Physics Trinity Term - 2019

MPhys Projects Trinity Term 2019

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Foreword

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

You will start your Major Option Classes and your MPhys project Michaelmas Term 2019. You may be given some reading or work to do over the long vacation, and you will therefore be a little better informed and prepared. The project may be your first insight into life in a physics research group and be a chance to see developments at the cutting edge of the subject. It is also a first look at problems whose solution may well be unknown, to both you and your supervisor.

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

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

Prof. Hans Kraus, Head of Teaching

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 Dr Moriz Riede, Moritz Riede (Physics) (moritz.riede@physics.ox.ac.uk)

The information in this handbook is accurate as at 29 April 2019, 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 third year, Part B, ranking will also be used to assign students to projects;

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

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

Project risk assessment

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

Project assessment

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

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

Each MPhys candidate will be expected to attend a meeting 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 2019

Week 1 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 6 Complete the *Project Choice Form*
(Fri 3 pm) [On-line or by e-mail]

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

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

Michaelmas Term 2019

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 2020

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 2020

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

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

Timetable for Supervisors

Hilary Term 2019

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

Trinity Term 2019

Week 1 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 2019

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 2020

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 2020

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

MPhys Project Descriptions

Atomic and Laser projects

A&L01 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&L02 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&L03 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&L04 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&L05 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&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 Gamma-ray and electron-positron production by electrons in intense laser fields

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

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

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

A&L08 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&L09 Optical lattice setup for exploring supersolid behaviour of ultracold erbium atoms

In the study of novel effects in many-body quantum systems the nature of interactions between the particles play a crucial role. This project will form part of a bigger project to study an ultracold gas of Erbium. Erbium atoms possess a large magnetic dipole moment and will thus open up many new possibilities by allowing us to explore the effects of longer-range dipole-dipole interactions on many-body behaviour.

This project will focus on designing and building a 1D optical lattice that will then be applied to our erbium Bose-Einstein condensate (BEC). The idea behind the lattice is to search for a possible supersolid state which is mediated by the long-range dipole-dipole interaction; such a state is very unusual because it has both long-range phase ordering (like a superfluid) and long-range spatial ordering (like a solid).

The initial part of the project would involve determining the requirements of the optical lattice (wavelength, depth etc.) and then designing an appropriate laser setup to implement such a lattice on our atomic sample. An ambitious student may also get the chance to take part in some of the initial experiments in search of supersolid behaviour.

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

A&L10 Bragg spectroscopy setup to probe ultracold erbium atoms

In the study of novel effects in many-body quantum systems the nature of interactions between the particles play a crucial role. This project will form part of a bigger project to study an ultracold gas of Erbium. Erbium atoms possess a large magnetic dipole moment and will thus open up many new possibilities by allowing us to explore the effects of longer-range dipole-dipole interactions on many-body behaviour.

This project will focus on designing and building a Bragg spectroscopy setup to probe our erbium Bose-Einstein condensate (BEC). By setting up a moving lattice of light (using two laser beams with different orientations and frequencies) it is possible to selectively Bragg diffract atoms into states with certain energy and momentum; this allows us to probe the elementary excitations of the condensate which play a crucial role in determining the superfluid properties of the system.

In practical terms, the project will involve developing the optical and electronic set-up for directing and controlling the two laser beams on to the atomic sample. An ambitious student may also get the chance to perform some measurements of the excitation spectrum of the dipolar BEC of erbium atoms.

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

A&L11 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

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

A&L12 High Finesse Cavity QED

Assembly and characterization of optical micro-cavities for light-matter interaction in the strong coupling regime. This includes setting up the resonator, a piezo control of the cavity length and spectroscopic or cavity-ringdown measurements to determine the finesse, mirror reflectivity and mirror losses.

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

A&L13 Solving the “Hubbard-wheel”: Interpolation between one and infinite dimensions

The spatial dimension has a strong influence on the properties and the behavior of quantum many-body systems. Just to provide two examples, in one-dimensional systems the significance of the exchange symmetry is suppressed (massive particles can even not be interchanged) and infinite-dimensional systems exhibit mean-field character. The present project shall interpolate between those two cases in the form of the Hubbard wheel [1]. This model contains a ring of lattice sites with nearest-neighbor hopping (strength t). In addition, a central site is added which allows the particles to hop from the ring sites to the central site (and backwards) with hopping strength s. The ground state physics of the Hubbard wheel shall be studied analytically and also numerically by using the density matrix renormalization group (DMRG) ansatz. Particular focus shall lie on the two extremal regimes, i.e. $t \gg s$ and $t \ll s$. The first one describes the one-dimensional regime with hopping merely on the ring while the second one simulates an infinite-range hopping model (the particles can hop via the central site with same probabilities from every ring site to any other ring site). Furthermore, by comparing the Hubbard wheel system for fermions, bosons and hard-core bosons, the influence of the exchange symmetry shall be explored.

[1] E.J.G.G.Vidal, R.P.A. Lima, and M.L.Lyra, Phys. Rev. E 83, 061137 (2011)

Requirements: analytical background, good knowledge of the second quantization (fermions and bosons)

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

Supervisors: ***Dr C Schilling*** and ***Dr O Legeza*** (Wigner Research Center for Physics in Budapest)
Email: ***Christian.Schilling@physics.ox.ac.uk***

A&L14 1-body N-representability problem for hard-core bosons

One of the important questions in many-body physics is to understand the influence of the particle exchange symmetry in the reduced one- and two particle picture. It has recently been shown for fermions that the exchange symmetry implies --- in contrast to the case of boson --- constraints on the one-particle picture. These are the so-called generalized Pauli constraints (see e.g. [1]). In the present project, we will study the “intermediate” case of hard-core bosons: Their wave function is symmetric under particle exchange, yet they are not allowed to sit at the same place, similar to spinless fermions. The main goal is to work out consequences of this mixed exchange behavior for the one-particle picture. This would then allow scientists to efficiently determine ground states of systems of hard-core bosons and may provide new insights into Bose-Einstein condensation of ultracold atoms. A promising approach is to work out the analogous hierarchy of N-representability constraints as it has been done by D.A.Mazziotti for fermions (on the two-particle level) [2].

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

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

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

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

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

A&L15 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***

AA&L16 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

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

A&L17 Developing a functional theory based on occupation numbers

One of the most promising numerical approaches to many-body physics is "Reduced Density Matrix Functional Theory" (RDMFT) (see, e.g., the introductory talk [1]). There one seeks an exact functional of the one-particle reduced density matrix whose minimization yields the ground state. Besides the problem of finding the correct functional, the success of RDMFT is still significantly hampered due to computational problems: During the minimization process of the functional one needs to ensure that the eigenstates of the density matrix remain orthogonal. In this project, we will take advantage of the fact that those eigenstates ("natural orbitals") are actually known from the very beginning for all translationally-invariant lattice systems. They are namely given by the Bloch states and thus do not need to be optimized anymore. We will then propose new functionals which depend on the occupation numbers, only. These functionals will be tested numerically for the most prominent lattice model systems.

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

Requirements: analytical background, basic programming skills, knowledge of the concept of reduced density matrices

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

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

A&L18 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***

A&L19 Exchange-correlation functional based on generalized Pauli constraints

One of the most promising numerical approaches to many-body physics is "Reduced Density Matrix Functional Theory" (RDMFT) (see, e.g., the introductory talk [1]). There one seeks an exact functional of the one-particle reduced density matrix whose minimization yields the ground state. Besides the problem of finding the correct functional, one may also wonder over which set S of density operators such functionals need to be minimized. It has been proven [2] that RDMFT can be constructed in such a way that S is only restricted by Pauli's famous exclusion principle. In the present project, we will observe, however, that discarding the more stringent generalized Pauli constraints (GPCs) (see, e.g., Refs. [3,4]) manifests itself in highly involved functionals, implicitly containing the information about the GPCs. In particular, it shall be shown that each GPC contributes to the exact functional in the form of a repulsive force ensuring that none of the GPCs can ever be violated by ground states.

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

[2] S.M.Valone, J. Chem. Phys. 73, 1344 (1980)

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

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

Requirements: analytical background, basic programming skills, knowledge of the concept of reduced density matrices

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

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

A&L20 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).

