods is often associated with extreme weather (e.g. flooding in the UK), it is of great interest to accurately predict the onset and decay of these regimes as far in advance as possible.

Understanding this question is obviously contingent on how one defines the weather regimes in the first place. While evidence from multiple directions have suggested these exist, ambiguities concerning their exact number and the spatial patterns corresponding them have remained. Recent methods have suggested ways to resolve this ambiguity, leading to a clear set of 5 weather regimes that are extremely stable and therefore amenable to robust analysis. The purpose of this project is to understand how accurately and how far in advance these weather regimes can be predicted, and comparing the level of predictability of these new regimes with more traditional definitions.

The student will be analysing existing forecast model data, as well as data output from climate simulations, using the ECMWF Integrated Forecast System (one of the world's foremost weather forecasting model).

Prerequisites: This project is best suited for someone with experience coding in Python or Matlab.

Supervisors: ***Dr Kristian Strommen*** and ***Prof T Palmer***
Email: ***kristian.strommen@physics.ox.ac.uk***

AO14 The impact of a stochastic sea-ice scheme on Arctic climate variability and European weather.

Representing Arctic sea-ice in climate models is a challenging but crucial goal. Besides the role of sea-ice in determining the extent of sea-level rise under global warming, research has increasingly demonstrated that yearly variations in the amount of autumn sea-ice can modulate the following wintertime weather over Europe and North America. As a result, a decline in future sea-ice due to global warming may, besides contributing to rising sea-levels, also have more immediate impacts on e.g. the frequency of extreme weather events (such as flooding in the UK). However, climate models often exhibit biases in both the representation of Arctic sea-ice as well as the observed connection between sea-ice and the North Atlantic region.

The aim of this project is to study the impact of a novel stochastic scheme on the representation of Arctic sea-ice in a climate model, as well as the link between sea-ice and European winter weather. Stochastic schemes are often added to various components of a climate model in order to represent inherently uncertain processes that cannot be resolved directly, due to limitations imposed by the computational costs of running a climate model. Early work suggests that adding a stochastic component to the sea-ice part of a climate model can both alter the Arctic sea-ice and its link to Europe. The student will be working on analysing these changes in more detail. In particular, the stochastic sea-ice scheme changes both the mean sea-ice extent in the Arctic, as well as its month to month variability. The student will be working to unpick the relative impacts of these changes, with a focus on how both are affecting the subsequent response in the atmospheric circulation.

The student will be analysing existing climate model data, using the EC-Earth coupled climate model, as well as comparing the performance of the model against observational datasets.

Prerequisites: This project is best suited for someone with experience coding in Python or Matlab.

Supervisors: ***Dr Kristian Strommen*** and ***Dr H Christensen***
Email: ***kristian.strommen@physics.ox.ac.uk***

AO15 Deep learning for aircraft turbulence warnings.

Clear air turbulence is a significant problem for commercial aviation, occasionally causing injuries to those onboard an aircraft or damage to the aircraft itself. In this project, you will explore the potential of machine learning techniques to determine where cruise-level (between 8-12km altitude) turbulence is likely to occur. You will generate training data from airliner reports of turbulence over the USA and then apply this dataset to images produced by the GOES-16 meteorological satellite in order to determine which features of the satellite data are of most value in determining when and where turbulence is likely to occur. This project will be computer-based and will require you to write code in the Python programming language. Existing experience of programming is essential, and Python experience is desirable. Knowledge of aviation and/or satellite data would be a strong asset. Please contact Dr Simon Proud (simon.proud@physics.ox.ac.uk) for more information

Supervisor: ***Dr S Proud***
Email: ***simon.proud@physics.ox.ac.uk***

AO16 Cloud top properties of convective, volcanic and fire-driven storms.

Convective storms can be initiated by multiple means, including volcanic eruptions and land fires. In this project, you will look at the properties of these volcanic and fire driven convective storms compared to the properties of typical meteorology driven storms. You will explore whether there are differences in the maximum altitude of these storms, the distribution and size of ice crystals in the cloud tops and whether driven storms are more likely to overshoot into the lower stratosphere. To do this, you will use data produced by the latest generation of meteorological satellites for a variety of storms, including those generated by the recent Australian bushfires and the 2018 eruption of Anak Krakatau in Indonesia. This project requires extensive use of the Python programming language, and you will need some existing programming experience, preferably in Python. Knowledge of satellite data and/or convective processes would be a plus. Please contact Dr Simon Proud (simon.proud@physics.ox.ac.uk) for more information.

Supervisor: ***Dr S Proud***
Email: ***simon.proud@physics.ox.ac.uk***

AO17 Estimating Surface Reflectance Using a Neural Network

Aerosols are particles suspended in the atmosphere such as soot, dust, and acid droplets. By acting as nucleation sites for water droplets and ice crystals, aerosols can change the properties of clouds through a complex series of interactions that are currently the most uncertain influence on future climate. Aerosols also impact human health when small particles enter the lungs and blood stream. As they only remain in the atmosphere for a few days to weeks, there is great need for regular observations to monitor the loading of aerosols around the world.

Researchers in Oxford have produced a high quality climate record of aerosol properties using a series of satellite radiometers. This is a difficult measurement over land as only a small fraction of the light observed was scattered by aerosols, making measurements highly sensitive to our assumptions. This project will work to improve our record of this Essential Climate Variable by quantifying our sensitivity to various land surfaces.

Our calculations currently use observations of the surface from another satellite, but errors result from differences in the precise wavelengths monitored by each instrument. Our current correction is no longer fit for purpose. The student will produce a training dataset of surfaces as seen by multiple satellite instruments and generate a neural network that extends our existing wavelength correction. These will then be trialled within our satellite processor to assess the impact on the aerosol retrieval.

This research will be computer-based, so prior experience of scientific computer programming in IDL or Python is beneficial, if not required. Familiarity with basic statistical analysis is essential.

Supervisors: ***Dr A Povey*** and ***Prof R G Grainger***
Email: ***Don.Grainger@physics.ox.ac.uk***

AO18 Using CO2 slicing to obtain the height of volcanic ash in the stratosphere

Volcanic ash is one of the main hazards associated with volcanic eruption. It poses a threat to human health and can cause significant damage to infrastructure. It is also a significant hazard to aircraft and the closure of airspace following a volcanic eruption can lead to billions of dollars of loses; best demonstrated by the Eyjafjallajökull eruption in 2010. Knowledge of the plume's location and height is an essential for mitigating against this hazard. The injection height is also essential in models of ash cloud propagation.

A method known as CO2 slicing, originally developed for obtaining the height of meteorological clouds, has been shown to have promise for acquiring the height of volcanic ash (Richards, 2006; Tupper et al. 2007). This method utilises a CO2 absorption feature within the thermal infrared which affects how transparent the atmosphere appears. A study by Taylor et al. (2019) adapted the technique for the Infrared Atmospheric Sounding Interferometer (IASI) for tropospheric volcanic ash clouds. The aim of the proposed project is to adapt the technique to work in the stratosphere. This would involve:

(1) Using modelled volcanic ash spectra to demonstrate that this technique works in the stratosphere and to select the best IASI channels to use.

(2) Identifying appropriate case studies to test the technique on

(3) Applying the technique to a few case studies and comparing the results against other tools used to obtain the height of volcanic ash.

The project is computer based and will use the Interactive Data Language (IDL) on machines which run the Linux operating system. Prior experience of either of these (or programming in general) would be useful but is not essential.

Supervisors: ***Dr I Taylor*** and ***Prof R G Grainger***
Email: ***isabelle.taylor@physics.ox.ac.uk*** , ***Don.Grainger@physics.ox.ac.uk***

AO19 The role of ocean physics in interannual variability of the jet stream

The Atlantic jet stream is a strong, narrow current of air which blows from North America towards Europe, and year to year variability of this jet has profound implications for climate in Europe and neighbouring regions. For example, the mild and stormy UK winter of 2019/20 was caused by a persistent northward shift of the jet.

The behaviour of the jet is controlled by the physics of atmospheric fluid dynamics but also has important influences from variability in the oceans. This project will investigate the role of the oceans in jet variability, with a focus on determining how much of the interannual variability of the jet might be related to the ocean, and how much could simply be random 'weather noise'.

The work will consist of data analysis and statistical modelling using a language such as matlab or python. The project will quantify aspects of jet variability in simulations from a state of the art climate model run in two configurations - one with interactive ocean physics and one without.

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

AO20 Dynamics of local Hadley circulation and droughts in Africa in a changing climate

This project combines elements of climate dynamics and dynamical systems theory [1,2] with statistical and machine learning methods for analysis of selected climate datasets. We will examine variability and change of the Hadley cells (the large-scale latitude-height tropical circulation of the tropospheric heat engine) that exert a substantial influence on precipitation in tropics. Droughts in Africa [3] are recurrent extreme climate events with potentially tremendous socio-economic consequences. There are indications that the Hadley cells are expanding while at the same time frequency, duration and intensity of droughts in Africa is increasing due to long-term global climate change. However, disentangling anthropogenic influence from natural variability in Africa is an interesting challenge.

This study aims to advance our understanding of the dynamics and predictability, and improve risk assessment and attribution of meteorological droughts (low precipitation events) in Africa from the conditional perspective of the large-scale circulation. The dynamical focus is on the decomposition of vertical flow into the local Hadley (and local Walker) circulation based on the Helmholtz's vector theorem [4]. We will use a clustering method and the convergent cross mapping based on the Takens' embedding theorem [5] to explore the relationship, including causality, between key climate change and variability indices and droughts in Africa, in conjunction with aspects of circulation crucial for the formation of precipitation patterns. This project would be suitable for a student interested in investigating Earth's climate as an example of a complex dynamical system with tangible impacts on our rapidly expanding society, and in developing additional skills as a versatile data scientist.

References:

[1] Randall, D., 2012, Atmosphere, Clouds, and Climate, Princeton University Press, 277 pp.

[2] Ghil, M., and V. Lucarini, 2020, The Physics of Climate Variability and Climate Change, https://arxiv.org/abs/1910.00583

[3] Masih, I., et al., 2014, A review of droughts on the African continent: a geospatial and long-term perspective, Hydrol. Earth Syst. Sci., 18, 3635–3649.

[4] Schwendike, J., et al., 2014, Local Partitioning of the overturning circulation in the tropics and the connection to the Hadley and Walker circulations, J. Geophys. Res. Atmos., 119, 1322–1339

[5] van Nes, E., et al., 2015, Causal feedbacks in climate change, Nature Clim Change 5, 445–448.

Supervisors: ***Dr N Fučkar*** nd ***Prof M Allen***
Email: ***neven.fuckar@ouce.ox.ac.uk***

AO21 Sectoral climate change contribution and mitigation in 1.5 degree strategies

The Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5 °C includes a range of different emissions scenarios that could keep total anthropogenic warming within this limit by the end of the century. All pathways meeting this criterion require rapid, large-scale changes, but there is considerable variation between them, particularly in the timing of decarbonisation and role of non-CO2 greenhouse gases. This project will explore the ranges in total contribution to global warming and mitigation responsibilities of different sectors in these different pathways.

For this project, the student should have an interest in climate change communication and policy. Reduced complexity climate models will be used alongside a range of simple climate metrics. Programming will be required (Python recommended), but the focus of this project is not on physical modelling. The student should also be comfortable gathering and handling data from public repositories.

Supervisors: ***Dr J Lynch*** and ***Prof M Allen***
Email: ***john.lynch@physics.ox.ac.uk***

AO22 Implications of different greenhouse mitigation strategies in UK climate policy

Current greenhouse gas mitigation policy frameworks essentially assume direct fungibility between annual emissions of different greenhouse gases, if they are scaled by an appropriate factor (generally the 100-year Global Warming Potential). This overlooks important physical differences between the gases, particularly when mitigations to short-lived gases such as methane are treated in the same manner as those of long-lived gases, especially CO2. This project will explore some of the resultant implications in the context of the United Kingdom's ambitions for greenhouse gas mitigations.

This project will require an interest in climate change policy, and the student should be comfortable synthesising information from government documents (for example, the Climate Change Act 2008). Using stated ambitions and emissions from the UK National Inventory Report, the student will use reduced complexity climate models (requiring some programming experience – Python recommended) to generate a series of illustrative scenarios highlighting the implications of the timing of mitigation for different gases.

Supervisors: ***Dr J Lynch*** and ***Prof M Allen***
Email: ***john.lynch@physics.ox.ac.uk***

AO23 Do climate model biases impact projected climate change?

General circulation models of the coupled climate system used for short-term predictions of the next season to climate projections at the end of this century can be subject to large systematic errors. In most cases, especially on time-scales beyond the typical weather forecast range of around 10 days, climate signals of these models are estimated by accounting for these systematic errors, e.g. by subtracting mean biases. However, due to the non-linear nature of the climate system it might be expected that predictive skill and/or projected changes might depend on the model's ability to reasonably represent the observed climate state. In this study we will analyse subseasonal-to-seasonal predictions as well as climate change projections to compare their simulated/predicted signals in comparison to the magnitude of the models' systematic errors. This will be checked for different regions of the Earth, different seasons and physical variables. The project demands good analytical and programming skills (e.g. python, bash-scripting) but previous experience is not essential.

Supervisors: ***Prof T Palmer***, ***Dr A Weisheimer***, ***Dr D Befort*** and ***Dr C O'Reilly***
Email: ***tim.palmer@physics.ox.ac.uk; antje.weisheimer@physics.ox.ac.uk; daniel.befort@physics.ox.ac.uk*** and ***christopher.oreilly@physics.ox.ac.uk***

AO24 Signatures of Southern Hemisphere Natural Climate Variability

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

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

Skills required

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

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

AO25 A wind sensor for Titan

One of the most intriguing bodies in our solar system is Titan, the largest moon of Saturn. Its atmosphere is composed mostly of nitrogen, and has a hydrological cycle not of water but of methane and ethane. With an atmospheric density five teams greater than Earth but a gravitational acceleration seven times weaker, it is an ideal place for flying exploration vehicles.

We are designing a thermal wind sensor which will be not only crucial not only for science but also to reduce flight risks for Titan exploration craft [1]. The design needs to be tested in Earth conditions, and the laws for scaling this to Titan conditions need to be tested. The project will involve mainly lab testing, and so would suit someone with an interest in electronics and data acquisition, but some Computational Fluid Dynamics simulations may also be performed.

References:

[1] Wilson & Lorenz, Design of a Thermal Anemometer for a Titan Lander, https://www.hou.usra.edu/meetings/lpsc2017/pdf/1859.pdf

Supervisor: ***Dr C Wilson***
Email: ***Colin.Wilson@physics.ox.ac.uk***

AO26 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

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

AO27 Deep learning using high temporal resolution satellite data

The planetary energy balance between incoming and outgoing radiation, and hence global temperature, is very sensitive to the properties and distribution of clouds in the atmosphere. Large continuous decks of stratocumulus clouds occur in the cold upwelling regions of the major oceans and play a crucial role in this balance.

An important and poorly understood phenomena occurs where a large region of the cloud deck dissipates and leaves open regions, so called Pockets of Open Cells (POCs). It has been hypothesized that these occurrences are affected by anthropogenic activity, specifically through aerosol perturbations. Hence, POCs could have important implications for climate change.

Previous work has developed a model to detect and classify these important phenomena in individual satellite images using deep neural networks deployed on large cloud-hosted GPU clusters. This project will build on that work by developing a temporal aspect to the model (using e.g. Long Short Term Memory) to understand the temporal evolution, and critically the physical mechanisms, of POC formation. These implications will feed back into regional and global assessments of their effect on global cloud forcing.

An interest in state-of-the-art machine learning techniques and some basic Python experience is essential, but training will be provided.

Supervisors: ***Dr D Watson-Parris***, ***Dr M Christensen*** and ***Prof P Stier***
Email: ***duncan.watson-parris@physics.ox.ac.uk***;
matthew.christensen@physics.ox.ac.uk;
philip.stier@physics.ox.ac.uk

AO28 Lagrangian analysis of aerosol optical properties

In the context of climate change, atmospheric aerosols such as dust, biomass burning or anthropogenic aerosols (pollution) play an important role in the climate system. They can warm or cool the atmosphere, depending on their chemical and microphysical properties, as well as their interaction with radiation and clouds. Despite improved in-situ and remote sensing observational methods, the aerosol properties, along with their associated effects remain a large source of uncertainty when quantifying and interpreting the aerosols impact on climate. The study of aerosol optical and microphysical properties becomes even more complex when the properties of aerosols transported over large distances are altered due to aging processes linked to photochemical interactions.

This project attempts to estimate the changes in aerosol optical properties during transport.

Satellite imagery allows for large spatial coverage retrievals, while in-situ technics are spatially limited, but have lower measurement uncertainties. A synergy of these methods along with a Lagrangian tracking of different air masses, could improve the aerosol characterization and our understanding of aerosol effect on climate.

The candidate should have an interest in atmospheric science and some basic Python experience, but training will be provided.

Supervisors: ***Dr L Deaconu*** and ***Prof P Stier***
Email: ***lucia.deaconu@physics.ox.ac.uk***;
philip.stier@physics.ox.ac.uk

AO29 Mapping Venus

Venus is completely enveloped by a thick layer of clouds, extending from 50 – 70 km altitude. New images of this cloud layer, of unprecedented resolution, are being obtained by the Japanese Akatsuki orbiter, at a range of wavelengths. Of particular interest are images form the IR2 camera at wavelengths of 1.7 and 2.3 microns, which reveal patterns in the lower clouds, backlit by thermal radiation from the deep atmosphere [1, 2]. The ratios between these radiances can be used to constrain cloud properties in particular cloud droplet size [3].

In this project, the student will learn to process and reproject planetary mission data, creating maps and analyses of IR emission of Venus and analysis of cloud feature lifetime. This project will be computer based, using IDL, Matlab or Python languages; experience in at least one of these would be an advantage.

References

[1] https://www.springeropen.com/collections/akt

[2] A new look at Venus with Akatsuki, http://www.planetary.org/blogs/guest-blogs/2018/0116-a-new-look-at-venus-with-akatsuki.html

[3] Wilson et al, Evidence for anomalous cloud particles at the poles of Venus, JGR-Planets, https://doi.org/10.1029/2008JE003108

Supervisor: ***Dr C Wilson***
Email: ***Colin.Wilson@physics.ox.ac.uk***

Astrophysics projects

AS01 Orbital evolution of planets in mean motion resonances

Planetary systems comprising planets with a mass comparable to that of the Earth and orbiting very close to their parent star have been detected. In some cases, these planets are in or close to mean motion resonances, meaning that the ratio of their orbital periods is the ratio of two integers.

In most systems with only two planets, there is a significant departure from exact resonance, which has raised questions about how these systems have formed. The aim of this project is to study systems with more than two planets, to establish whether departure from exact resonances is different for those systems, and understand the dynamics that has led to such configurations.

The project requires good background in mathematics and mechanics.

Supervisor: ***Prof C Terquem***
Email: ***caroline.terquem@physics.ox.ac.uk***

AS02 Dissipation of tides in the convective envelope of stars

A large proportion of stars are found in binary systems. When the distance between the two stars in such systems is small enough, oscillations are excited in each of the stars by the tidal potential of its companion. These tidal waves are dissipated in the convective regions of the stars. Such dissipation of energy leads to circularisation of the orbits. Observations do show that close orbits are circular whereas wider orbits have eccentricities. The period at which the transition occurs for a type of stars is called the 'circularisation period'. So far, theoretical studies have predicted circularisation periods smaller than the observed ones. Theoretical studies of tidal oscillations in stars rely on mixing length theory to model convection. The discrepancy between theory and observations means that dissipation of tides is underestimated in this model. The aim of the project is to review other models of convection, in particular those used in geophysics, to identify how the interaction between convection and tidal oscillations in stars could be better described.

The project requires some knowledge of fluids.

Supervisor: ***Prof C Terquem***
Email: ***caroline.terquem@physics.ox.ac.uk***

AS03 Galaxy Mergers and Quenching

The present-day galaxy population is undergoing significant quenching, as systems transition from vigorous star formation to mostly quiescent evolution. A huge variety of mechanisms have been proposed to account for this behaviour, amongst them the effects of major mergers of galaxies. This project makes use of a large sample of mergers and post mergers classified by citizen scientists through the Galaxy Zoo project to investigate the effects of mergers, and to quantify for the first time their contribution to the quenching of the population as a whole. Data from the Sloan Digital Sky Survey is supplemented by recent classifications of DeCALS, a deeper survey which is more capable of identifying low surface brightness merger signatures, and which may include the southern sky for the first time. The project will require moderate python, though this could be learnt along the way if necessary.

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

AS04 A Machine Enabled Search for Ring Galaxies

Ring galaxies are typically the result of a merger or interaction, and as such can help us understand how such events trigger star formation and affect the galaxies involved. While many have been found serendipitously, a systematic search has not been carried out. This project will train modern deep learning networks - probably a convolutional neural network - on a sample of rings identified by participants in the Galaxy Zoo project to search for rings. The aim is to provide limits on the prevalence of rings in the galaxy population, and to study the properties of the resulting sample. It therefore combines a chance to learn the tools of data science with a chance to do some astrophysics. Students picking this project should enjoy coding - as there will be a lot of it - but it should be fine to learn as you go if necessary.

the long-running Galaxy Zoo project, which records galaxy morphologies, key to tracing a galaxy's dynamical history, but there is a possible extension to other projects, including a search for exoplanets in TESS data which should be available from Hilary 2019.

The project will involve working with TensorFlow or similar machine learning implementations, and with code written in Python. Though prior experience with these tools is not necessary, it would suit a student who wants to acquire skills appropriate for data-driven science and who is happy writing their own code. Links to the Zooniverse's outreach program are also possible.

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

AS05 Finding the optimal way of extracting density profiles from Gaia data

The Gaia spacecraft has recently provided full six-dimensional phase-space information (three positions and three velocities) for the stellar motions in the Milky Way. This new dataset is allowing us to infer the density distribution of the Milky Way with unprecedented accuracy using dynamical models. However, the Milky Way is not axisymmetric and not in equilibrium. This implies it may not satisfy the dynamical model's assumptions to sufficient accuracy. Here the student will asses the reliability of the dynamical models using N-body simulations of galaxies similar to the Milky Way, by checking how different modelling assumptions affects the results. Using these simulations, the student will try to find optimal ways of extracting density distributions from the Gaia data.

Special skills: Knowledge of the Python programming language.

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

AS06 & AS07 Weak lensing with the Euclid mission

The ESA Euclid mission will launch in 2022 and carry out a survey of cosmological weak gravitational lensing, to measure the universe's geometry and its growth of structure, with unprecedented accuracy. In order to realise the science goals, we must carefully propagate our understanding of the measurement process into the data analysis. This project will investigate the effect of errors in the modelling of the telescope and detector point spread function on the cosmological accuracy that can be obtained. This will involve first evaluating the effect of instrumental effects on the weak lensing shear measurement, and then propagating those through to the estimation of cosmological parameters. This project will use some existing software, but additional coding in python by the student will also be required.

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

AS08 & AS09 Dynamical analysis from time-lapse spectroscopy of eclipsing binary star systems

Time-lapse spectroscopy of evolving star systems in our Galaxy is a powerful technique for understanding their dynamics and how they evolve. The spectroscopic data-streams of various Galactic targets from the Global Jet Watch are supplemented by newly-installed on-board cameras that deliver accompanying photometric data-streams as well.

In this project, the student will explore the data-stream for a given stellar system and investigate its current dynamical state in the light of past behaviour, and elucidate its evolutionary path. This will involve a range of data analysis techniques, and will necessitate good analytical and programming skills in Python.

Supervisor: ***Prof K Blundell***
Email: ***katherine.blundell@physics.ox.ac.uk***

AS10 & AS11 Very-high-energy gamma-ray astrophysics with the Cherenkov Telescope Array

Very high-energy gamma-ray astrophysics is an exciting field spanning high-energy particle physics and extreme processes in astronomy. Our investigations range from the nature and variety of particle acceleration around supernovae and black holes, to physics beyond the Standard Model including dark matter, axion-like particles and Lorentz invariance violation.

The group in Oxford works on both experiment and theory. We are members of the High Energy Stereoscopic System (H.E.S.S.) in Namibia, presently the world's largest gamma-ray observatory, and the next-generation gamma-ray observatory, the Cherenkov Telescope Array (CTA). CTA will consist of up to one hundred telescopes using state-of-the-art 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. The telescope prototypes are under construction, and deployment to the observatory sites at Paranal, Chile, and La Palma, Canary Islands, will commence in 2020.

M.Phys. students will have an opportunity to choose their project from a variety of our activities. On the experimental side of the prgramme, we are leading efforts to develop advanced analysis techniques for the large volumes of data that will be generated when CTA becomes operational, including co-ordination of the CTA Machine Learning Task Force. On the theoretical/observational side, we have recently developed a new class of models for the broad-spectrum emission from relativistic jets in active galaxies, which let us use the gamma-ray 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 the entrainment of heavy particles as the jets propagate through their host galaxy, the resulting possibility of hadronic particle processes within the jets, and propagation effects in intergalactic space that may provide evidence for axion-like particles or Lorentz invariance violation.

These projects are particularly suited to students who are taking astrophysics or particle physics major options.

For more information please contact Professor Garret Cotter.

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

AS12 The Tully-Fisher relation as a tool to study galaxy growth.

The dynamical scaling relations of disk galaxies exhibit tight correlations between the main galaxy properties: size, mass and rotational velocity. Among these is the Tully-Fisher relation (TFr), linking the baryonic content of a galaxy to its rotational velocity. Comparing the TFr at different redshifts is a powerful tool to constrain gas accretion and more generally how galaxies grow. The presence of a significant TFr evolution suggests an imbalance in the accretion histories and mass assembly of Dark Matter (DM) and baryons. At low redshifts neutral hydrogen (HI) is used as the kinematic tracer, as it provides the best measure of the total gravitational potential of a galaxy. However, HI remains undetectable in emission at significant redshifts. Carbon monoxide (CO) has been used as the kinematic tracer at high redshifts, but its distribution is known to be compact and may not probe the DM halo potential. A careful and homogeneous study of the CO- and H I-based TFrs at $z \approx 0$ is thus required to investigate how the choice of kinematic tracer affects the zero-point, slope and scatter of the TFr.

The student will conduct this study using existing CO ($J = 1 - 0$) and HI mapping of a sample of galaxies in the Ursa Major cluster. This study will allow us to gauge the reliability and limitations of CO as a kinematic tracer, what will improve our current understanding of the evolution of the TFr with redshift. The student will learn how to analyse 3D radio data, as well as will gain experience working with photometrical data and statistical techniques. Knowledge of python and astropy is a plus, but not required.

Supervisor: ***Dr A Ponomareva***
Email: ***anastasia.ponomareva@physics.ox.ac.uk***

AS13 Astro Optimal collection of new data for Cosmology

Modern physics problems often involve making predictions for large amounts of data using supervised machine learning algorithms e.g. photometric redshifts for large astronomical datasets - an essential requirement for contemporary efforts to measure the equation of state of Dark Energy. Recent work has focussed on quantifying how much uncertainty on predictions is from intrinsic variation in the data, and how much is from lack of training data. In this project, the student will investigate how to statistically determine what is the optimal new data to collect to improve predictions for a range of problems (in particular galaxy redshifts for cosmology), and trial the algorithm on new data sets. This will involve reducing data, applying supervised machine learning algorithms to astrophysical data sets, and finding new ways to use existing algorithms. The project requires basic programming skills (Matlab, python or similar).