Supervisors: ***Dr S M Vinko*** and ***Prof G Gregori***
Email: ***Sam.Vinko@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 **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).

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 The N-plume problem: a theoretical and experimental study of the collective dynamics of turbulent convective fluid flow

Convection is ubiquitous in both the natural and engineering environments, and is an essential part of the dynamics of the atmosphere, oceans, and interior of the Earth and other planetary bodies, and the outer layers of stars [1,2] . Convective fluid motions are driven by density differences, and are often caused by by gradients in temperature or composition in geophysical and astrophysical settings. Strongly convecting fluids tend to release buoyant plumes that advect density anomalies down gradient, consuming available potential energy from the background density gradient. This makes the plumes the building blocks of convection.

The behaviour of a single buoyant plume has been extensively studied both theoretically and experimentally, and is well understood [3]. However, a snapshot of a typical turbulent convective flow field contains a very large number of plumes of different strengths. Their nonlinear interactions lead to rich and complex behaviour.

This projects aims to study the interactions of N buoyant plumes using theory and experiments. The project will extend the theory of two-plume interaction from a previous study [4] to include multiple plumes. The predictions from the theory on the height at which plumes merge, the mass flux from these merged plumes, and the rate of entrainment will then be tested using laboratory experiments that will probe the coupling of an array of multiple dense salt plumes. The validated theory will then be applied to study more complex configurations of plume strength and spacing, with the goal of understanding the contribution of plume mergers to the development of large scale coherent flow structures in turbulent convective systems.

This project will feature a mixture of applying fluid mechanical theory, development of simple computational models for systems of coupled differential equations, and hands-on experimental work in fluid dynamics. Whilst computational methods and programming will be used during the project for modelling and experimental data analysis, no prior familiarity is required beyond the level of the usual undergraduate computing and laboratory practicals.

Suggested background reading:

[1] J. S. Wettlaufer, The universe in a cup of coffee. Phys. Today vol. 64(5), p66 (2011). https://doi.org/10.1063/1.3592018

[2] L. P. Kadanoff, Turbulent heat flow: structures and scaling Phys. Today vol. 54(8), p34 (2001) https://doi.org/10.1063/1.1404847.

[3] J. S. Turner, Buoyant plumes and thermals. Ann. Rev. Fluid Mech. vol. 1 p29 (1969) https://doi.org/10.1146/annurev.fl.01.010169.000333.

[4] N. B. Kaye and P. F. Linden, Coalescing axisymmetric turbulent plumes. J. Fluid Mech. vol. 502, p41 (2004). https://doi.org/10.1017/S0022112003007250

Supervisors: ***Dr A Wells*** and ***Dr S Toppaladoddi***
Email: ***andrew.wells@physics.ox.ac.uk; srikanth.toppaladoddi@all-souls.ox.ac.uk***

AO02 Stokes drift in oceanic Rossby waves

Long Rossby waves are primary physical mechanism through which the large scale ocean circulation adjusts to wind and buoyancy anomalies. In exactly the same way that surface water waves approaching a beach result in a rectified on-shore Stokes drift, requiring rip currents to return the water off-shore, so Rossby waves result in a rectified westward Stokes drift, requiring "Rossby Rip currents" to return the water eastward, https://onlinelibrary.wiley.com/resolve/doi?DOI=10.1002/grl.50842.

In this project, the student will investigate how these results extend to long Rossby waves with increased vertical structure, I.e., with multiple layers and/or higher vertical modal structure. The project is likely to involve a combination of analytical calculation and numerical calculations using an idealised ocean circulation model. The project requires a student with good analytical skills and an aptitude for working with computational codes.

Supervisor: ***Prof D P Marshall***
Email: ***david.marshall@physics.ox.ac.uk***

AO03 Helmholtz decomposition of surface wind stress and its impact on global ocean circulation

Any vector can be decomposed into rotational (divergence-free) and divergent (curl-free) components, known as a Helmholtz decomposition. In an incompressible fluid, the divergent component of a body force projects purely onto the pressure gradient and is unable to generate vorticity and hence a circulation; in contrast, the rotational force projects purely on the fluid acceleration and is able to generate vorticity and hence a circulation, https://journals.ametsoc.org/doi/10.1175/2011JPO4528.1.

In this project, the student will carry out a Helmholtz decomposition of the surface wind stress for both an idealised ocean basin with a circumpolar Southern Ocean channel and the global ocean with the observed wind stress. The resultant rotational wind stresses will be used to investigate the extent to which wind forcing at different latitudes drives a circumpolar current and/or a closed wind-driven gyre (a closed circulation pattern confined to an ocean basin). Depending on the interests of the student, the project can be extended in a number of different directions. The project requires a student with good analytical skills and an aptitude for working with computational codes.

Supervisor: ***Prof D P Marshall***
Email: ***david.marshall@physics.ox.ac.uk***

AO04 Global Distribution of Carbonyl Sulphide

Carbonyl Sulphide (OCS, or COS) is the most abundant sulphur compound in the atmosphere. It originates from biological processes in the oceans, from volcanic emissions, and from various human activities, and it is thought to be the main source of sulphate aerosol in the stratosphere which plays an important role in global temperature regulation. Although atmospheric concentrations of OCS are low, about 0.5 parts per billion, it has a distinct infrared absorption spectrum in the 5 micron atmospheric window region, which makes it detectable from space.

The Infrared Atmospheric Sounding Interferometer (IASI) is a nadir-viewing instrument on the polar-orbiting MetOp satellites, measuring the infrared emission spectra from the earth's surface in the range 3.6-15.5 microns.

The Oxford group have developed a number of algorithms to retrieve the concentrations of various molecules from IASI spectra, ranging from fast 'linear' methods - effectively just taking the dot product of IASI spectra with a fixed vector of coefficients - to more accurate, but slower, iterative techniques requiring full radiative transfer calculations.

The aims of this project are to analyse the results for the global/seasonal distribution of OCS generated by the Oxford linear retrieval, to validate these by comparison with a few selected cases for the iterative retrieval and with other published work.

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***

AO05 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***

AO06 Modeling the atmospheric Quasi-Biennial Oscillation in the laboratory

The Quasi-Biennial Oscillation (QBO) is a cyclic reversal of the zonal winds in the middle and lower tropical stratosphere on a timescale of roughly two years. It dominates the climate of the tropical stratosphere, influencing the long range transport of momentum, heat and chemical constituents. It is also thought to play an important role in influencing the predictability of various features at higher latitudes and in the troposphere. Although the basic mechanisms that drive the QBO are reasonably well understood, arising from the nonlinear interaction of upward-propagating internal gravity and planetary waves (generated in the troposphere) with the zonal flow, its detailed variability is complex, chaotic and much less well understood. The atmosphere often surprises modelers with events such as the recently observed "stalling" of the QBO that their models failed to predict. The likely impact of future global climate change on the QBO is also quite controversial and uncertain.

In this project, we propose to study a number of mechanisms that might influence the behavior of the QBO using a laboratory analogue of the QBO, in which factors such as the wave forcing and other parameters can be closely controlled and varied. Internal waves are launched into a salt-stratified fluid in an annular channel by oscillating flexible membranes in the bottom of the tank. Each segment of the membrane can be separately controlled by computer to enable varying spectra of internal waves to be excited and for the amplitude of the waves to be varied in time (thereby emulating the seasonal cycle and other modulations). The response of the fluid to this forcing in the form of time varying velocity fields will then be measured by optical particle imaging techniques.

This project would involve setting up and running the experiment over a range of wave forcing profiles and frequencies, acquiring images of tracer particles and analyzing them to determine flow velocities as a function of time and space.

Skills required: Laboratory and some programming experience is desirable (e.g MATLAB, Python etc) though not essential.

Project may be carried out in laboratories in Engineering Science or AOPP (TBD).

Supervisors: ***Prof P Read*** and ***Prof A Castrejon-Pita (Engineering Science)***
Email: ***peter.read@physics.ox.ac.uk***

AO07 Altimetric Imaging Velocimetry

In a rapidly rotating fluid, the pressure field is closely connected to the horizontal velocity via the geostrophic balance relation. In a shallow layer of fluid with a free surface, dynamical variations in pressure are reflected in variations in the height of the surface. Such variations in the surface elevation of the Earth's oceans may be on the order of cm - metres, and are now routinely measured by radar altimetry from orbiting satellites. On a laboratory scale, however, these perturbations to the free surface may be extremely small (<< 1mm) and difficult to measure.

In this project, we will set up an optical system to measure and map such small perturbations to the interface in a flow pattern obtained under laboratory conditions. Rhines, Lindahl & Mendez (2007) have recently demonstrated a novel method of measuring the free surface elevation of a rotating fluid, by using it as a parabolic, Newtonian telescope mirror to form an image of a carefully designed light source in a CCTV camera. Small perturbations from dynamical motions in the fluid result in distortions of an image reflected from the free surface that can be used to determine the local elevation to a precision of 1 micron or better. This project will use the method of Rhines et al. (2007) to study and measure simple, barotropically unstable flow patterns set up in a cylindrical tank on a rotating table. Colour images from this experiment will be calibrated and analysed using a set of MatLab software provided by researchers at the University of Washington.

Suggested Reading:

Andrews, D.G., "An introduction to atmospheric physics", Cambridge University Press, 2000

Rhines, P. B., Lindahl, E. G. & Mendez, A. J. 2007 "Optical altimetry: a new method for observing rotating fluids with applications to Rossby- and inertial waves on a polar beta-plane", J. Fluid Mech., 572, 389-412, 2007

Afanasyev, I., P.B.Rhines and E.G.Lindahl, 2009: Velocity and potential vorticity fields measured by altimetric imaging velocimetry in the rotating fluid., Experiments in Fluids, May 2009, doi: 10.1007/s00348-009-0689-3.

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

AO08 Modelling wave-driven zonal flow oscillations in the tropics of Earth, Jupiter and Saturn

One of the most remarkable features of the Earth's tropical stratosphere is the occurrence of a pattern of east-west (zonal) winds that reverses back and forth in a cycle that takes around 28 months to repeat. This is now widely understood to arise through a nonlinear interaction between various types of atmospheric waves (internal gravity and inertia-gravity), generated by convective motions in the lower atmosphere, and zonal flows. Its behavior is somewhat chaotic but influenced by partial synchronization with the seasonal cycle. A similar phenomenon is also observed in the stratospheres of Jupiter and Saturn, though on different (longer) timescales. In this project we will adapt and extend a simplified numerical model to simulate this phenomenon under conditions appropriate for each planet, based on different assumptions about which particular wave modes are responsible for controlling the zonal wind behavior. The model may be amenable to including effects of the seasonal cycle on each planet and investigating nonlinear effects such as synchronization. Results may be compared with atmospheric measurements and full climate model simulations. This project entails some coding and programming to adapt an existing model (written in Fortran). Some experience of computer programming and data analysis would be desirable, though prior experience of Fortran is not essential.

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

AO09 Exploring the cloud boundary: changes to clouds

At any moment 2/3 of the Earth is covered by cloud, directly affecting the Earth's radiative balance. The Earth Observation Data Group has developed the Optimal Retrial of Aerosol & Cloud (ORAC) algorithm to estimate cloud properties, such as optical thickness, cloud top height and droplet radius, from satellite observations. A weakness of the algorithm occurs near cloud edges. As the algorithm assumes clouds are infinitely wide, retrievals fail to account for light exiting the cloud sides, leading to incorrect results.

In this project, the student will quantify the distance from the cloud edge required to achieve accurate cloud retrievals, both theoretically and using existing ORAC retrievals. This will feedback into an climate data record used by scientists around the world. In the second part of the project, the students will explore methods to correct cloud retrievals for cloud edge effects.

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

AO10 Exploring the atmosphere near clouds: changes to aerosol

At any moment 2/3 of the Earth is covered by cloud, directly affecting the Earth's radiative balance. The interactions between aerosols and clouds are currently the most uncertain aspect of our ability to predict future climate. The Earth Observation Data Group has developed the Optimal Retrial of Aerosol & Cloud (ORAC) algorithm to estimate aerosol properties, such as optical thickness and particle size, from satellite observations. A weakness of the algorithm occurs near cloud edges. The algorithm fails to account for light exiting the cloud sides, such that extra illumination of the atmosphere near to a cloud results in incorrect results. In addition, the shadowing of the surface by cloud is not considered.

In this project, the student will quantify the distance from the cloud edge required to achieve accurate aerosol retrievals, both theoretically and using existing ORAC retrievals. This will feedback into a climate data record used by scientists around the world. In the second part of the project, the student will explore methods to correct aerosol retrievals for cloud edge effects.

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

AO11 Measuring the Martian atmosphere with a seismometer.

The latest NASA mission to Mars (InSight) landed and placed a seismometer on the planet's surface to investigate how seismic waves travel through the planet, to help constrain the internal structure of Mars. As well as signal from Martian seismic events, the recorded seismic signal will also contain signals due to atmospheric wind, pressure and temperature variations. This project would involve investigating signal source models to understand how the wind, pressure and temperature variations are recorded in the mission's seismic data. We can then apply these new results to provide additional information about the surface conditions in the vicinity of the lander and provide important new data on the mechanical and thermal properties of the surface of Mars.

Skills: Coursework covering the fundamentals of atmospheric dynamics and fluid flows e.g. from Atmos or Astro major options. Programming either in MATLAB or Python.

Reading : Mimoum, et al, 2017, "The Noise Model of the SEIS Seismometer of the InSight Mission to Mars." https://core.ac.uk/download/pdf/129782557.pdf

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

AO12 Simulating 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. A previous MPhys project has carried out design work with a setup where a 3D printed custom asteroid shape is levitated by a superconductor inside a vacuum chamber. The asteroid shape is then illuminated in such a way as to induce the asteroid to slow its rotation via the YORP effect. This project will extend this work to include additional asteroid and test shape models and explore the connections to our lab experiments to measurements of the YORP effect currently being made by NASA OSIRIS-REx spacecraft at asteroid Bennu.

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

Reading: Rubincam, D.P., "Radiative Spin-up and Spin-down of Small Asteroids," Icarus, vol. 148, pp. 2-11, 2000. https://www.sciencedirect.com/science/article/pii/S0019103500964856

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

AO13 Modelling the heat flow around the Moon.

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

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

We have developed our own 3D thermal model here at Oxford. Our model (written in MATLAB) is similar to previous 3D thermal models, except, our model induces non-Lambertian scattering, which other models do not. Initial model runs of the lunar surface have shown a few interesting anomalies, such as the derived surface emissivity being dependent on latitude and the surface temperatures in permanently shadowed regions near the poles being predicted as too high. We have so theories to explain these results that would require some edits being made to the code in how it treats scattering in the TIR. We would also like to run our model to solve the surface of asteroid Bennu (the target asteroid for NASA's OSIRIS-Rex sample return mission).

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

Reading: Paige et al. 2010 http://science.sciencemag.org/content/330/6003/479 , LRO Diviner instrument website-http://www.diviner.ucla.edu

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

AO14 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***

AO15 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***
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AO16 Measuring atmospheric temperature, relative humidity, cloud and wind profiles with weather balloons

In this project, a simple weather balloon system and novel cloud detector (basically 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 and analytical 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***

AO17 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.

In this project, these observations will be reduced and analysed with our radiative transfer and retrieval tool, NEMESIS, to map the distribution of cloud, methane, and hydrogen sulphide in Neptune's stormy atmosphere. In particular, we believe our SINFONI observations may have coincided with the outbreak of a large dark spot on Neptune, of a type that has not been seen since the 'Great Dark Spot' observed by Voyager 2 in 1989. Our observations will enable a detailed study of the cloud structure around this feature and may provide crucial evidence to determine what these features actually are and how they form and evolve.

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***

AO18 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 images where each individual pixel is in fact a complete spectrum covering the wavelength range 490 – 930 nm, and returns of 'cubes' of data that contain an incredible amount of information.