Supervisor: ***Dr P W Hatfield***
Email: ***peter.hatfield@physics.ox.ac.uk***

AS14 Fast statistical methods for redshift uncertainties in weak lensing data

Cosmological weak lensing experiments offer a unique window to study the impact of dark energy on the growth of structure and the geometry of the Universe. However, their main source of systematic uncertainty lies in the poor knowledge of the galaxy redshift distributions. This project will focus on applying advanced statistical and computational methods (Hamiltonian Monte-Carlo and Gibbs sampling) to the problem of robustly marginalizing over these uncertainties to recover unbiased constraints on cosmological parameters.

Skills: coding experience with python is recommended.

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

AS15 The properties of extended radio galaxies in the MIGHTEE survey

The newly-built MeerKAT telescope is the most powerful radio telescope in the Southern Hemisphere and it has recently started taking data for several large survey projects, one of which is the MIGHTEE survey. This will be the deepest radio survey to cover a significant area, and aims to help us understand how galaxies evolve with time. In some galaxies, matter is accreting onto the central super-massive black hole, causing an active galactic nuclei (AGN). Many of these AGN emit powerful jets which are very bright in radio observations, such as the MIGHTEE survey. These radio jets are thought to play a key role in the evolution of galaxies but are not fully understood.

In this project, the student will classify the radio morphologies of a sample of AGN detected in the MIGHTEE survey. Using multi-wavelength data from a range of other surveys, such at the VIDEO near-infrared survey, the student with then investigate the relationship between the morphologies of the radio galaxies and other galaxy properties. There will also be the opportunity to investigate galaxies with particularly interesting or weird morphologies in more detail. This project will use python so some experience with python or similar is an advantage but not essential.

Supervisors: ***Dr I Whittam*** and ***Prof M Jarvis***
Email: ***imogen.whittam@physics.ox.ac.uk***

AS16 Illuminating the interstellar medium towards relativistic jets with MeerKAT

Stellar X-ray binaries comprise a black hole or neutron star that is accreting material from a massive companion. The accretion discs in these systems are luminous in high energy X-rays and periodically form highly collimated relativistic outflows of plasma, which emit synchrotron radiation that can be best detected at radio wavelengths. These extreme stars allow us to study the astrophysics of mass accretion onto compact objects and jet formation, from which we may determine how seed black holes formed in the early Universe and the role of supermassive black holes in the growth and evolution of galaxies. At Oxford we are using the new MeerKAT radio telescope in South Africa to observe the relativistic jets from hundreds of X-ray binaries. MeerKAT is the most sensitive radio interferometer in the world, allowing us to make deep images of the radio sky in exquisite detail. In this project we will pioneer a technique that uses spectroscopic information from the telescope to detect absorption due to cold atomic hydrogen clouds that intercept our sight line. Since we know the distribution and kinematics of atomic hydrogen in the Galaxy, we will use this spectroscopic information to determine the distance to each X-ray binary. This will allow us to determine the physical properties of the compact star, including luminosity, temperature, accretion rate, mass and spin. We can also use this information to measure the temperature of the intervening hydrogen gas, allowing us to measure the distribution of cold, star-forming, interstellar medium throughout the galactic plane. During the project the student(s) will be expected to carry out analysis of the MeerKAT data, requiring some coding in Python or similar language, and careful theoretical interpretation. This is a unique opportunity to work with real astronomical data from a pathfinder telescope to the Square Kilometre Array.

Supervisor: ***Dr J Allison***
Email: ***james.allison@chch.ox.ac.uk***

AS17 The cool gas fuelling distant radio galaxies with MeerKAT

All galaxies are thought to contain a massive central black hole. During a brief and extreme period of activity, the matter accreting onto this black hole releases a huge amount of radiated

energy known as an active galactic nucleus (AGN). In some cases these AGN radiate across the entire electromagnetic spectrum and can outshine even the entire stellar light from the rest of the galaxy. However, the majority are not very bright at most wavelengths and are only detected by radio telescopes. Nonetheless, these radio galaxies can still release a huge amount of energy in the form of giant collimated jets of plasma, sufficient to drive gas out of the galaxy and prevent further star formation. At Oxford, we are using the MeerKAT radio telescope in South Africa to study the kinematics of cold gas in radio galaxies that are billions of light years away. MeerKAT is the most sensitive radio interferometer in the world, allowing us to make deep images of the radio sky in exquisite detail. The student will use data from this telescope to detect and model the absorption lines seen against the radio emission due to surrounding clouds of neutral gas. This approach allows both the abundance and kinematics of gas to be determined on sight-lines towards the radio source, establishing in individual active galaxies the existence of infalling clouds, feedback-driven outflows and circumnuclear discs. During the project the student(s) will be expected to carry out analysis of the MeerKAT data, requiring some coding in Python or similar language, and careful theoretical interpretation. This is a unique opportunity to work with real astronomical data from a pathfinder telescope to the Square Kilometre Array.

Supervisor: ***Dr J Allison***
Email: ***james.allison@chch.ox.ac.uk***

AS18 Uncovering active black holes in distant galaxies

The first 2 billion years after the Big Bang was characterised by the formation and evolution of the first galaxies, leading to a rapid increase in the total star-formation rate density in the Universe. Within these early galaxies there must be supermassive black holes, which can be pinpointed by their strong X-ray and radio emission and unusual optical/near-infrared spectra. Current data is not sufficient to detect these signatures on an individual galaxy level however, making it a challenge to know when and where the first active black holes made an impact on early galaxy formation.

The goal of this project is to uncover the weak signatures of active black holes in distant galaxies using stacking. In this project the student will stack multi-wavelength data from the X-ray to radio to identify which type of galaxies host active galactic nuclei. The project is computational and will involve writing code, manipulating large data files and working with astronomical images.

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

AS19 Galaxy interactions in dense environments

Until recently, the merger of two galaxies was thought to be one of the main processes driving galaxy evolution. However, many studies have shown that only 10% of galaxies will undergo a merger in their lifetime. This brings into question the assumed ubiquity of mergers in galaxy groups and clusters, thought to be responsible for the correlation between the increased fraction of elliptical galaxies and the density of a galaxy's environment. Instead, focus has turned to understanding how fly-bys and interactions between galaxies (causing tidal tails, stripping of gas and morphological disturbances) contribute to a galaxy's evolution.

In this project, the student will investigate how the fraction of disturbed galaxies changes with increasing group size observationally. This will require the student to become familiar with both the Galaxy Zoo morphological classification database and the methods used to identify groups and clusters of galaxies in large surveys. The student will become acquainted with large astronomical data sets and the physics behind galaxy interactions in dense environments. The project will require good analytical and programming skills (Python).

Supervisor: ***Dr B Smethurst***
Email:***rebecca.smethurst@chch.ox.ac.uk***

AS20 Measuring magnification by Large Scale Structure in the VIDEO dataset

Gravitational lensing denotes the process by which the path of light is bent by the presence of matter, leading to measurable distortions in observed galaxy properties such as shape, size and brightness. The measurement of large statistical samples of weakly lensed galaxies can therefore be used to investigate the matter distribution and geometry of the universe. "Magnification bias" describes the change in number density of distant background sources due to the change in observed flux and position of lensed galaxies. The measurement of this affect relies mainly on accurate photometry, and can therefore be used on faint or distant galaxies which cannot be used for a traditional shape measurement analysis, but requires tight control of the properties of the galaxy population used for such studies.

In this project, you will attempt to measure the magnification signal in the VIDEO dataset (http://www-astro.physics.ox.ac.uk/~video/public/Home.html). You will select a sample of source galaxies and lenses, investigate and remove confounding factors in the dataset, and apply statistical measures to measure properties of the large scale structure in the VIDEO field.

This project will require some coding, and will give you experience in research, manipulating astronomical data-sets, understanding the processes by which we measure galaxy properties from astronomical images, and applying statistical measures to extract a cosmological signal.

Supervisors: ***Dr C Duncan*** and ***Prof M Jarvis***
Email: ***christopher.duncan@physics.ox.ac.uk***;
Matt.Jarvis@physics.ox.ac.uk

AS21 Designing a frequency comb source for HARMONI line spread function calibration

HARMONI is the first light integral field spectrograph for the Extremely Large Telescope. Part of the instrument's calibration involves calibrating the "line spread function" (LSF) – the response of the instrument to a truly monochromatic source. The LSF is expected to vary considerably with position along the (pseudo) slit and with wavelength. Accurate knowledge of the LSF is required for correct subtraction of the (time variable) sky background at near-infrared wavelengths. To adequately measure the LSF shape, we need a tunable frequency comb that covers the entire wavelength range of the instrument, from 450 nm to 2400 nm. The project will look at different possible designs for a Fabry-Perot based frequency comb, and determine the optimal design that best fits the instrument requirements. There will be an experimental component using commercial fibre / plate etalons to verify the comb's operation.

Supervisor: ***Prof N Thatte***

Email: ***Niranjan.Thatte@physics.ox.ac.uk***

AS22 Exploring the late-time radio evolution of the chameleon supernova SN2014C

SN2014C is a radio-bright supernova (SN), that was observed to evolve from a stripped envelope Type Ib SN into a strongly interacting Type IIn SN within a year of explosion. For this reason, it has been dubbed a "Chameleon Supernova" [1]. Subsequent radio measurements obtained with the Arc-minute Microkelvin Imager (AMI) showed two distinct peaks in the radio light curve, indicating interactions with different densities of circumstellar material (CSM). The double-peak light curve is interpreted as different phases of mass-loss (see Anderson et al. 2017), whereby hydrogen is expelled in winds pre-explosion. By modelling the light curve, intrinsic parameters of the system such as mass-loss rate, shock velocities and CSM densities can be obtained, which are vital from probing the pre-SN environment of the source. AMI has continued to monitor SN2014C and it remains to be seen whether additional radio peaks are observed in the light curve. This project involves reducing and analysing the AMI data from the last 2.5 years and comparing it to the already published AMI data to look for additional CSM interactions and hence model the mass-loss rate in the progenitor star pre-explosion. The project will require data analysis, some modelling and coding, and is suitable for one person. Successful completion of this project may lead to a published research paper.

[1] https://www.inverse.com/article/26869-chameleon-supernova-sn-2014c-old-star-explosion-hydrogen?refresh=12

[2] Anderson, G.E., et al. 2017, MNRAS, Vol. 466, Issue 3, p.3648-3662

Supervisor: ***Dr D Williams***
Email: ***david.williams@physics.ox.ac.uk***
matt.jarvis@physics.ox.ac.uk

AS23 Detection of transiting exoplanets with the TESS space mission

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 planning to use for TESS data. The project will consist in analysing the live stream of TESS data to detect new planet candidates, and liaising with our collaborators to arrange spectroscopic follow-up observations. Depending on progress, the project may lead to publications in refereed journals, which the student will be an author on. We are also planning to set up an online interface to enable the wider public to participate in the planet discovery effort, via the Zooniverse platform (see www.planethunters.org for an example of such a project on Kepler data), and there will be an opportunity to interact with the public through this if the student is interested.

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 model individual planet candidates).

Supervisor: ***Prof S Aigrain***
Email: ***Suzanne.Aigrain@physics.ox.ac.uk***

AS24 V404 Cyg: powerful winds form a highly accreting nearby black-hole

V404 Cyg is a binary system formed by a black hole of about 10 solar masses, and a low mass companion star, very similar to the Sun. V404 Cyg was one of the first confirmed stellar mass black holes in our Galaxy, and it is among the closest black hole binaries (~2kpc).

In accreting black hole binary systems, the material stripped from the stellar companion forms an accretion disc around the black hole. Such disc becomes very hot especially in its central region, and shines bright in the X-rays.

Most black hole binaries are typically observed in a dormant state, during which the emission from the accretion disc is very faint. This state is interrupted from time to time by relatively brief "outbursts", during which the amount of matter coming from the companion star feeding the disc - the accretion rate - increases dramatically. As a consequence, the intensity of the radiation coming from the accretion disc rises by several orders of magnitude, and its properties change dramatically on short time-scales, from days down to seconds or less. During this phases, the source in outburst can easily become one of the brightest X-ray sources in the sky.

The first observed X-ray outburst of V404 Cyg started in 1989 and lasted a few weeks. Then, V404 Cyg went back to sleep for 26 years, until 2015, when it suddenly woke up to the surprise of the astronomical community, showing one of the most violent outbursts ever observed from a Galactic black hole binary. Beside very strong and frequent X-ray flares, V404 Cyg displayed the spectacular launch of different type of outflows, from collimated relativistic radio jets, to strong winds. Among these, we observed a peculiar type of outflow, a clumpy wind launched from the inner regions of the accretion disc, that has never been observed before around a stellar mass black hole, but is thought to be produced in certain highly accreting super-massive black holes in Active Galactic Nuclei.

In this project we will make use of a X-ray data collected during the 2015 outburst of V404 Cyg, still largely unexplored, to study how the properties of the clumpy winds change over time, and how the emission of the X-ray engine at the center of the accretion disc - the very hot material spiralling very close to the central black hole - is changed by the presence of this peculiar outflow. Modelling of these data will allows us to simultaneously probe the structure of the clumpy outflow, and the properties of the central X-ray source.

The project will require analysis of the available X-ray data (mainly energy spectra from the Swift X-ray satellite), theoretical interpretation, and some coding.

Supervisor: ***Dr S Motta***

Email: ***sara.motta@physics.ox.ac.uk***

AS25 Cygnus X-1: a relativistic black hole jet in a dense stellar wind

Cygnus X-1 is a binary system composed of a hot massive star of around 20 solar masses and a black hole of around 10 solar masses, in a 5.6-day orbit. Observations of this system persuaded Stephen Hawking that astrophysical black holes were real, as a result of which he conceded a 16-year bet with Kip Thorne and bought him a year's subscription to Penthouse. Matter lost in the wind from the massive star is partially accreted onto the black hole, forming a bright accretion disc visible in X-rays. A relativistic jet is simultaneously produced, revealed by its radio synchrotron emission, and carries away a large fraction of the available gravitational potential energy. Uniquely for such black hole binary systems, the radio-emitting part of the jet is partially embedded within the stellar wind of the companion star, resulting in quasi-sinusoidal modulation of the radio emission at the orbital period (as the line-of-sight absorption varies). In this project we will make use of an untapped and unique resource of 20+ years' of daily radio monitoring of Cygnus X-1 to study how the orbital modulation varies in shape and amplitude with epoch, luminosity and accretion 'state' of the X-ray source. Modelling of these data will allows us to simultaneously probe the structure of the jet and the stellar wind, as well as the connection of the jet to the accretion disc. The project will require some data analysis, theoretical interpretation and coding (most likely in python), and is suitable for one or two persons. Successful execution of the project should lead to a published research paper.

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

AS26 Shape twisting of galaxies and halos in the NewHorizon 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 also 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. In this project, the student will develop a series of measurements of intrinsic galaxy alignments in the NewHorizon simulation, a higher resolution zoom-in of Horizon-AGN cosmological hydrodynamical 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 ***Horizon simulation collaborators***

Email: ***elisa.chisari@physics.ox.ac.uk***

AS27 Vorticity orientation in the cosmic web: spin flip along filaments

The cosmic web is the distribution of matter at large scales: a vast network of walls surrounding voids, intersecting at filaments, which connect at nodes.

The angular momentum acquisition of haloes in walls and filaments is induced by the large-scale coherence of the flow vorticity, whose geometry and orientation is expected to be a function of the multiplicity of the shell-crossing.

As a matter of fact, the geometry of the vorticity has already been measured in filaments, while focusing on transverse cross-sections (Laigle et al. 2015). This study successfully explained the alignment of low-mass haloes with their filaments and the transition mass from alignment to mis-alignment. It nonetheless fell short explaining why the angular momentum of haloes and galaxies would flip in the azimuthal direction at high mass, a signal which has been reported in the previous years. Indeed, this study focused only on second shell crossing corresponding to the formation of filaments, and ignored subsequent shell crossings.

In this project, the student will rely on a state-of-the-art cosmological dark matter simulation to extend this study while focusing on measuring the longitudinal evolution (i.e along the filament as a function of the distance towards nodes) of the vorticity alignment and geometry, therefore also analysing regions which have shell-crossed more than twice. With this analysis, the student will be able to present a complete picture of halo alignment in the cosmic web, which is crucial both to understand galaxy formation and quantify intrinsic alignments, a potential source of systematics for lensing studies. Some programming skills are required.

Supervisor: ***Dr C Laigle***
Email: ***clotilde.laigle@physics.ox.ac.uk***

AS28 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. Unfortunately 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***
Email: ***fraser.clarke@physics.ox.ac.uk***

AS29 High-redshift disk formation

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

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

Good programming skills required.

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

AS30 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

Aprajita Verma (aprajitaverma1@gmail.com, https://www2.physics.ox.ac.uk/contacts/people/verma)

Supervisor: ***Dr A Verma***
Email: ***aprajita.verma@physics.ox.ac.uk***

AS31 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: ***mike.jones@physics.ox.ac.uk***

AS32 tbc

More details from the supervisor.

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

AS33 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 red-shifts, 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***

AS34 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***

AS35 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: ***mike.jones@physics.ox.ac.uk***

AS36 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: ***mike.jones@physics.ox.ac.uk***

AS37 Large-scale galaxy alignments in the cosmic web

Understanding how galaxies trace the underlying dark matter distribution in the Universe is a key issue in galaxy evolution and cosmology. In this project, the student will use a combination of the best optical and near-infrared data in order to determine the cosmic web in two extragalactic deep fields. With this information they can then determine how different galaxy populations observed across a range of wavelengths influence and/or are influenced by where they reside within this filamentary structure. For example: are radio jets powered by supermassive black holes aligned or misaligned with the filaments? Does the neutral hydrogen gas trace these filaments? Are galaxy orientations dependent on their position within the cosmic web? Answering these questions will help us to determine how galaxies are fuelled and also whether black-hole accretion provides enhanced feedback along the filamentary structures, addressing one of the most crucial outstanding questions in galaxy evolution.

Supervisors: ***Prof M Jarvis*** and ***Dr I Whittam***
Email: ***matt.jarvis@physics.ox.ac.uk***

AS38 Predicting the Interstellar Object Population

The recent passage through the Solar System of 'Oumuamua and Comet 2I/Borisov has created interest in interstellar objects (ISOs), many of which should be detected by the upcoming LSST survey by the Vera Rubin Observatory. This project uses simple models of ISO formation along with simulations of Milky Way analogue galaxies to predict features of the population of ISOs which will be detected. The properties of ISOs reflect the conditions of their birth, and so this is a rare chance to constrain models of our galaxy's history using (very) local observations. The project will involve working with data, as well as building simple models and code, and will build on existing background work to, for example, explore the impact of varying efficiency of ISO production on our observables. It would suit a student with skill in Python (or a desire to learn).

Supervisors: ***Prof C Lintott*** and ***Prof M Bannister*** (University of Canterbury)
Email: ***chris.lintott@physics.ox.ac.uk***

Biological Physics projects

BIO01 & BIO02 **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: use experimental or machine-learning approaches to study the diffusion of DNA-repair machines inside bacterial cells; establish smartphone-based single-particle imaging and optimize its sensitivity to detect pathogenic viruses and bacteria; apply machine-learning methods to study the structure and dynamics of particles of influenza and other viruses; apply theoretical models to describe diffusion and interactions of molecules inside living bacteria; develop biosensors that probe the physiology of bacterial cells through physical descriptions of the cell interior (a novel method that can detect whether certain antibiotics are 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 of biophysics is necessary; experience in optics and programming (Python and/or MATLAB) would be an advantage. Introductory literature, as well as the relevant risk assessments for the specific experiment, will be provided.

Supervisors***: Prof A Kapanidis*** and ***Dr N Robb***
Website: **kapanidis.web.ox.ac.uk; robb.web.ox.ac.uk**
Email***: achillefs.kapanidis@physics.ox.ac.uk; nicole.robb@physics.ox.ac.uk***

BIO03 **Back-scattering dark-field microscopy with mobile phones, for malaria detection**

The aim of the project is to develop a microscope built around a mobile phone camera for field detection of malaria.

Point-of-care diagnostics for malaria is currently best done by biochemical kits that cost on the order of $1 per test. This is limiting in many parts of the world where malaria is prevalent. The gold standard for malaria diagnostics is microscopic examination of blood samples, requiring relatively expensive microscopes and highly trained observers who can recognize infected blood cells.

Malarial parasites sequester heme from blood cells in the form of crystals of hemozoin. These are small and scatter light strongly in all directions, making them ideal for detection by the newly-developed method of back-scattering laser dark-field (BSDF) microscopy. Basically, laser light is scattered back in the direction from which it came much more by small (Rayleigh) scatterers than by larger objects. When back-scattered light is used to form an image of an infected blood sample the hemozoin crystals shine out brightly against the background of cells.

This project will involve building and testing prototype BSDF microscopes that can be scaled down to enable mobile phone camera lenses to replace expensive microscope objectives, mobile phone cameras to replace expensive microscope optics and cameras, and mobile phone apps to replace PC-based image processing algorithms for automatic recognition of malarial infection. Alternatively, the project could involve developing and testing algorithms for assessment of the presence and severity of infection.

There is potential for Vodaphone to become involved in this project.

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***

BIO04 **3D tracking of single fluorescent molecules for application in live bacteria**

The aim of the project is to develop a microscope for tracking single biomolecules in live cells in 3 dimensions.

Living cells are intricate collections of biological molecular machines. These range in size from thousands to millions of atomic mass units (Daltons, D), and are mobile to different degrees. The smaller ones are simpler, and have functions that include carrying information between the larger ones – usually by diffusing, binding and possessing at least two distinct states that can be recognized by the larger machines. For example, the protein CheY is a small (14 kD) molecule found in swimming bacteria with two functional states: with or without a phosphate group added to a particular site on its surface. CheY is converted to CheY-P depending on the output of large sensory complexes (100s of MD) at the cell surface, and carries that message to a rotary motor (~10 MD) that controls how bacteria swim: CheY-P binds to the motor and changes its rotation direction, CheY (no-P) doesn't.

Recent developments have allowed proteins like CheY to be purified from cells, labelled with small bright fluorescent dye molecules, and put back into cells by "electro-poration". The label then allows them to be tracked by fluorescence microscopy. However most existing methods track molecules only in 2 dimensions, while the tracks are 3-dimensional

This project will involve building and testing a microscope that can track single molecules in 3 dimensions. Initial tests of the optics and tracking algorithms will be performed on objects much slower-moving and brighter than single molecules. From this reference point the performance and limits of the system will be explored.

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***

BIO05 **Structural, functional and computational studies of ion channels**

The projects involve determining the relationship between the structure and function of ion channels found in the membranes of living cells. Ion channels regulate the 'bio-electricity' that control all forms of cellular electrical excitability. As a result they control or influence almost every process in the human body from the way our nerves and brain work, to the way our heart and kidneys function. We principally study K+ ion channels using a combination of techniques that includes electrophysiological recording of channel activity (including kinetic analysis of single channel behaviour), computational studies of channel structure and ion permeation (molecular dynamics simulations), plus various molecular biology and protein biochemistry approaches. There are options to suit almost every taste (https://biophysics.physics.ox.ac.uk/tucker/)

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

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

BIO06 & BIO07 **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***

BIO08 ***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***

BIO09 **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***

Condensed Matter Physics projects

CMP01 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:

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

CMP02 Novel flux-tuneable qubits in superconducting quantum circuits

In superconducting circuits a powerful resource is the potential to build circuit elements that are tuneable by magnetic field using a component called a SQUID. This can enable components such as qubits with tuneable properties or qubit-qubit couplers that can be turned on and off at will. We have recently developed (partly through previous MPhys projects) a highly coherent flux-tunable superconducting qubit with a well localised magnetic field control. In this project you will explore the coherence, control and coupling to other qubits of such flux-tunable designs. This will include the design and testing of the circuits themselves, the engineering of their control with fast magnetic fields, and measurements of their quantum coherence and capability to support fast quantum logic gates. The project will involve any of: circuit design, electromagnetic simulation, hands-on soldering and component assembly, 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.

Supervisors: ***Dr B Vlastakis*** and ***Prof P J Leek***
Email: ***brian.vlastakis@physics.ox.ac.uk***,
peter.leek@physics.ox.ac.uk

CMP03 Doping of Semi-Transparent Conductive Single-Walled Carbon Nanotube:Polymer Films

Making better flexible transparent or semi-transparent conductive films is crucial for future technologies like foldable or head-up displays, which offer exciting possibilities. Recently, carbon nanotube:polymer films using the polymer ethylene-vinyl acetate (EVA) have been shown to be a promising candidate for such applications [1]. Wrapping single-walled carbon nanotubes (SWNTs) with polymers, for whose development Oxford researchers played a key role, is by now a common technique to enable solubilisation of SWNTs in organic solvents. This is the foundation for further facile processing of SWNTs into thin films whilst simultaneously allowing to employ the outstanding physical properties of carbon nanotubes.

Electronic properties of semiconductors are in general tunable by doping. For SWNTs in particular doping with nitric acid and chloroauric acid has been shown to lead to a manifold decrease in sheet resistance in corresponding thin films [2,3].

In this project the student will investigate the effects of doping on SWNT:polymer transparent conductive films in more detail. The work will involve preparing the nanotube:polymer solution, depositing films by spin- or spray-coating and various optical and electrical experimental characterisation techniques to better understand the doping of our SWNT:EVA composite films and to reach new record values in their sheet resistance. If you would like to discuss project details, feel free to contact us:

[1] G. Mazzotta et al., ACS Appl. Mater. Interfaces 2019, 11, 1185−1191.

[2] A. Znidarsic et al., J. Phys. Chem. C 2013,117,25,13324-13330.

[3] A. Tsapenko et al., J. Phys. Chem. Lett 2019, 10, 14, 3961-3965.