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 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***

AO19 Can we determine the salinity of Arctic sea ice by taking its temperature

The recent rapid changes to the Arctic sea ice cover have lead to increasing seasonality of ice growth. This gives increasing significance to dynamic ice cover that is less than one year old, which is less understood than the older multiyear ice that dominated the past. The evolving salinity of sea ice is one such poorly constrained quantity, with a dearth of observations. As sea ice grows each winter by freezing saline ocean water, it forms a porous mixture of ice crystals that initially trap saline liquid brine. The salinity of sea ice impacts thermal properties controlling ice growth and melt, mechanical properties impacting break up, and the productivity as a biological habitat.The rate at which salty brine drains from sea ice into the ocean also provides an important control on buoyancy fluxes, mixing and circulation in the polar oceans [1]. However, direct measurements of the salinity of Arctic sea ice are challenging, and thus these salt fluxes remain poorly constrained. The goal of this project is to investigate a method for estimating the salinity of sea ice indirectly using measurements of ice temperature, via a novel application of adjoint-based inverse theory.

The temperature of sea ice evolves according to a heat equation, where the thermal properties are known functions of ice salinity. By comparing solutions of this heat equation to temperature measurements from Ice Mass Balance Buoys deployed in the Arctic [e.g. 2], we will infer the thermal properties that best explain the observational data (a so-called inverse problem). This project will approach this inverse problem by applying techniques from Partial-Differential-Equation constrained optimisation [3], exploiting the mathematical adjoint of the heat equation to efficiently identify the optimal thermal properties. By inferring how the thermal properties evolve over time, this suggests a new way to determine the corresponding time series of sea-ice salinity. This will provide a new method to estimate the salinity of sea ice, and a step towards significantly expanding the available salinity data, using the larger historical archive of temperature measurements.

This project provides an opportunity to build practical experience in computational methods for modelling continuum physical systems, along with the mathematical theories underpinning numerical methods, optimisation and inverse problems. Whilst computational methods and programming will be used during the project, no prior familiarity is required beyond the level of the usual undergraduate computing laboratory practicals.

Suggested background reading:

[1] Worster MG, Rees Jones DW. 2015 Sea-ice thermodynamics and brine drainage. Phil. Trans. R. Soc. A 373: 20140166. http://dx.doi.org/10.1098/rsta.2014.0166.

[2] Perovich, D. K., Richter-Menge, J. A. Jones, K. F. and Light B. (2008), Sunlight, water, and ice: Extreme Arctic sea ice melt during the summer of 2007, Geophys. Res. Lett., 35, L11501, doi:10.1029/2008GL034007.

[3] https://cs.stanford.edu/~ambrad/adjoint_tutorial.pdf

Supervisor: ***Dr A Wells***
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AO20 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***
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AO21 Nonlinear aerosol effects on clouds

Clouds act as air conditioners of the climate system by reflecting a vast amount of the sun's energy to space. An increase in anthropogenic aerosols, tiny particles commonly produced by combustion, are hypothesized to enhance cloud reflectivity through nucleation of more cloud droplets. As a result, anthropogenic aerosols may offset part of the global warming response due to the buildup of greenhouse gases. Although, the amount of cooling by aerosols is highly uncertain due in part to an assumed linear relationship between the cloud reflectivity and cloud droplet number concentration. The goal of this project is to quantify the linearity of the aerosol-cloud relationship over a wide range of spatial scales and meteorological conditions. The project will make use of multiple state-of-the-art satellite data sets and output from global climate models. The retrieved quantities will be obtained from active (e.g. radar and lidar) and passive imaging satellite products in a comprehensive analysis, also including corroborating measurements from surface-based instruments. These products will utilize the collocation tools within the Community Intercomparison Suite (CIS). Statistical methodologies will need to be developed based on theoretical models describing aerosol-cloud interactions in order to the quantify climate impacts.

The student will have the opportunity to deepen their computer programming skills, learn about and develop the theory behind aerosol cloud interactions, and apply numerous integrated datasets together to test a wide range of theoretical relationships on aerosol-cloud interactions. The project demands basic analytical and programming skills (preferably in IDL, Matlab, or Python).

Supervisors: ***Dr M Christensen*** and ***Prof P Stier***
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philip.stier@physics.ox.ac.uk

AO22 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***

AO23 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***

AO24 Retrieval of SO_2 (and ash) from HIMAWARI measurements

Desert dust is one of the most abundant and important aeroSulphur dioxide (SO_2) is an important atmospheric constituent, involved in many atmospheric processes. In the troposphere these include acidification of rainfall, modification of cloud formation and impacts on air quality and vegetation. In the stratosphere, SO_2 oxidises to form a stratospheric H_2SO_4 aerosol that can affect climate for several years. Volcanoes contribute about one-third of the tropospheric sulphur burden and data on the emission fluxes and total amount emitted are valuable to study volcanic process. There is a lot of uncertainties on the amount of SO_2 emitted from the volcano, and on the sulphur budget in atmosphere. Satellite measurements are used to detect and retrieve volcanic ash and SO_2.

Himawari-8 is a new geostationary satellite, operated by the Japanese Meteorological Agency, has exceptional space and time resolution (measurements every 10 minutes).

In this project the student will use Himawari-8 data to study the evolution of a volcanic plume. This will involve:

(i) Adapting existing radiative transfer to work for Himawari.

(ii) Studying the information content and performing an error analysis of a join ash & SO2 retrieval

(iii) Adapting the ash/cloud retrieval code (ORAC) to estimate SO2 amount.

(iv) Applying the code to measurements during of Aoba eruption (April 2018).

The project is computer-based, using the Interactive Data Language (IDL), and Fortran90, on machines which run the Linux operating system. Prior experience of either of these would be useful but is not essential.

Supervisors: ***Dr E Carboni, Dr S Proud*** and ***Prof R G Grainger***
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AO25 Representing small scale wind variability for improved weather and climate prediction

Weather and climate prediction is mathematically challenging. The atmosphere, oceans, land-surface, and their interactions, must be represented in a computer simulator. Due to limited computer resources, we can only afford to explicitly calculate the largest scales – those of the order 5-10km in a weather forecast, or 50-100km in a climate prediction. Smaller-scale processes, such as turbulence or clouds, are included using simplified representations called 'parametrisation schemes'. One pathway towards improved weather and climate prediction is to improve these parametrisation schemes. A new approach to parametrisation, called stochastic parametrisation, recognises that, given knowledge of the large-scale atmospheric flow, it is not possible to predict the evolution of the smaller scale processes with certainty. A stochastic parametrisation uses random numbers to represent our lack of knowledge about processes happening on these smaller scales.

This project involves developing a stochastic parametrisation scheme for turbulent transfer of momentum, heat and moisture between the ocean and atmosphere. This process is traditionally parametrised as a function of the large-scale wind speed; however, this does not account for the effects of unresolved sub-grid scale variability. As part of an international collaboration, we have collected statistics for the sub-grid scale variability in wind speed over ocean. The student would use these measurements to construct a stochastic parametrisation and explore the potential impacts of the stochasticity. How are the average turbulent fluxes impacted by the stochastic approach? How does the scheme impact the prediction of other atmospheric processes, such as convective thunderstorms? Can we improve probabilistic weather forecasts using the scheme?

In this project, the student will have the opportunity to cultivate his or her programming skills, work with an operational weather forecasting system, and learn about stochastic processes as a tool for representing uncertainty in dynamical systems.

Skills: Programming experience is very useful, though not essential: a drive to learn programming is more important. The project will make use of ideas about fluid dynamics and turbulent flows from the third year course. Ideally the student should be taking the fourth-year option 'Physics of the Atmosphere and Ocean'.

Supervisor: ***Dr H Christensen***
Email: ***Hannah.christensen@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***
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***AO28* Next-generation techniques for monitoring hazardous weather from space**

Severe convective storms, commonly known as thunderstorms, are a particularly hazardous type of weather: Such storms can produce hail, lightning, tornadoes, localised flooding events and extreme turbulence for aircraft nearby. Strong updrafts in the core of a convective storm can reach the tropopause, 12-18 km above sea level. For most storms, the tropopause acts as a barrier that prevents further vertical growth, with air in the updraft instead spreading horizontally along the tropopause, forming the distinctive anvil shaped cumulonimbus clouds that are often associated with stormy weather. The most severe storms, however, contain enough energy to break through the tropopause into the lower stratosphere, forming a dome-shaped cloud that extends above the main body of the anvil cloud. These dome features are known as overshooting tops, and are an excellent indicator that a storm poses a hazard to life and property. To enable adequate warning to be given to people in the path of such a storm, the rapid detection and analysis of overshooting tops is therefore a high priority issue for weather forecasters.

In this project, the student will implement a technique that enables the detection of overshooting tops in images from next-generation weather satellites, such as the Japanese Himawari-8/9 and American GOES-R/S satellites. This technique will form part of the Optimal Retrieval of Aerosol and Cloud (ORAC) algorithm being developed at Oxford and RAL-Space, enabling a step-change in our ability to detect, monitor and understand overshooting tops.

This project is computer based and will involve programming using Python and/or Fortran 90. Prior knowledge of these would be useful, but is not essential. This project will suit a student with an interest in severe weather and will involve working with world-leading convection and satellite data specialists in the UK, Europe and USA.

Supervisors: ***Dr S Proud*** and ***Prof R G Grainger***
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AO29* *Causal discovery in aerosol-cloud interactions

Anthropogenic aerosol particles, such as sulphate and soot, act to offset some of the global warming caused by the emission of greenhouse gasses, both directly by reflecting sunlight and indirectly by changing the properties of clouds. The magnitude of these effects, and hence projections of future global warming, are highly uncertain. Most of this uncertainty persists because of the difficulty in measuring the very small changes in cloud properties due to aerosols as compared to the main, meteorological, drivers of cloud formation. Strong non-linear feedbacks also prohibit traditional regression and correlation based approaches.

This project will use a novel class of machine learning algorithm which perform causal discovery based on the momentary conditional independence of observables, suitable for these non-linear interactions, to determine the role of aerosol in driving cloud properties. By determining the strength of any relationship in different regimes around the globe we may be able to discern the overall global effect.

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*** and ***Prof P Stier***
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AO30* *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***
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AO31 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***
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Astrophysics projects

AS01 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***
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AS02 The impact of a non-Gaussian likelihood on cosmological parameter constraints from weak gravitational lensing

Weak gravitational lensing is considered to be one of the most promising probes of the underlying cosmology as a result of its particular sensitivity to both the large-scale structure and expansion of the Universe, and forms a cornerstone in the present efforts to understand the properties of the dark energy that is causing the expansion of the Universe to accelerate. In cosmological parameter inferences from weak lensing, the likelihood is generally assumed to be Gaussian. Using a large suite of N-body simulations this has been shown to be incorrect by up to 30% of the measurement uncertainty for current surveys (Sellentin et al. 2018). We will develop methods to describe the full shape of the likelihood without employing the Gaussian approximation, and propagate this into parameter constraints to quantify the biases this approximation induces given current and future lensing data.

Required skills: General understanding of cosmology, statistics, and programming (ideally Fortran).

Supervisors: ***Dr S Joudaki*** and ***Dr H Desmond***
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harry.desmond@physics.ox.ac.uk

AS03 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.Strong programming skills will be required, preferably Python and/or C.

Supervisor: ***Dr J Allison***
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AS04 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***

AS05 **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 Arcminute 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***
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AS06 **Revealing the cosmic star formation history to high-redshifts with emission line galaxies**

Emission lines in galaxy spectra are produced in the ionised regions around young hot stars. The strength of these lines is therefore a tracer of the recent star-formation of a galaxy. Galaxies with strong lines (emission line galaxies; ELGs) can be found using spectroscopy, however this is inefficient and time intensive. An alternative approach is to use broad and narrow band photometric bands to select large samples of ELGs, as the strong lines produce unusual colours in certain filter combinations [e.g. 1,2]. This project will focus on using emission line galaxies in our new deep dataset [3] to measure the cosmic star-formation rate density as a function of cosmic time. Once a sample of emission line objects has been identified, the galaxy properties (e.g. stellar mass, star-formation rate) will be determined from spectral-energy distribution fitting allowing their relationship with the full galaxy population to be established. The multi wavelength data available (from X-ray to radio) will also allow the relationship between ELGs and active galactic nuclii to be determined. The exact direction of the project is flexible depending on the interests of the student. An alternative approach would be to use a recent machine learning code developed by our group, to learn the relationship between emission line luminosity and the multi-band photometry.

[1] https://arxiv.org/abs/0707.3161

[2] https://arxiv.org/abs/1202.3436

[3] http://www-astro.physics.ox.ac.uk/~video/public/XMM-LSS.html

Requirements

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

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

AS07 **Modified gravity explored through hydrodynamical simulation**

Tests of General Relativity and its alternatives abound on laboratory, Solar System and cosmological scales, but are very rare on the intermediate scale of galaxies. This is despite a number of interesting theories exhibiting their strongest if not their only signals in galaxy structure and dynamics; these include offsets between the kinematics and centres of mass of stars and gas, warping of stellar disks and irregularities in rotation curves, all correlated with gravitational environment.

The factor limiting the use of these signals to probe gravity is the degeneracy between gravitational and baryonic degrees of freedom. The latter describe gas dissipation and stellar feedback, and may mimic the effects of modified gravity by means of processes such as hydrodynamical drag, ram pressure and energy exchange between galactic mass components. The best way to explore these effects is through ‘cosmological hydrodynamical simulations’, which track the effects of baryonic physics on galaxy evolution under standard gravity.

In this project the student will analyse the output of Oxford’s flagship hydrodynamical simulation -- the Horizon-AGN simulation and its successor New Horizon -- to quantify the magnitude and environment-dependence of potential modified gravity signals produced by galaxy formation physics alone. This is crucial groundwork for assessing the significance of any putative deviation from General Relativity in observational data.

Strong programming skills will be required, preferably Python and/or C.

Supervisor: ***Dr H Desmond***
Email: ***harry.desmond@physics.ox.ac.uk***

AS08 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***
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AS09 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***

AS10 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***

AS11 & AS12 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***

AS13 Modelling the connection between galaxies and dark matter halos

While correlations among galaxy properties are known empirically from surveys, and those among halo properties are known from dark matter-only simulations, the relations between galaxy and halo properties remain unclear. It is these that we expect to hold the key to galaxy formation in a universe dominated by cold dark matter.

A popular technique for inferring the relation between galaxy and halo mass is 'abundance matching': essentially one assigns the nth most massive galaxy observed in a given region to the nth most massive halo produced in a simulation box of the same volume. Traditionally the measure of galaxy mass has been stellar mass, which is relatively easy to measure. However, a sizeable fraction of galaxies' baryonic mass budgets -- particularly at low mass -- is comprised of cold gas, and the requisite data now exists to upgrade abundance matching to use total baryonic mass (stars + gas). Not only will this provide insight into the physical processes governing the co-evolution of baryons and dark matter, but may also shed light on several apparent failings of LCDM at the dwarf galaxy scale.

To perform this project the student will combine data on galaxies' gas masses from the ALFALFA HI survey with stellar masses from optical surveys, connect this with the halo population from an N-body simulation by abundance matching, and test the result by examining statistics of the galaxy population such as clustering and internal dynamics. Knowledge of Python will be required, and C/C++ may come in handy.

Supervisor: ***Dr H Desmond***
Email: ***harry.desmond@physics.ox.ac.uk***

AS14 Machine Learning for Citizen Science

As astronomical datasets become larger, the need to find new ways of identifying objects of interest is becoming ever more important. This project will make use of data from the Oxford-led Zooniverse project, which invites hundreds of thousands of volunteers to help analyse astronomical data, alongside modern `deep learning' machine learning techniques. Our work so far has shown that this combination of human and machine classification has great potential, and this project will explore either novel applications of machine learning or novel ways of combining with citizen science projects. The initial project will likely use data from 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*** and ***Dr B Smethurst***
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AS15 Gravitational lensing magnification and its effect on cosmological measurements.

Weak gravitational lensing has become one of the cornerstones of our understanding of cosmology, and the Euclid space mission will launch in 2021 to measure weak lensing to unprecedented precision. In this project we investigate the biasing effect of lensing magnification on the measurements and how this might affect our conclusions about the cosmological model.

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

AS16 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***

AS17 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***

AS18 Modelling the variable X-ray spectrum of an accreting black hole binary system

The accreting black hole binary system V404Cyg had an extraordinary period of highly variable outbursts of X-ray emission in 2015. We still struggle to fully understand the physics of what happened. In this project we will use a Monte Carlo approach to modelling the propagation of X-rays through the gas around the black hole system, and test whether a simple model of that gas can reproduce some of the key features of the observations.