Supervisors: ***Dr M Riede*** and ***Prof R Nicholas***
Email : ***moritz.riede@physics.ox.ac.uk;***
robin.nicholas@physics.ox.ac.uk

CMP04 Improving quantum logic gates in superconducting quantum circuits

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 with promising quantum coherence and scaling potential. An important current topic in the field is to understand the long-term stability of qubit properties such as their transition energies, energy relaxation and coherence times, which are found to fluctuate in time, leading to difficulty in using them for the exquisitely fragile process of quantum computation. In this project you will explore this topic by measuring and analysing the statistical correlations of these qubit properties, both between each other (e.g. correlations between coherence of different qubits) and also with environmental parameters such as the temperatures of key components in the measurement setup. Success in this project could lead to crucial improvements in performance of quantum logic gates. The project will likely mostly involve computer programming, measurements, data analysis, numerical simulation and understanding of related physics, but may also involve more hands-on lab work. 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: ***Prof P J Leek***
Email: ***peter.leek@physics.ox.ac.uk***

CMP05 **High-fidelity multiplexed readout of qubits in circuit QED**

One of the key requirements for operation of a quantum computer is to be able to carry out high fidelity (trustworthy) measurements of the states of the qubits at the end of quantum algorithms, or during, to enable reliable error correction. In superconducting circuits, this is commonly achieved by coupling LC resonators to qubits and observing how their frequencies shift as the qubit state changes. In recent MPhys projects on this topic, we have shown that we can improve this readout by optimising signal filtering and making use of the higher excited qubit states. In this project you will experimentally investigate methods to extend the readout to operate on multiple qubits simultaneously using signal 'multiplexing' via specially designed filters. Successfully achieving this will be very important for scaling our circuits up for quantum computing. The project will likely involve circuit design and simulation, computer programming, measurements, data analysis, and understanding of related physics, but may also involve more hands-on lab work. 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: ***Prof P J Leek***
Email: ***peter.leek@physics.ox.ac.uk***

CMP06 **Decoding the science of ultimate performance in perovskite solar cells: the beauty of interfacial engineering**

Following an unprecedented rise in power conversion efficiencies within the past few years, metal halide perovskites (MHPs) have surged as a new class of photovoltaic materials and hold great promise to revolutionise the solar industry in the next decade. However, many studies have suggested severe non-radiative recombination that exists at the imperfect interfaces between perovskite light absorbers and charge collection layers could hinder photo-carrier collection, hence limiting the ultimate photovoltaic performance using MHPs in solar energy harvesting applications. Taking these basic understanding forward, it seems natural to ask whether the photo-carriers dissociated within MHPs could be effectively collected through engineering preferential interface properties. This question provides the springboard for this project.

The specific approach that will be used here is to integrate various types of polymer electrets (i.e. dielectric polymers) in-between charge-collection layers and perovskite light absorbers. This work demands good experimental (solar cell fabrication) and electrical-characterisation (J-V measurement) skills. The main activities include that 1) understanding how the dipole-induced built-in electric-fields in polymeric materials could reduce non-radiative recombination losses; and 2) implementing selected polymer electrets into MHP cell structures, hence decoding what limits the ultimate cell performance both theoretically and experimentally.

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

CMP07 **"There's Plenty of Room at the Bottom" – Nanostructure-assembly towards high-performance perovskite solar cells**

Commenting on the possibility of directly manipulating individual atoms, more than half a century ago Nobel laureate Richard Feynman gave a lecture in Caltech, called "There's Plenty of Room at the Bottom". The idea conveyed in this lecture is believed to be the very first conceptual origin in the field of nanotechnology. In fact, the ability to control each individual photo-induced carrier in nanoscale/molecular-scale is particularly important for the applications of metal-halide perovskites (MHPs) in photovoltaics. This is because the non-radiative recombination loss that takes place at the interfaces between MHP and charge-collection layers plays a major role that limits perovskite solar cells (PSCs) from reaching their theoretical efficiency.

In this project, we will carry out our research in a nano-world. The specific approach will be used is to integrate various types of organic molecules into charge-collection layers through the means of nano-assembly. This project demands good experimental (solar cell fabrication) and electrical-characterisation (J-V measurement) skills. The main activities are to identify potential organic nanostructures that can facilitate charge transport as well as to design the processing routes to nano-assembling feasible organic molecules into PSCs, hence unlocking PSC's theoretical performance.

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

CMP08 **Developing a pulsed electron spin resonance spectrometer with arbitrary pulse shaping capability**

Pulsed electron spin resonance (pESR) is a technique for manipulating quantum spins coherently with microwave pulses and has versatile applications in physics, chemistry, biology and quantum information. Conventional pESR experiments are conducted by simply switching the microwave signal between on and off to form square excitation pulses. In recent years, the development of high-frequency arbitrary waveform generators (AWG) has introduced the possibility of engineering pulse shapes (including amplitude and frequency) to gain much greater control over the spins.

In this project, the student will design and build a pESR spectrometer with AWG pulse shaping options that will match (and potentially exceed) the performance of the state-of-the-art commercial pESR spectrometers. This involves programming the AWG to generate required waveforms and use them to modulate high frequency (~ 10 GHz) microwave signals. The student will also perform pESR experiments with molecular nanomagnets to test the performance the spectrometer. The project demands good programming skills (in Python) and basic microwave electrical engineering knowledge.

Supervisors***: Dr J Liu*** and ***Prof A Ardavan***
Email***: junjie.liu@physics.ox.ac.uk***

CMP09 Quantum oscillations probing the Fermi surface of iron-based superconductors

Quantum oscillations is a well-established and powerful technique for the experimental characterisation of the Fermi surface at low temperatures. Due to the Landau quantisation of electronic states in an applied magnetic field, oscillations of various physical properties, periodic in inverse magnetic field, are observed. The frequency of oscillations relates directly to extremal areas of the Fermi surface, and the temperature-dependence of the amplitude of oscillations reveals the orbitally-averaged quasiparticle masses. The quasiparticle masses compared with band structure mass quantify the extend of electronic correlations inside different superconducting materials and they provide clue on how to enhance superconductivity.

This is a computational project that aims to establish the Fermi surface of novel superconducting materials using high magnetic fields and low temperatures. A suitable candidate should have a strong background in condensed matter physics and advanced computational skills (Matlab, Python) as well as interest to pursue further research in condensed matter physics. The student will compare existing experimental data with band structure calculations using Wien2k and make proposals of Fermi surface to describe the experimental data and estimate relevant parameters. For further questions please email amalia.coldea@physics.ox.ac.uk.

Further reading:

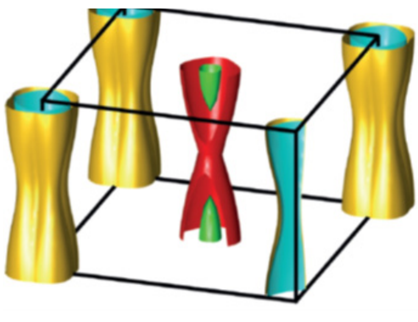
The key ingredients of the electronic structure of FeSe
Amalia I. Coldea, Matthew D. Watson
Annual Review of Condensed Matter Physics, Vol 9 (2018)
https://arxiv.org/abs/1706.00338

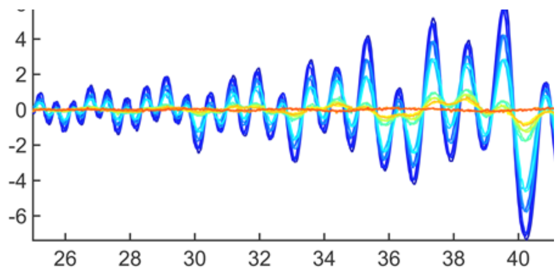
Quantum oscillations probe the Fermi surface topology of the nodal-line semimetal CaAgAs
Y. H. Kwan, P. Reiss, Y. Han, M. Bristow, D. Prabhakaran, D. Graf, A. McCollam, S. A. Parameswaran, A. I. Coldea
https://arxiv.org/abs/2001.02434

Linear magnetoresistance caused by mobility fluctuations in the n-doped Cd3As2
Phys. Rev. Lett. 114, 117201 (2015
https://arxiv.org/abs/1412.4105

Quantum oscillation studies of the Fermi surface of iron-pnictide superconductors, Reports on Progress in Physics, 74 124507, 2011, http://iopscience.iop.org/article/10.1088/0034-4885/74/12/124507

Wien2k; http://susi.theochem.tuwien.ac.at/





Fermi surface of an iron-based superconductor and an example of quantum oscillations in magnetic fields up to 45T and temperatures below 1.5K.

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

CMP10 Enhancing superconductivity by applied pressure in iron-based superconductors

Applied hydrostatic pressure is an important tuning parameter that can induce and significantly enhance superconductivity as well as it can change the size of the unit cell, the electronic bandwidth as well as the strength of electronic interactions. FeSe is a unique high temperature superconductor in a monolayer form close to 100K. On the other hand, pressure applied to single crystals of FeSe strongly enhances its superconductivity from 9K towards 40K.

This is an experimental project to perform pressure experiments under pressure using either transport or tunnel diode oscillator technique to probe the skin depth and penetration depth of novel materials. Tunnel diode oscillator based-technique is known to be sensitive to the London magnetic penetration depth in superconducting materials and can probe the transition temperature and the upper critical field. These experiments will be performed on high quality single crystals of FeSe-based superconductors and the superconducting phase diagrams under pressure will be constructed.

A suitable candidate should have a strong background in condensed matter physics and basic knowledge of electronics. Computational skills, such as using Matlab and Python would be useful and candidates are encouraged to consider PhD projects in condensed matter physics. To apply for this project please send your CV and a cover letter to justify your interest in the proposed topic to amalia.coldea@physics.ox.ac.uk.

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

For further reading consult:

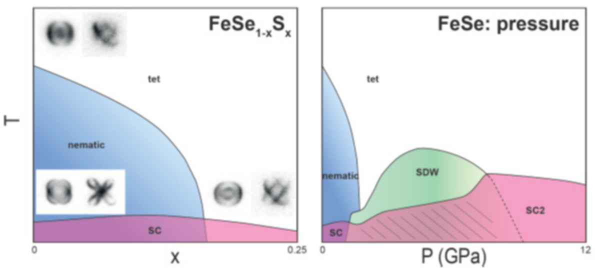
The key ingredients of the electronic structure of FeSe
Amalia I. Coldea, Matthew D. Watson
Annual Review of Condensed Matter Physics, Vol 9 (20180
https://arxiv.org/abs/1706.00338

Quenched nematic criticality separating two superconducting domes in an iron-based superconductor under pressure
P. Reiss, D. Graf, A. A. Haghighirad, W. Knafo, L. Drigo, M. Bristow, A. J. Schofield, A. I. Coldea, Nature Physics (2019); https://arxiv.org/abs/1902.11276; https://www.nature.com/articles/s41567-019-0694-2

Maximizing T c by tuning nematicity and magnetism in

$FeSe_{1-x}S_x$ superconductors,
K. Matsuura, Y. Mizukami, Y. Arai, Y. Sugimura, N. Maejima, A. Machida, T. Watanuki,
https://arxiv.org/abs/1704.02057

https://www.nature.com/articles/s41467-017-01277-x



Phase diagrams of FeSe tuned by chemical (using chemical substitution) and applied hydrostatic pressure. The components of a pressure cell are shown on the right.

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

CMP11 Exploring the electronic structure and superconductivity of iron-based superconductors under external strain

The iron-based superconductors 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 towards 100K.

This project will investigate the response of iron-based superconductors to applied external strain. These materials display many electronic processes that occur simultaneously, which can be difficult to disentangle when looking at the unstressed system alone. One can gain much more information by understanding how elastic lattice distortion, applied through hydrostatic, biaxial, or uniaxial stress, affects the electronic properties of a material. For example, lattice strain may be used to suppress an electronic instability, or to enhance one or more of the processes in the material. Iron-based compounds display electronic nematicity, a form of electronic order which breaks rotational but not translational symmetries that may play an important role in high-temperature superconductivity. Uniaxial stress can be used to increase nematic polarisation in a material, by adding to the orthorhombic lattice distortion associated with nematic order.

This project is an experimental study focused on understanding the electrical resistivity and superconductivity under applied strain in iron-based superconductors. The experiment will consist in applying strain to superconducting FeSe. A suitable candidate for this experimental project should have good knowledge of condensed matter courses, attention to detail and good experimental skills. A suitable candidate will perform experiments as function of strain, temperature and magnetic field. Good computational skills, such as Matlab and Python would be valuable for the project.

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

Further reading:

The key ingredients of the electronic structure of FeSe https://arxiv.org/pdf/1706.00338v1.pdf

Emergence of the nematic electronic state in FeSe, https://arxiv.org/abs/1502.02917

Strong Peak in Tc of Sr2RuO4 Under Uniaxial Pressure-https://arxiv.org/ftp/arxiv/papers/1604/1604.06669.pdf

Quantum oscillation studies of the Fermi surface of iron-pnictide superconductors, http://iopscience.iop.org/article/10.1088/0034-4885/74/12/124507

Transport properties of FeSe epitaxial thin films under in-plane strain https://iopscience.iop.org/article/10.1088/1742-6596/1054/1/012023

Divergent Nematic Susceptibility in an Iron Arsenide Superconductor Science, Vol. 337, no. 6095 pp. 710 (2012), https://arxiv.org/abs/1203.3239

Measurement of the B1g and B2g components of the elastoresistivity tensor for tetragonal materials via transverse resistivity configurations, Rev. Sci. Instrum. 87, 063902 (2016), https://arxiv.org/abs/1603.03537

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

CMP12 Modelling vortex dynamics inside novel superconductors in magnetic fields

This project aims to understand the complex vortex dynamics inside two-dimensional superconductors in the presence of different defects and impurities. This is crucial for the implementation of high-temperature superconductors in applications as the vortex pinning on defects help to maintain very large critical currents. Simulations will rely on time-dependent Ginzburg Landau theory, which is already implemented in the commercial software package COMSOL Multiphysics. In this project, simulations of vortex lattice and relevant superconducting parameters will be perform using realistic parameters in order to understand the presence of large critical currents in novel iron-based superconductors. This project will be performed in the new Oxford Centre for Applied Superconductivity (CfAS).

A suitable candidate should have a strong background in condensed matter physics and strong computational skills, such as COMSOL, Matlab or Python. For further queries contact amalia.coldea@physics.ox.ac.uk.