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

AS19 Characterising Asteroids with Spectroscopy on the PWT

Asteroids are taxonomically classified into different types based on the shape of their spectra. Most asteroids fall into three groups: C, S, and X; but there are about 20 other rarer groups. Around 1500 asteroids currently have classifications (primarily from the SMASS survey in 2002). This is enough to understand the general population, but many asteroids remain unclassified. This project will extend a previous successful MPhys project to make the classification a semi-automatic long term programme from Oxford.

The Philip Wetton Telescope (PWT) is a 40-cm telescope on the roof of the Denys Wilkinson building. It has a fairly advanced control system and set of instruments, meaning that even though it is relatively small, it can make interesting observations. A previous MPhys project (2015) demonstrated the potential for using the PWT to spectroscopically classify asteroids, but only managed a handful of objects (though in enough detail to warrant a potential publication currently in progress).

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

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

Special Requirements

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

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

AS20 tbc

More details from the supervisor.

Supervisor: ***Prof D Rigopoulou***
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AS21 **The Merger Fraction in the Galaxy Group environment**

The merger of two galaxies is thought to be one of the main processes driving galaxy evolution. Mergers of galaxies become more likely in dense environments of galaxy groups and clusters. However, theory tells us that the more massive a group of galaxies, the more energy is available in the system and so the relative velocity between galaxies will increase. This predicts that mergers should therefore become less common in more massive galaxy groups.

In this project, the student will investigate how the fraction of merging 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).

Supervisors: ***Dr B Smethurst*** and ***Prof C Lintott***
Email: ***chris.lintott@physics.ox.ac.uk***

AS22 **Instrumentation on the Philip Wetton Telescope**

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

Potential instrumentation projects include;

+ Automating the existing slit spectrograph to allow robotic operation

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

+ Designing a new spectrograph for an integral field unit

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

+ Characterising a new cheap fast camera for wavefront sensing

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

Special Requirements

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

Supervisors: ***Dr F Clarke*** and ***Dr R Barnsley***
Email: ***fraser.clarke@physics.ox.ac.uk***

AS23 **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***

AS24 **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***

AS25 **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***

AS26 **tbc**

More details from the supervisor.

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

AS27 **Breaking the dark matter degeneracy using stellar proper motions**

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

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

Special skills: Knowledge of the Python programming language.

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

AS28 **Quantifying and classifying the cosmic web**

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

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

AS29 Combining photometric redshift surveys and HI intensity mapping

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

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

AS30 **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***

AS31 **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***

AS32 **C-Band All Sky Survey project s(C-BASS)**

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

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

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

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

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

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

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

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

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

AS33 **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***

AS34 Astro: Statistical cross-matching of galaxies at radio and optical/near-infrared wavelengths

We are entering an era where deep radio data from the South African MeerKAT telescope provide us with new insights into the star formation rates and black-hole accretion activity in distant galaxies (from the nearby Universe through to redshifts z>6). However, on their own they are of limited use, and to enable clearer understanding of the formation and evolution of galaxies we need to cross-match the radio emission with the galaxies that are found at optical and near-infrared wavelengths. However, the radio data has much poorer angular resolution (~5arcsec) compared to the ground-based optical imaging (typical <1arcsec), therefore identifying which optical galaxy produces the radio emission becomes challenging. In this project the student will develop a Bayesian method to attach a probability for each galaxy in being responsibly for any associated radio emission in its vicinity. Building on well developed ideas that use a single optical colour, the student will extend this to include multiple colour data and hence obtain a much better measurement of the likelihood of a galaxy generating radio emission. The project will contribute to the MeerKAT international Giga-Hertz Tiered Extragalactic Exploration (MIGHTEE) survey collaboration , one of the key science projects underway on the MeerKAT telescope, and the work by the student could form one of the key data products to the team, providing the student with ample opportunities to contribute to publications.

Supervisor: ***Prof M Jarvis***
Email: ***matt.jarvis@physics.ox.ac.uk***

Biological Physics projects

BIO01 **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: study the diffusion of DNA-repair machines inside bacterial cells; establish smartphone-based single-particle imaging and optimize its sensitivity; perform image analysis of single-particle images from smartphone cameras; apply smartphone imaging to detect pathogenic viruses and bacteria; 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 or experience 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.

Supervisor***: Prof A Kapanidis***
Website:***kapanidis.web.ox.ac.uk***
Email***: achillefs.kapanidis@physics.ox.ac.uk***

BIO02 **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***

BIO03 **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***

BIO04 Biosensors for Rapid Virus Detection

Infectious diseases caused by viruses (influenza, HIV, hepatitis, measles etc.) represent a huge global public health concern. The earlier a viral infection is detected the more effective the treatment, however, currently available tests require a long time and can lack specificity/sensitivity. We use a compact TIRF microscope that has the potential to be used in clinical settings to develop novel virus detection methods, based on single-molecule fluorescence imaging and single-particle tracking. In this way, detection can be completed in just a few minutes, as opposed to current in-use technologies that require many hours.

The project will extend the existing biosensing work being carried out in the lab in many possible ways. Examples include the use of aptamer- and nanotechnology-based approaches (such as sialic acid functionalised gold nanoparticles) to label viruses, as well as exploring how the assays can be adapted to clinical settings and clinical virus isolates (through the use of microchannel devices, fluidics or smartphone microscopy for example). The project will also involve large-scale batch-analysis data reduction and the use of supervised machine-learning algorithms to classify detected viruses.

No prior knowledge or experience of biophysics is necessary; however good analytical and programming skills (particularly with MATLAB) would be an advantage. Introductory literature will be provided.

Supervisor***: Dr N Robb***
Website: ***https://robb.web.ox.ac.uk***
Email***: Nicole.Robb@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 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***

CMP02 "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 nanoworld. 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***

CMP03 Dipolar fields at muon sites in complex crystal and magnetic structures

Muons implanted into materials can be used to measure local microscopic fields [1]. This theoretical and computational project will link crystal structures, as codified in the ".cif" (crystallographic information framework) file format [2,3], with predictions of the dipolar field [4] measured in muon-spin rotation experiments, exploiting any symmetries possessed by the particular crystal or magnetic structure. Programs will be written using the Python computer language.

Background reading:

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

[2] S. R.Hall, F. H. Allen, and I. D. Brown, Acta Cryst. A47, 655-685 (1991).

[3] https://www.iucr.org/resources/cif

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

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

CMP04 Simulating level crossing resonances in muon-spin relaxation spectra

Implanted muons [1] will interact with the local environment via dipolar, quadrupolar or hyperfine interactions. In some circumstances the energy levels of the muon will match an energy level in its environment and a resonant interaction can occur [2,3]. These level crossing resonances can be produced by sweeping the applied magnetic field to produce this energy-level matching condition and can be observed by detecting a dip in the muon's polarisation. The purpose of this project is to simulate [4] this effect for a wide variety of interactions and also including dynamical effects. Programs will be written using the Python computer language.

Background reading:

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

[2] A. Abragam, C. R. Acad. Sei. Paris 229, 85 (1984).

[3] S. F. J. Cox, Z. Naturforsch. 47a, 371 (1992).

[4] P. L.W. Tregenna-Piggott, E. Roduner, S. Santos, Chem. Phys. 203, 317 (1996).

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

CMP05 Fermi surface topography of iron-based superconductors

A Fermi surface is an essential concept to understand metallic and unconventional electronic states. Fermi surface can display beautiful and complex geometrical shapes that contains important information about the physical phenomena displayed by real materials. Among these, superconductivity is an instability of the Fermi surface in the presence of unconventional attractive interactions that cause pairing of electrons. The resulting superconducting gaps or the type of pairing is strongly linked to the details of the Fermi surface. Thus, in order to develop new models for superconductivity as well as to predict superconductivity at high temperatures one needs to be able to understand all essential ingredients of the electronic structure of a material.

This project is a computational and analytic study of the electronic structure of FeSe and related compounds in order to determine the exact topography of its Fermi surface. The student will use existing software in Matlab and further develop functions to predict the angular dependence of the Fermi surface and compare to available quantum oscillations data. Once the Fermi surface is fully determined the project can be extended to include predictions about the magnetotransport behaviour and specific heat.

This is a computational project and a suitable candidate for this project should have good knowledge of condensed matter courses and strong computation skills (Matlab, Phyton). For further questions please email amalia.coldea@physics.ox.ac.uk.

For further details, please read:

The Key Ingredients of the Electronic Structure of FeSe https://arxiv.org/abs/1706.00338, Annual Review of Condensed Matter Physics, Vol 9 (2018)

Emergence of the nematic electronic state in FeSe, Phys. Rev. B 91, 155106 (2015), https://arxiv.org/abs/1502.02917

Detailed Topography of the Fermi Surface of Sr2RuO4,

Phys. Rev. Lett. 84, 2662 (2000), https://doi.org/10.1103/PhysRevLett.84.2662

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

CMP06 Quantum oscillations of novel quantum materials with Dirac dispersions

Topological Dirac-semimetals are electronic materials with strong spin-orbit interaction that can display unconventional protected electronic properties. Their behaviour originates from Dirac-band dispersions either of the bulk and unusual topological surfaces protected by symmetry. In ordinary materials, backscattering, in which electrons take a turn back owing to collisions with crystal defects, effectively degrades the current flow and increases the resistance. On the surface of topological protected systems, backscattering processes are completely suppressed, so charge transport is in a low-dissipation state with exceptional transport mobility and reduced energy consumption, extremely attractive for different practical applications.

This project aims to probe the Fermi surface and the topological signatures in quantum oscillations of novel Dirac materials. This project is mainly a computational study of quantum oscillations and requires comparing experimental data with predictions based on first-principle band structure calculations. This project can be expanded to include quantum oscillations experiments using high magnetic fields and low temperatures.

A suitable candidate should have a strong background in condensed matter physics and advanced computational skills, such as using Matlab and Python. The student will compare existing experimental data with band structure calculations using Wien2k.

Further reading:

Linear magnetoresistance caused by mobility fluctuations in the n-doped Cd3As2

Phys. Rev. Lett. 114, 117201 (2015)

Topological surface electronic states in candidate nodal-line semimetal CaAgAs

https://arxiv.org/abs/1708.06484

Quantum Oscillations in Nodal Line Systems

https://arxiv.org/abs/1801.02733

Wien2k is a software allowing electronic structure calculations of solids using density functional theory (DFT); http://susi.theochem.tuwien.ac.at/

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

CMP07 Micromagnetic Study of the Stability and Interactions of Magnetic Skyrmions

Magnetic skyrmions are recently discovered vortex-like magnetization structures with a non-zero topological winding number. This winding prevents the skyrmion from being smoothly deformed into other low-energy magnetization states, as well as granting skyrmions a myriad of novel properties. It has recently been shown experimentally that symmetry breaking at the surface of materials forces the skyrmion texture to twist over a length scale of hundreds of atomic layers [1]. The impact that this has on the stability of skyrmions, as well as their interactions, is currently unknown.

In this project, the student will numerically calculate minimum energy paths between magnetization states to derive the energetic stability of twisted surface skyrmions in geometrically conned systems. Additionally, twisted skyrmion interaction potentials will be studied numerically/analytically. The student should be familiar with Python and have a strong interest in programming.

References

[1] S. L. Zhang et al. Reciprocal space tomography of 3D skyrmion lattice order in a chiral magnet. Proceedings of the National Academy of Sciences, 115:6386, 2018.

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

CMP08 Tunnel diode oscillator technique to explore electronic properties of novel quantum materials

The tunnel diode is an excellent amplifier element in cryogenic circuits. Its operation of the diode is a consequence of quantum mechanics and it is resilient under a wide range of harsh conditions that do not interfere with the tunneling itself. Tunnel diodes can be used at frequencies well into the GHz, are stable at cryogenic temperatures, operate in magnetic fields of at least 45T. Disadvantages include the need to bias the 2-terminal device, sensitivity to heat by soldering and static electricity, and the narrow range of different diodes presently available. Measurement circuits with a tunnel diode oscillator can use an inductor as the transducer element, as a coil wrapped around a single crystal. The oscillation frequency of the circuit is perturbed by the sample is placed inside the inductor.

Tunnel Diode oscillator is considered as a powerful technique in studying a wide range of material properties because of its flexibility, sensitivity, high resolution and the contactless nature of the measurement. The TDO can probe different physical properties like skin depth or resistivity in metals, upper critical field and penetration depth in superconductors and dynamical susceptibility and magnetic transitions in insulating magnetic materials. The TDO has been successfully used to measure superconducting transitions and the quantum oscillations in resistivity as a function of the magnetic field. TDO has an advantage on other techniques since it can be used to perform a contactless measurement when studying samples with poor contact surfaces. The TDO is a valuable method in studying quantum oscillation in different materials.

This project aims to optimize and use an existing tunnel diode oscillator at low temperature and high magnetic fields. This technique will be used to probe experimentally the electronic properties of novel quantum materials (either topological Dirac materials or superconducting materials) in high magnetic fields and at low temperatures. A suitable candidate for this experimental project should have good knowledge of condensed matter courses and electronics, attention to detail and good experimental skills. Good computational skills would be valuable to the project.

Further reading:

Tunnel diode oscillator for 0.001 ppm measurements at low temperatures

Review of Scientific Instruments 46, 599 (1975); https://doi.org/10.1063/1.1134272

Radio-frequency impedance measurements using a tunnel-diode oscillator (TDO) technique

Review of Scientific Instruments 70, 3097 (1999); https://arxiv.org/abs/cond-mat/9904026

Linear magnetoresistance caused by mobility fluctuations in the n-doped Cd3As2

Phys. Rev. Lett. 114, 117201 (2015); https://arxiv.org/abs/1412.4105

Topological insulators and superconductors,

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

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

CMP09 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.

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***

CMP10 Modelling vortex dynamics inside novel superconductors in magnetic fields

Superconductivity has a very large number of practical applications from superconducting magnets, used in MRI scanners, to levitating trains. Due to its zero resistance state, the ultimate use of a superconductor is for the reduction of the energy consumption. One challenge is to find suitable materials to work at higher temperatures towards room temperature. To test realistic materials for potential applications one needs to know their phase diagrams, in particular of the critical current and the critical magnetic field.

This project 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, 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.

Further reading:

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

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

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

https://ieeexplore.ieee.org/document/8249836

Numerical approximations of the Ginzburg–Landau models for superconductivity

https://aip.scitation.org/doi/pdf/10.1063/1.2012127?class=pdf

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

Ultra-high critical current densities, the vortex phase diagram and the effect of granularity of the stoichiometric high-Tc superconductor, CaKFe4As4 https://arxiv.org/pdf/1808.06072v1.pdf

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

CMP11 Microphotoluminescence measurements of carrier diffusion in semiconductors

The project involves using cryogenic microphotoluminescence techniques to investigate the diffusion of carrier 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***

CMP12 Control of antiferromagnetic order by applied stress

The spin Jahn-Teller effect stabilises 3D magnetic order in an otherwise frustrated system via magnetoelastic coupling, spontaneously at a magnetic phase transition. Examples are rare, and limited to crystals of high symmetry. We have recently shown that certain low symmetry crystals can also exhibit spin Jahn-Teller antiferromagnetism. In these cases low dimensional magnetism persists above the Neel temperature, allowing, in principle, for the 3D antiferromagnetic order to be switched on and off by an applied stress – a novel material functionality of interest in the field of spintronics and oxide electronics. In this project, the student will experimentally characterise structural and magnetic properties of new, low symmetry spin Jahn-Teller magnets under applied stress. They will also develop phenomenological theories to describe their experimental results.

Suitable for a student taking the C3 CMP option.

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

CMP13 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***

CMP14 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 eld gradients, making them attractive as energy ecient 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, reshuers 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 effectively modelled using molecular dynamics [2].

This project will involve the student using and further developing code to study, benchmark and explore skyrmionic devices on length-scales 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 eld 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.