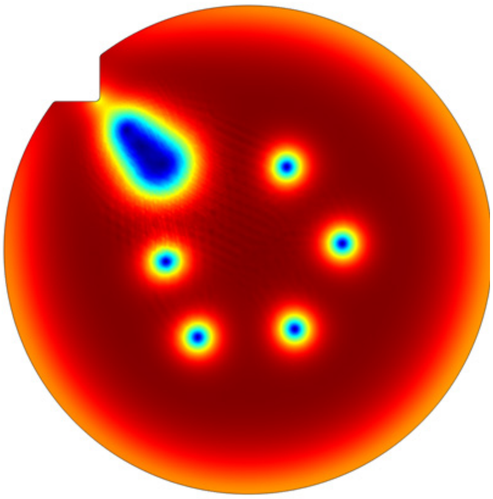
For further reading see:

1. COMSOL Multiphysics https://www.comsol.com/comsol-multiphysics

2. https://www.comsol.com/blogs/modeling-superconductivity-ybco-wire/

3. Time-Dependent Ginzburg — Landau Simulations of the Critical Current in Superconducting Films and Junctions in Magnetic Fields

4. See also the video of simulations on http://www.cfas.ox.ac.uk/discover



Simulation of the vortex state formation in the presence of an external magnetic field for a type II superconductor.

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

CMP13 Instrument control using Python to control sample rotation in magnetic fields

An electronic nematic ordered state can occur in a strongly interacting electronic system in which a Fermi surface undergoes a spontaneous distortion to a shape with lower symmetry compared to the underlying crystal lattice. The observation of electronic nematic order in different families of high-temperature superconductors suggests that the same interactions may be involved in stabilizing both the nematic and superconducting states. Establishing the phase boundaries of nematic and other anisotropic phase transitions require complete experimental investigation along different crystallographic axes, beyond the single-axis rotation currently available. A full angular dependence is necessary for complete understanding competing electronic phases of correlated matter and superconductivity.

We have recently acquired Attocube rotators made from Titanium and CuBe which allow rotation of very small samples at low temperature and high magnetic fields. Two rotators can be coupled together to allow physical properties measurements as a function of orientation in magnetic field. A positioning controller permits the integration of different stepping module to finely control each rotator separately.

We are looking for an enthusiastic student with good computational and electronics skills to implement this rotator in an existing Python software that control most of our low temperature experiments. This project will be performed in the new Oxford Centre for Applied Superconductivity (CfAS). The aim is to control accurately sample position in magnetic field using two-axis rotator and calibrate the instruments for different temperatures and magnetic fields. A suitable candidate should have strong computational and electronics skills. For further details contact amalia.coldea@physics.ox.ac.uk.

For further reading please visit

https://www.attocube.com/en and https://www.python.org/

Different components of the Attocube system which enables sample rotation in magnetic fields and at low temperatures.

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

CMP14 Dipolar fields at muon sites in randomized structures.

Muons implanted into materials can be used to measure local microscopic fields [1]. This gives information about the field distributions inside the crystal structure [2]. This theoretical and computational project will investigate the effect of the random insertion of different atoms into a crystal structure and the effect that this will have on the muon response. Programs will be written using the Python computer language.

Background reading:

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

[2] S. J. Blundell, Physica B 404, 581 (2009).

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

CMP15 Stray field distributions, spin ice, and demagnetization.

When a magnetic field is applied to any material, a stray field is invariably produced. This arises because of demagnetization and is a function of sample shape [1,2]. Stray fields can be particularly significant in a material known as spin ice [3] which exhibits magnetic frustration and has excitations which can be described as magnetic monopoles. These stray fields can be used to understand the properties of spin ice and to study the fluctuations that arise in spin ice [4,5]. Calculations will be developed to understand the stray field in spin ice. Programs will be written using the Python computer language.

Background reading:

[1] J. A. Osborn, Phys. Rev. 67, 351 (1945).

[2] M. Beleggia, M. De Graef, J. Magn. Magn. Mater. 263, L1 (2003).

[3] S. J. Blundell, Phys. Rev. Lett. 108, 147601 (2012).

[4] F. K. K. Kirschner, F. Flicker, A. Yacoby, N. Y. Yao, and S. J. Blundell, Phys. Rev. B 97, 140402(R) (2018).

[5] R. Dusad, F. K. K. Kirschner, J. C. Hoke, B. R. Roberts, A. Eyal, F. Flicker, G. M. Luke, S. J. Blundell, J. C. S. Davis, Nature 571, 234 (2019).

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

CMP16 **Predictive calculations of band effective masses from hybrid density functional theory**

The development of computational methods that are capable to predict electronic structure properties of semiconductors and insulators with high accuracy is a key priority area for computational materials modeling. Among properties of interest, charge carrier effective masses are fundamental materials parameters for assessing the applicability of semiconductors and insulator in optoelectronic devices. Hybrid density functional theory, and in particular the novel approach based on optimally tuned range separated hybrid functionals [1], is a promising methodology for calculating predictive electronic band structures at a much lower computational cost than state-of- the-art many-body perturbation theory methods.

In this project we will aim to critically assess the performance of range separated hybrid functionals for predicting the band curvature of conventional III-V semiconductors and insulators. In particular, we will focus on calculating electron and hole effective masses, by optimally tuning hybrid functional parameters in such a way that computed band gaps are in agreement with experiment.

As part of this MPhys project the student will have the opportunity to calculate the electronic band structure of standard III-V semiconductors, using state-of-the art first principles computational materials modeling techniques, within hybrid DFT. The student will use the Quantum Espresso DFT package [2] and the Wannier90 code [3] to obtain their data, with the help of high performance computers. A good command of Solid State Physics and Quantum Mechanics, as well as some basic coding or scripting skills would be desirable for undertaking this project.

[1] Kronik & Kummel, Adv. Mater, 30,1706560 (2018).

[2] Gianozzi et al, J.Phys.: Condens.Matter 29, 465901 (2017).

[3] Pizzi et al, J. Phys. Cond. Matt. 32, 165902 (2020).

Supervisor***: Dr M Filip***
Email***: marina.filip@physics.ox.ac.uk***

CMP17 From 3D to Q2D: Understanding Electronic Structure of Quasi-2D Halide Perovskites

Organic-inorganic quasi-2D hybrid halide perovskites are a family of materials that has gained increasing interest for applications in optoelectronics, due to a great breadth of chemical variety, robust stability and tunability of optoelectronic properties [1]. However, unlike the closely related 3D metal halide perovskites, the structural chemical complexity of this family of semiconductors, the underlying fundamental optoelectronic properties of Q2D perovskites are not yet understood.

In this project, we will aim to study the electronic structure Q2D perovskites starting from model systems derived from their 3D counterparts, using a combination of first principles density functional theory (DFT) calculations and tight binding modeling.

As part of this MPhys project the student will have the opportunity to apply their basic Solid State Physics knowledge to understand electronic properties of state-of-the-art optoelectronic materials. The student will learn the basics of DFT, learn how to calculate electronic band structures using the Quantum Espresso DFT package [2] and high performance computers and learn how to interpret computational modeling data with the help of standard tight binding models. A good command of Solid State Physics and Quantum Mechanics, as well as some basic coding or scripting skills would be desirable for undertaking this project.

[1] Smith, Crace, Jaffe & Karunadasa, Annu. Rev. Mater. Res. 48, 111-136 (2018).

[2] Gianozzi et al, J.Phys.: Condens.Matter 29, 465901 (2017) .

Supervisor***: Dr M Filip***
Email***: marina.filip@physics.ox.ac.uk***

CMP17 **Skyrmion Gas Manipulation and Computing**

In recent years, topologically nontrivial spin-textures known as magnetic skyrmions have been the subject of enormous interest in the physical sciences. Magnetic skyrmions can be driven by ultra-low current densities and controlled by magnetic field gradients, making them attractive as energy efficient next-generation information carriers [1]. Their topological protection against superparamagnetism makes them promising candidates for scaled-down magnetic random-access memory, while their rich dynamics have led to proposed implementations of skyrmion based logic gates, reshufflers and reservoir computers.

Typically one models the dynamics of a skyrmion hosting system using the theory of micromagnetism -- while this technique is very accurate, its computational complexity renders it inadequate to study the behaviour of large systems. The approach pioneered by Thiele to model the motion of magnetic domain walls has recently been extended to describe skyrmions, allowing macroscopic skyrmion systems to be efficiently modelled using molecular dynamics [2, 3].

This project will involve the student using and further developing code to study, benchmark and explore skyrmionic devices on length-scales and in geometries which were previously computationally inaccessible. The student should be familiar with C++ and have a strong interest in programming.

References

[1] S. L. Zhang et al. Manipulation of skyrmion motion by magnetic field gradients. Nat. Commun, 9:2115, 2018.

[2] S. Z. Lin et al. Particle model for skyrmions in metallic chiral magnets: Dynamics, pinning and creep. Phys. Rev. B, 87:214419, 2013.

[3] R. Brearton et al. Magnetic skyrmion interactions in the micromagnetic framework. arXiv preprint arXiv:2001.07193, 2020.

Supervisors***: Prof T Hesjedal*** and ***Dr R Brearton***
Email***: thorsten.hesjedal@physics.ox.ac.uk***

CMP18 Construction of a Vibrating Sample Magnetometer

Magnetometry is key for the detailed study of any kind of magnetic material. An ideal magnetometer should allow for variable temperatures down to <4.2 K, a large magnetic field of up to 7 T, and ultrahigh sensitivity. These so-called (superconducting quantum interference device) SQUID systems are commercially available and common to most physics departments. Nevertheless, for most samples, there is no need for the SQUID's high sensitivity or field and temperature characteristics. Instead, a simpler and less sensitive magnetometer, which can be much more accessible, allows for higher throughput and accelerated materials discovery.

A vibrating sample magnetometer, or VSM, is such a simple system that relies on the sinusoidal movement of the magnetic sample in a magnetic field, which induced a magnetic flux in a pickup coil [1,2]. The magnetic moment of the sample is proportional to the induced voltage in the coil. To enhance the sensitivity, phase-sensitive detection (lock-in amplification) is used.

The goal of the project is to design and build a room-temperature vibrating sample magnetometer with a low-temperature (liquid nitrogen) option, and to improve its resolution [3]. The project is hands-on and requires CAD design, mechanical workshop training, electronics development [4], programming, and last but not least, the characterization of a state-of-the-art magnetic heterostructure, which will be grown in-house.

Reading list:

1. S. R. Hoon, An inexpensive, sensitive vibrating sample magnetometer, Eur. J. Phys. 4, 61 (1983); https://doi.org/10.1088/0143-0807/4/2/001

2. V. Lopez-Dominguez et al., A simple vibrating sample magnetometer for macroscopic samples, Rev. Sci. Instrum. 89, 034707 (2018); https://doi.org/10.1063/1.5017708

3. P. J. Flanders, An alternating-gradient magnetometer, J. Appl. Phys. 63, 3940 (1988); https://doi.org/10.1063/1.340582

4. http://www.arduino.cc/

Special skills required:

For this project, a real passion for hands-on construction and experimental work is needed. Further, as power supplies, field and temperature sensors need to be interfaced with the open-source electronics prototyping platform Arduino, solid computer, programming and electronics skills are required.

Supervisor***: Prof T Hesjedal***
Email***: thorsten.hesjedal@physics.ox.ac.uk***

CMP19 & CMP20 Multi-Million Atom Molecular Dynamics Simulations of Matter under Planetary Core Conditions

Recent advances in high power optical and x-ray laser technology allow us to compress solid-state matter to pressures comparable to those within planetary cores, and to study the material via femtosecond X-ray diffraction However, we can only keep matter under these conditions for a few nanoseconds. We simulate the results of these experiments with molecular dynamics (MD) - knowing an empirical form for the potential between atoms we can track the structure and temperature of the matter as it is compressed, and as it rarefies upon release. Whilst these simulations have been highly successful, there are several outstanding pieces of basic physics that remain poorly understood, and which could be successfully addressed during the course of an MPhys project. These include developing a better understanding of the physics of the huge number of defects (dislocations) that get generated in our crystals as we compress them to millions of atmospheres within a few nanoseconds, and issues such as the 'thermoelastic anomaly', which is a poorly-understood discrepancy in how a sample cools when the pressure is finally released. In this project the student will undertake multi-million atom MD simulations to address the issues mentioned above. Whilst a detailed knowledge of coding is not strictly required, a good familiarity with C/C++ would be advantageous.

Reading

Wehrenberg et al, Nature 550, 496 (2017)

Sliwa et al, Phys. Rev. Lett. 120, 265502 (2018)

Heighway et al, Phys. Rev. Lett. 123, 245501 (2019)

Supervisors: ***Prof J Wark and Dr P Heighway***
Email: ***Justin.Wark@physics.ox.ac.uk*** and ***patrick.heighway@st-hughs.ox.ac.uk***

CMP21 Microphotoluminescence measurements of semiconductor nanostructures

The project involves using cryogenic microphotoluminescence techniques to investigate the opto-electronic properties and dynamics of carriers in semiconductors by mapping the emission using a laser-based microscope capable of sub-micron spatial resolution and sensitive enough to detect single photons. Both time-integrated and time-resolved measurements will be undertaken.

Supervisor***: Prof R Taylor***
Email***: Robert.Taylor@physics.ox.ac.uk***

CMP22 PL and EL imaging of perovskites solar cells

Photoluminescence (PL) and electroluminescence (EL) are commonly used to characterise the quality of perovskite materials used in optoelectronics devices. However, the spatial homogeneity as well as transient responses to an applied voltage are currently little known. Therefore we intend to use PL and EL imaging to optimise our fabrication processes and our understanding of the operation of such devices.

The objective of the project is to build an imaging set-up and use this tool to characterise perovskites solar cells and light-emitting diodes. It involves a little bit of programming to build a user interface (e.g. LabVIEW) and the student will learn the complete fabrication process of the perovskites devices to be investigated.

Supervisors: ***Dr B Wenger*** and ***Prof H Snaith***
Email: ***bernard.wenger@physics.ox.ac.uk***;
henry.snaith@physics.ox.ac.uk

CMP23 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***

CMP24 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***

CMP24 Simulation of spin dynamics for Dirac and Weyl magnons

This is a combined theory/computational project to simulate/visualize the spin oscillations in interacting spin systems, as part of the broader research effort in the quantum magnetism group to explore experimentally using inelastic neutron scattering the spin dynamics of magnets with strong spin-orbit coupling. Of particular interest are magnetic materials that can support linear touching points between spin-wave bands, analogous to the electron band touchings in a single honeycomb layer of carbon atoms (graphene) where electrons behave like Dirac particles with a relativistic dispersion (linear in momentum) near the touching points. We are interested in magnetic analogues of such physics, where dispersive bands of collective spin oscillations (spin waves) can display touching points, leading to Dirac (in two dimensions) and Weyl magnons (in three dimensions) [1]. The aim of the project is to develop computer code to simulate/visualize how the spins oscillate near the band-touching points, and understand the effects of spin-orbit coupling and externally applied magnetic fields, which can shift the bands and in certain circumstances open gaps. The project will require theoretical derivations of „normal modes" of spin oscillations and coding to create movies of the time-evolution of the spins. Support can be offered for coding in matlab. The project will benefit from existing numerical code to determine the eigevector of normal spin-wave modes for a multi-sublattice system.

[1] S.A. Owerre, Journal of Physics: Condensed Matter 28, 386001 (2016). https://iopscience.iop.org/article/10.1088/0953-8984/28/38/386001/meta

This project would require the ability to learn independently from books and papers and a very keen interest and experience in programming (suitable for 1 student taking the C6 Theory or C3 CMP option).

Supervisor: ***Prof R Coldea***
Email: ***radu.coldea@physics.ox.ac.uk***

Industrial projects

IND001 tbc

The task is either using machine learning to interpret measured Raman spectra, or setting up a SORS (Spatially Offset Raman) Spectrometer.

Industrial Supervisor: ***Dr C Muldoon*** (VeriVin)
Oxford Supervisor: ***Prof A Kuhn***
Email: ***axel.kuhn@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***

NT03 & INT04 **Very-high-energy gamma-ray astrophysics with the Cherenkov Telescope Array**

Very high-energy gamma-ray astrophysics is an exciting field spanning high-energy particle physics and extreme processes in astronomy. Our investigations range from the nature and variety of particle acceleration around supernovae and black holes, to physics beyond the Standard Model including dark matter, axion-like particles and Lorentz invariance violation.

The group in Oxford works on both experiment and theory. We are members of the High Energy Stereoscopic System (H.E.S.S.) in Namibia, presently the world's largest gamma-ray observatory, and the next-generation gamma-ray observatory, the Cherenkov Telescope Array (CTA). CTA will consist of up to one hundred telescopes using state-of-the-art 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. The telescope prototypes are under construction, and deployment to the observatory sites at Paranal, Chile, and La Palma, Canary Islands, will commence in 2020.

M.Phys. students will have an opportunity to choose their project from a variety of our activities. On the experimental side of the prgramme, we are leading efforts to develop advanced analysis techniques for the large volumes of data that will be generated when CTA becomes operational, including co-ordination of the CTA Machine Learning Task Force. On the theoretical/observational side, we have recently developed a new class of models for the broad-spectrum emission from relativistic jets in active galaxies, which let us use the gamma-ray 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 the entrainment of heavy particles as the jets propagate through their host galaxy, the resulting possibility of hadronic particle processes within the jets, and propagation effects in intergalactic space that may provide evidence for axion-like particles or Lorentz invariance violation.

These projects are particularly suited to students who are taking astrophysics or particle physics major options.

For more information please contact Professor Garret Cotter.

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

INT05 **Design and build an electronic circuit of your choice**

More information from the supervisor.

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

INT06 **Nuclear Spin Pumping in a metallic Ferromagnet**

It has been known for many decades that if a paramagnetic metal is microwave irradiated at the Larmor frequency of the conduction electrons, the nuclear spins become polarised. The process involves two steps: firstly the microwave irradiation produces what is known in modern parlance as a spin accumulation - i.e. a difference in electrochemical potential for the two spin channels; then the nuclear polarisation occurs via the hyperfine interaction AI.J which contains a term in I+J-. The latter causes nuclear spin polarisation by virtue of electronic relaxation, since the competing term I-J+ is Pauli-suppressed. A topic of contemporary interest in Spintronics is the phenomenon of Spin Pumping in ferromagnetic metals which has striking similarities with the above process: the ferromagnetic metal is microwave irradiated at the Ferromagnetic Resonance (FMR) Frequency of the electronic spins and this gives rise to an electronic spin current which may be detected using the Inverse Spin Hall Effect. A point of contention is whether this process also involves the formation of a spin accumulation in the irradiated magnetic metal. The purpose of this project is to attempt a nuclear double-resonance experiment to confirm or negate this hypothesis. Sample preparation will involve some tricky chemistry and the experiment itself with require dexterity in both radio frequency and microwave electronics and an ability to work with cryogenic equipment.

Supervisors: ***Prof J Gregg*** and ***Dr A Karenowska***
Email: ***john.gregg@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 **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***

INT09 **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***

INT10 **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***

INT11 **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***

INT12 **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***

INT13 **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***

Particle and Nuclear Physics projects

PP01 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***

PP02 Identification and classification of acoustic signals:

Dark matter detectors aim to detect extremely rare events and thus have to operate in an environment that avoids accidental signals that could be confused with a dark matter interaction in the detector. One of the veto systems planned for these very sensitive dark matter detectors is an acoustic sensor system that records sound. The project is focussed on the analysis of data from such a veto system. The analysis algorithms to be developed within this project should achieve high efficiency in classifying events recorded in the data. The project is computational but there exists also an opportunity to record sound with the existing hardware in order to generate acoustic samples that the algorithm analyses. Good familiarity with programming, preferably in C++ is essential. As an extension to the project (not mandatory), there is further the opportunity for implementing trigger algorithms directly into the FPGA of the hardware. Familiarity with VHDL would be required for this optional part.

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

PP03 Simulation of background sources in dark matter detectors

Dark matter detectors rely on environments that are as free as possible of radioactive contaminants, at a level several orders of magnitude better than natural radioactivity. 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***

PP04 Event reconstruction from single photon detection

The use of scintillators with photo multiplier readout is popular in a large number of particle physics experiments. One such example is the search for dark matter candidates, another the adaptation of the technique to the determination of sample temperature in protein crystallography. This project looks at developing realistic simulations of the electronic response of photo multiplier tubes and algorithms to extract relevant physics information from the digitized signals recorded by the data acquisition system. This is a software project where knowledge of C++ is essential and familiarity with ROOT desirable.

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

PP05 Simulation and reconstruction of new Bc decays

Because of their comparatively long lifetimes, the properties of B mesons could be modified from a Standard Model (SM) expectation by the slow-acting, feeble effect of unknown particles. In the last decade, evidence of a deviation from the SM has been reported in some b-to-c quark transitions. An unturned stone in the study of b-to-c transitions is the annihilation decay of Bc mesons, which are a bound state of a b-quark and a c-antiquark. The Oxford LHCb group published the first observation of a Bc decay that is dominated by the annihilation topology in 2015 and have a continued interest in developing Bc decays at LHCb.

The project will be to use provided code to generate and simulate a large number of novel Bc modes. The student will write simple python tools to manage the simulation jobs on the Oxford particle physics cluster and analyse the result. The output of the simulation will be sets of `ntuples' from which histograms of decay properties (like reconstructed mass and lifetime) will be made. The goal of the project will be to calculate a good estimate of the reconstruction efficiency of these new decays and perhaps assist in defining an online selection for use by LHCb during Run3 of the LHC operation (2021-2024).

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

PP06 LHCb data analysis of semileptonic B decays

Semileptonic decays are those in which the B-meson changes into a lighter meson plus a muon and neutrino, reminiscent of old-fashioned beta decay. At the LHCb experiment at CERN, the presence of the muon leads to efficient and clear triggering giving datasets of exceptional quality and size. The Masters project is a data analysis project using ntuples (tables of data) produced by a D.Phil. student working in the LHCb group at Oxford. The project will be an excellent opportunity to understand event reconstruction, event selection and signal extraction in a real cutting-edge analysis. Depending on the student's interest, the work may concentrate on the data analysis to search for unobserved decays modes, or develop machine learning approaches to fast Monte Carlo relevant to our semileptonic data analyses. The coding should be mainly in python or C++ and prior experience is not expected.

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

PP07 Phenomenology of neutrino pion production

Accelerator neutrino experiments are searching for the signature of leptonic CP violation (LCPV) which is beyond the Standard Model of particle physics. Neutrino interaction plays an important role in this discovery, whereby pion production is one of the critical interaction mechanisms in current and future experiments. Precise theoretical description of these processes is of high demand by the progressing experimental sensitivity.

In this project, the student will explore the state-of-the-art event generators of neutrino interactions, examine the crucial theoretical framework for pion productions, and address their impact on the discovery potential of LCPV in future experiments. The project demands good programming skills in C/C++ and proficiency on Linux operating system.

Supervisor: ***Dr X Lu***
Email: ***xianguo.lu@physics.ox.ac.uk***

PP07 **PaMIr+: Interferometry on fast targets**

PaMIr is short for Phase Modulation Interferometry. The PaMIr group is developing a novel method to interferometrically measure rapid displacements with high accuracy and time resolution as well as low latency. PaMIr+ will extend this scope towards absolute distance measurements, which have abundant applications in large-scale science experiments. Among the highlight scientific applications so far are the alignment of the crab cavities in the upgrade HL-LHC, control of undulators at LCLS-II, relative positioning of the primary and secondary mirrors of several next generation telescopes (GMT, EELT, KECK), as well as future measurements of deployable space antennae on satellites.

PaMIr is a plug-compatible extension of an absolute distance interferometry technology (FSI, Frequency Scanning Interferometry) previously developed by Oxford Physics. This FSI technology is now used in its commercial form (Absolute Multiline™) in many scientific projects in accelerator science, particle physics, astrophysics but also in many industrial settings. The high speed, continuous differential measurements from PaMIr can be used in dynamic control loops to measure rapidly time variable positions continuously over long periods. These are needed in many of the above science problems and in the control of robots and CNC production machines in industry.

The PaMIr project is funded through an innovation partnership grant, which has inputs from STFC and from our two industrial partners, VadaTech Plc and Etalon GmBH. The student will be a member of the PaMIr group, which currently has five permanent members at Oxford. Prof Armin Reichold is the group leader, Dr Peter Qui is a PDRA, Dr Jubin Mitra is the groups FPGA engineer, Mr Mark Jones and Mr Johan Fopma are two further electronics engineers working part time on PaMIr. We have enjoyed input from four summer students and an MPhys student. Seven further part time team members are working on the project in our partner organisations.

This project student opportunity offers a wide range of possible engagements with the PaMIr project. The range of activities suitable for an MPhys project are:

1. Measurement of fast moving targets with PaMIr interferometers

a. Testing multiple modulation and demodulation techniques

b. Experimentally verify some of the demodulation algorithms in their real time form in an FPGA in collaboration with out FPGA engineer Jubin Mitra.

c. Develop PaMIr offline analysis algorithms in collaboration with our post-doc, Peter Qiu.

2. Comparison of PaMIr measurements to those made by our own and a commercial reference interferometer.

a. Test PaMIr at critical distances

b. Measure performance as a function of laser power

3. Evaluate new frequency stabilised lasers for PaMIr

a. Stabilise our own fibre lasers to gas absorption cells

b. Test a new commercial fibre laser in PaMIr algorithms and fully characterise it.

4. Analysis of Absorption spectra of gas-cells using frequency comb measurements which can contain.

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

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

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

d. 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.

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

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

The skills that would be useful for all of the above projects would be an interest and some experience with programming in Matlab and/or C/C++ as well as skills in optics and lasers.

Interested applicants can discuss project options with Prof Armin Reichold (armin.reichold@physics.ox.ac.uk).

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

PP08 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.

PP0801 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: ***Prof T Weidberg***
Email: ***tony.weidberg@physics.ox.ac.uk***

PP0802 Hunting matter-antimatter asymmetry in Higgs boson decays

The standard model of cosmology requres at least one unknown source of asymmetry between matter and antimatter in the fundamental interactions, and the discovery of the Higgs boson opens up a new set of interactions to probe for such a source. This project will investigate the sensitivity of the LHC to a matter-antimatter asymmetry in Higgs-boson decays to tau leptons, b-quarks, and c-quarks. The potential sensitivity of future colliders will also be explored.
Supervisor: ***Dr C Hays***
Email: ***chris.hays@physics.ox.ac.uk***

PP09 Measurements of matter-antimatter asymmetries at the LHC

Dark matter detectors have progressed to unprecedented Precise studies of the asymmetry in behaviour between matter and antimatter, known as CP violation, is a powerful probe for physics beyond the Standard Model. The overwhelming dominance of baryons over baryones in the universe is an indication for the existence of mechanisms of CP violation beyond our current understanding. The enormous data sample of beauty-hadron decays at the LHCb experiment can be harnessed to yield measurements that will allow the Standard Model predictions to be tested with unprecedented sensitivity.

In this project, data recently collected by the LHCb experiment will be analysed for the first time, and CP-violation effects will be measured in the decays of beauty hadrons. These measurements will be compared with the expectations from theory.

The project is computer based. No prior experience is needed, but knowledge of C++ or Python will be useful in getting started.

Supervisor: ***Prof G Wilkinson***
Email: ***Guy.Wilkinson@cern.ch***

PP10 The A2D2 silicon tracker detector for the ATRAP experiment

ATRAP is a Particle Physics experiment at the Anti-Proton Decelerator complex at CERN designed to precisely measure the properties of anti-Hydrogen atoms; in particular using laser spectroscopy to determine precisely the energy levels in anti-Hydrogen. Differences between anti-matter and matter are fundamental to understanding why there remains a matter-antimatter asymmetry in the modern universe. A2D2 (ATRAP Array of Discrete Diodes) is a design for an anti-proton annihilation detector system based on commercially available silicon PIN diodes, which is crucial for identifying anti-matter whilst performing these sensitive measurements. The student would have an opportunity to work on either: a) the development and characterisation of sensitive, analogue front-end electronics, b) the highly multiplexed, zero-supressed digital readout system (of ~200 000 channels), or c) the simulation and event reconstruction algorithms for the detector, depending largely on the student's preference. In the cases (a) or (b), an interest in electronics and low level software programming would be highly advantageous. For (c), previous experience of programming (ideally but not exclusively in C++ or python) would be desirable. This project is a great opportunity to be closely involved in the early stages of design and construction of a particle physics detector.

Supervisors: ***Prof I Shipsey*** and ***Dr R Plackett***
Email: ***richard.plackett@physics.ox.ac.uk***

PP11 High contrast optical gradient calibration for LSST instrumentation

The LSST is a next generation optical survey telescope which will constrain our knowledge about dark energy through weak lensing surveys. These surveys involve measuring the shapes of galaxies very precisely and are susceptible to many systematic errors, both astronomical and instrumental, which must be well understood and characterised. For example, correlated charge collection in the silicon CCD sensors used leads to asymmetric shape distortion effects. We investigate these effects using carefully controlled illumination of a sensor in a laboratory test bench environment.

In this project, the student will work on the setup, comissioning and calibration of a fringe gradient illumination and projection system (essentially an electronically adjustable Michelson interferometer) to be added to the optical test bench system in the OPMD laboratory. The project will involve practical work (chiefly in optical alignment though probably with some electronics work), basic image processing for calibration tests, and depending on progress, software integration work for the rest of the test system. The student will need a good mindset for experimental work, and ideally some previous experience and ability in programming (Python & c++).

Supervisors: ***Prof I Shipsey*** and ***Dr D Weatherill***
Email: ***daniel.weatherill@physics.ox.ac.uk***

PP12 Improved understanding of proton structure

The Large Hadron Collider (LHC) is the world's highest energy particle collider. Following the discovery of the Higgs boson, the machine continues to collect a wealth of data. Among the primary physics goals of the machine are to search directly for new, high mass particles, as well as to precisely measure the properties of the Higgs, which may also reveal evidence of as-yet unknown physics. 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 to improve our knowledge of proton structure, using either existing LHC data, or by looking at simulated data from possible future colliders. A set of proton parton distribution functions (PDFs) will be determined, and the impact of any improvements on the prospects for new physics discovery or Higgs properties will be investigated. This is a computing project. Some prior experience of C++ would be an advantage.

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

PP13 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*** and ***Prof J Tseng***
Email: ***Steven.Biller@physics.ox.ac.uk, Jeff.Tseng@physics.ox.ac.uk***

PP14 Evaluation of DMAPS sensors

The High Luminosity LHC (HL-LHC) project will require the replacement of the ATLAS tracker. New technologies that use high resistivity substrates with three or four well CMOS process options allow large depletion depths and full CMOS circuitry in a monolithic structure. These developments are generating large interest in particle physics since they could provide low-cost, thin, and radiation-tolerant detectors. The candidate will evaluate the performance of these sensors, denoted as DMAPS, 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***

PP15 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. The main decay mode for a 125 GeV Higgs boson is H->bb. The candidate for this project will work with our team to study the impact of 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 di-Higgs production in final states that include 4 b-quarks and can be used to test the Higgs self-coupling. The project demands good analytical and some programming skills (preferably in C++ and PYTHON).

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

PP16 Tracking in 4 dimensions

Silicon detectors allow to measure the position of elementary particles with exquisite precision of less than 10 μm. The addition of precision timing information will be especially beneficial for the High Luminosity LHC (HL-LHC) where the number of events per bunch crossing will be of the order of 150–200, with an average distance between vertexes of 500 μm and a timing rms spread of 150 ps. Ultra-Fast Silicon Detectors (UFSD) based on the Low-Gain Avalanche Detector (LGAD) design, employing n-on-p silicon sensors with internal charge multiplication due to the presence of a thin, low-resistivity diffusion layer below the junction can achieve a timing resolution of about 30 ps. The candidate will evaluate the performance of UFSD 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***

PP17 Extraction of ancient writing from X-ray fluorescence images

This project will look at a novel way of reconstructing archaeological finds from X-ray fluorescence measurements, in particular ancient writing on scrolls that were charred during the eruption of Mt. Vesuvius in 79 AD. Whilst the suggested methodology is reasonably simple, a pin-whole x-ray camera that is energy sensitive, the extraction of the very faint signal over background will require careful analysis of the recorded data. Many measurements have already been made, but few of the data has yet been analysed. The project will allow one to study the sensitivity of the apparatus, based on data recorded from templates, as well as trying to understand actual data recorded on a real object and giving the best shot a making a drem-come-true for the world of ancient classics and archaeology.

Most of the work will involve statistical analysis of recorded 3-dimensional data using either Python or a programming language of your choice. Code exists (in Python/C++) to read in data files and generate simple plots (2D images, 1D energy spectra) of the existing data.

Supervisors: ***Dr J Dopke*** and ***Prof A Weber***
Email: ***alfons.weber@physics.ox.ac.uk***

PP18 Medipix and Timepix Detectors applicability to multi-spectral x-ray imaging

Oxford physics is a member of the Medipix collaboration; we are currently working with the latest generation hybrid pixel detectors: Medipix3 and Timepix3, both of which have applications in muti-spectral x-ray imaging. This technique uses information of the different emerges of the x-rays detected to determine information about the material in the image, and distinguish it, by looking at elemental absorption characteristic. Calcium atoms in bone, and barium and iodine markers for other tissue types. The Medipix and Timepix detectors operate in fundamentally different ways, and in this project the student will determine the strengths and weaknesses of each system for the task of energy resolved imaging of x-rays. This will be done using a new x-ray generator that will be available in the OPMD facility, as well as working with well characterised radioactive sources.

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

PP19 Investigating Charge Transfer Inefficiency in sensors for LSST

The LSST is a next generation optical survey telescope which will constrain our knowledge about dark energy through weak lensing surveys. These surveys involve measuring the shapes of galaxies very precisely and are susceptible to many systematic errors, both astronomical and instrumental, which must be well understood and characterised. One major effect is that of charge transfer inefficiency caused by single electron "trap" states below the conduction band in silicon. Characterising these trapping states is important in determining how best to mitigate and/or correct for charge transfer inefficiency.Ł

ŁIn the OPMD lab we have the capability to perform "trap pumping" experiments at cryogenic temperatures and ultra-high vacuum which can measure the properties of individual silicon trapping sites. In theory, the trap properties are affected by local electric field, though this has yet to be directly demonstrated in experimental data. We have also devised a novel experiment which will use sub-bandgap illumination to fill traps in an energy-dependent fashion, allowing for the first time to measure trap emission time constants separately from their energy level.

The student will work on collecting and analyzing data from these experiments and have input into some aspects of the experimental design (perhaps including optical and electronic aspects). Some experience with programming (python) and image processing would be advantageous. This would ideally suit a student who is interested in working with (sometimes temperamental) experimental data.
Supervisor: ***Dr D Weatherill***
Email: ***daniel.weatherill@physics.ox.ac.uk***

PP20 Constraining atmospheric neutrino flux predictions for the SuperKamiokande Experiment using cosmic-ray muon data.

Neutrino oscillation was first seen in neutrinos that had been produced in the atmosphere from cosmic rays by comparing the rates of neutrinos from different directions in the SuperKamiokande experiment. The different directions translate into different oscillation distances. SuperKamiokande has continued to collect data and now has a formidable amount of statistics, and has recently undergone an upgrade that will allow Gadolinium to be introduced into the water in the near future. The Gadolinium will allow neutrons from the neutrino interactions to be detected by delayed emission of gamma rays after the neutrons are captured by the Gadolinium nuclei.

The flux predictions are made by Monte-Carlo simulation of the atmospheric interactions, and we are involved in a programme to substantially improve them. The simulation involves a whole chain of processes: Generating primary protons and other nuclei according to measured primary fluxes from balloons and satellites, including effects of solar wind and geomagnetic field, generating hadronic interactions when the primaries collide with nuclei in the atmosphere, propagating the resulting particles through the rest of the atmosphere. The simple neutrino-counting argument of the decay of a pion to a muon and neutrino and then the muon to two more neutrinos is insightful for understanding the oscillation phenomena, but because of the variations of the fluxes with energy, this much more detailed simulation approach is necessary for the data analysis.

The main difficulty is that because the strong interaction is unsuitable for calculation with perturbation theory, the hadronic interactions are not possible to predict, and so data from accelerator experiments is used to govern the Monte-Carlo generation instead. While SuperKamiokande has been running, the quality of experimental data on hadron production has increased significantly, and we are in the process of inserting them into the Monte-Carlo calculations. This will produce significantly improved calculations that can be used with the new data from SuperK. By using weighting techniques, it will also be possible to vary the assumptions from the hadron production modelling and provide uncertainties (as has been done before), and to use tuning techniques to apply different forms of input data as constraints. We are intending to use accelerator hadron production data, data from the T2K long-baseline accelerator experiment and from cosmic ray muon data.

The aim of the project is to tackle the application of constraints from the cosmic ray muon data, which has not been attempted by our simulation group before. Independent predictions of the fluxes were carried out in the early days, and the other major flux calculation does include these constraints. We will try to parameterise how both the muon flux and neutrino fluxes vary when the assumptions about hadron production are changed, and then apply the muon data as a constraint using a fitting procedure which we will devise. One of the investigations will be to understand whether all of the phase space for neutrinos is constrained by the muons, it is likely that it isn't, but there may be ways we can investigate to overcome this.

The project is computer based and will involve extensive use of either C++ or python programming (to make histograms)

Supervisor: ***Prof G Barr***
Email: **giles.barr@physics.ox.ac.uk**
Webpage with a bit more info: http://www-pnp.physics.ox.ac.uk/~barr/mphys/proj2019.html
Safety: Display screen equipment (computers) safety

Theoretical Physics projects

TP01 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***

TP02 Topological Insulators and Surface States

Over the last decade, a revolution has occurred in condensed matter physics. We now think of materials in terms of topological classes --- placing two materials in the same class if one Hamiltonian can be smoothly deformed into the other. This new was of classifying materials has led us to discover new materials and new, previously hidden, properties. The simplest example of the power of this type of thinking is given by what is known as a "topological insulator". For many purposes these materials appears like any non-interacting electron band insulator (a filled valence band and an empty conduction band), but on closer inspection they turn out to have fundamentally different properties --- such as protected surface modes. The first part of this project will be to understand this idea topological classification. The remainder of the project will be to explore the physics of protected surface states, using the framework of Fermi liquid theory. This project is suitable for a student who is mathematically very strong and is taking the C6 theory option. Some amount of computation will be required (almost any computer language would be acceptable).

Reference: M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010).

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

TP03 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***

TP04 Project in quantum condensed matter theory

More details from the supervisor.

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

TP05 Micro-stability of plasma immersed in 3D magnetic fields

Ionized gas, called plasma, generates and responds to electromagnetic fields and demonstrates collective behavior including unstable modes of oscillation that result in turbulence. In the context of magnetic confinement fusion — where strong magnetic fields are used to confine a hot, fusing plasma — this turbulence is problematic: It leads to mixing of the hot and cold regions of the plasma, thus limiting confinement. Understanding and subsequently limiting the plasma turbulence is thus a crucial challenge for controlled fusion.

In this project, the student will investigate the influence of the confining magnetic field geometry on the micro-stability of the plasma. This will involve conducting linear stability simulations for the plasma, analysing the resulting data, and seeking approximate analytical solutions to the underlying equations. A firm grasp of kinetic theory, fluid mechanics, and electrodynamics would be useful, as would some prior experience with or enthusiasm for programming.

Supervisor: ***Prof M Barnes***
Email: ***michael.barnes@physics.ox.ac.uk***

TP06 Decoding the stellar main sequence using machine learning

The colours and brightnesses of dwarf stars like the Sun are tightly correlated, with bright stars being blue and faint stars being red. A plot of brightness versus colour is known as a Hertzsprung-Russell diagram and this relationship is known as the Main Sequence. There is scatter around the main sequence due to the (usually unknown) chemical composition or rotation of the star. Unresolved binary stars contribute further scatter, because we observe stars whose brightness and colour are the combination of the light from two stars. With new data from the European Space Agency's Gaia space telescope, we are finally in a position to decode the position of a star on the main sequence into composition, rotation and binarity.

In this project, the student will use machine learning techniques and the latest stellar models to interpret the stellar main sequence. This will involve applying supervised or unsupervised machine learning to synthetic and observed stellar populations. At the end of the project, the student will have constrained the effect that chemical composition and rotation have on the colour and brightness of stars. They will also have assigned a probability to every star that it is actually an unresolved binary star. The project demands good analytical and programming skills (C/C++, Python, or similar).

Supervisors: ***Dr D Boubert*** and ***Dr J Magorrian***
Email: ***douglas.boubert@magd.ox.ac.uk*** and ***John.Magorrian@physics.ox.ac.uk***

TP07 Topics in Geometry, Number Theory and Gauge/String Theory

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. More recently, there has been much interaction of these fields also with machine-learning and data science, so those interested in computational aspects can also explore this direction.

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

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

TP08 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***

TP09 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***

Index