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

CMP15 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

CMP16 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***

CMP17 High power response in circuit quantum electrodynamics

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

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

CMP18 Flux-tuneable qubits and couplers 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. In this project you will explore the introduction of such tuneable elements into our quantum computing architecture, including the design and testing of the circuits themselves and the engineering of their control with magnetic fields. Depending on progress you may be able to measure and analyse quantum coherence properties of novel qubit designs, or implement quantum logic gates based on the tuneable elements. 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 ***Dr P J Leek***
Email: ***brian.vlastakis@physics.ox.ac.uk***, ***peter.leek@physics.ox.ac.uk***

CMP19 Stability of qubit properties 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 the statistical correlations of these qubit properties with environmental parameters such as the temperatures of key components in the measurement setup, and work on improving qubit stability by stabilising the correlated parameters. Success in this project could lead to crucial improvements in performance of quantum circuits. The project will involve any of: computer programming, measurements and data analysis, hands-on soldering and component assembly, electric circuit design. 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 S Jebari*** and ***Dr P J Leek***
Email: ***salha.jebari@physics.ox.ac.uk***, ***peter.leek@physics.ox.ac.uk***

CMP20 Josephson parametric amplifiers (JPAs) for superconducting qubit readout

Superconducting electric circuits are proving to be a strong candidate for building the world's first useful universal quantum computer within the next decade. These circuits exploit the existence of an exotic non-linear circuit element called a Josephson junction. These junctions can also be used to build a new kind of quantum-limited amplifier called a Josephson parametric amplifier (JPA), which can in turn be used in high fidelity readout of superconducting qubits, crucial for quantum computing. We are developing a new type of JPA which has good characteristics for measuring many qubits with different transition energies. In this project you will perform experiments on a range of these JPA devices built in the group to characterize key parameters like their gain, bandwidth and noise, and investigate ways to improve them. Depending on progress, you may move on to use the JPAs in quantum-limited qubit readout and generation of non-classical microwave signals. The project will involve any of: measurements and data analysis, hands-on soldering and component assembly, circuit design and simulation, computer programming. 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 M Esposito*** and ***Dr P J Leek***
Email: ***martina.esposito@physics.ox.ac.uk***, ***peter.leek@physics.ox.ac.uk***

CMP21 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***

CMP22 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***

CMP23 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 has been shown to lead to a manifold decrease in sheet resistance in corresponding thin films [2]. 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.

Supervisors: ***Dr M Riede*** and ***Prof R Nicholas***
Email : ***moritz.riede@physics.ox.ac.uk; robin.nicholas@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 **Characterisation of a modular insert for transport measurement of novel materials at high magnetic fields and cryogenic temperatures**

Oxford Instruments NanoScience has recently developed a new range of inserts for performing low-noise transport measurements in superconducting magnets and at temperatures as low as 50 mK. The new insert is compatible with a wide range of sample holders and incorporates a plug-and-play "universal interface" that allows the insert bottom to be easily changed. The system allows in-situ rotation via either a mechanical or piezoelectric rotator, and includes a specially designed low-noise signal chain with associated electronics.

The primary aim of this project would be to characterise the suitability of the new insert and sample holders for performing low-noise measurements on the novel materials of interest in condensed matter physics. Ideally, this project would involve measurement of a sample that is known to show interesting physical phenomena (such as Shubnikov-de Haas oscillations) as a function of angle, field and temperature using the new insert. This would then be compared with similar measurements on the same material in either a home-designed probe or alternative commercial solution (e.g. PPMS). Properties to be assessed are temperature stability, eddy current heating, the signal-to-noise ratio, the resolution of the rotation, and the effect of rotation on the sample temperature and on the noise level.

The experimental project will be performed in the Oxford Centre for Applied Superconductivity and at Oxford Instruments facilities in Tubney Woods. The academic supervisor is Dr Amalia Coldea. The student will have the opportunity to interact closely with the industrial supervisor and engineering community located at Oxford Instruments. A suitable student for this project would require good knowledge of condensed matter physics and keen interest in experiments, electronics and noise analysis.

Industrial Supervisor: ***Dr Z Melhem*** (Oxford Instruments)
Oxford Supervisor: ***Dr A Coldea***
Email: ***Amalia.Coldea@physics.ox.ac.uk***

IND002 **Raman spectroscopy of confined liquids**

The task is to set up a variety of Raman spectrometers operating at different wavelengths to analyse the chemical decomposition of liquids through the wall of a confining glass container. The feasibility of spatially-offset Raman spectrocopy (SORS) and stimulated Raman scattering (SRS) will be explored.

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

Interdisciplinary projects

INT01 **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***

INT02 **Particle acceleration by astrophysical shocks**

Cosmic rays are particles (mostly protons) arriving at the Earth with energies up to 1020eV. The origin of the highest energy cosmic rays is unknown, but the most likely scenario is that they are accelerated by shocks generated by relativistic jets emerging from massive black holes at the centre of active galaxies. Particle acceleration by shocks is generally a stochastic process, but a single-shot interaction with the shock may be needed to provide the final energy boost beyond 1020eV. The aim of the project is to write a computer program to model proton trajectories in magnetic fields to see whether single-shot energy gains by a factor of 5-10 are possible. Programming skills are essential.

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

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

INT03 & 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 & INT06 **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***

INT07 **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***

INT08 **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***

INT09 **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***

INT10 **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***

INT11 **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***

INT12 **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***

INT13 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***

INT14 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***

INT15 **Monitoring depth of anaesthesia**

Anaesthetists currently have no robust way of knowing when an individual experiencing general anaesthesia stops perceiving the outside world. At the Wellcome Centre for Integrative Neuroimaging at the John Radcliffe Hospital, we are developing a depth of anaesthesia monitor based on our individualised measure of perception loss called slow wave activity saturation (SWAS). Our previous experiments, using electroencephalography (EEG) and functional magnetic resonance imaging (FMRI), indicate that the brain's electrical activity at slow wave frequencies (0.5-1.5Hz) saturates with increasing anaesthetic dose. We believe this saturation point represents the key transition when an individual's brain becomes disconnected from the external world and sensory events.

We have recently developed a real-time Bayesian prediction model that will allow titration of anaesthesia to SWAS, thus achieving perception loss within that individual. It dynamically tracks changes in the individual's brain's electrical activity as a function of drug concentration. The model has several free parameters that may be dynamically updated across time and with varying anaesthetic dose. For the MPhys project, you will help optimise the SWAS model using EEG datasets acquired during surgery and in healthy volunteers. You will also work with us to refine a prototype anaesthesia monitoring system that is currently being applied in patients pre-surgery to titrate anaesthesia to SWAS. It would help for you to have taken the S10 short option, although this is not essential, but you should have experience of Matlab programming and good written and verbal communication skills.

Supervisors***: Dr K Warnaby, Prof M Allen, Dr S Jbabdi*** and ***Prof P Jezzard***
Email: ***myles.allen@ouce.ox.ac.uk***

Particle and Nuclear Physics projects

PP01 **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***

PP02 **Using Machine Learning to select dark matter particles at the LHC**

The ATLAS experiment takes 40 million shapshots per second of proton-proton collisions from the Large Hadron Collider. However only it's practical to save one in 100,000 of those collisions. The choice of which events to record is made by online algorithms known as the triggers, which select a range of the most interesting events for further physics analysis. A particularly important case is selection events with apparent momentum imbalance – the characteristic signature of invisible dark matter particles.

In this project the student will the student will use state-of-the-art machine learning tools, such as convolutional neural networks, to create a trigger for dark matter. They will make use of LHC data and on simulations of dark matter events for training it, and compare its performance to existing ATLAS algorithms. Previous experience of programming, particularly in python, would be helpful.

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

PP03 **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.

Supervisors: ***Dr X Lu*** and ***Prof A Weber***
Email: ***xianguo.lu@physics.ox.ac.uk***

PP04 ***Physics sensitivity of T2K Near Detector Upgrade***

The T2K Experiment in Japan is under-going an upgrade that will potentially enable a 3-sigma discovery of leptonic CP violation (LCPV) which is beyond the Standard Model of particle physics. Its Near Detector (ND) is responsible for determining the neutrino beam properties and measuring neutrino interaction details with high precision. Simulation data have been produced to study the impact of the ND upgrade. Analysis of these data provides both crucial feedback to the R&D on the future physics capability, and preparation for physics analyses planned with data to be taken from 2021.

In this project, the student will analyse the simulation data produced by T2K, extract detector performance information, establish physics analysis framework, and assess the physics potential of the upgraded T2K. The project demands good programming skills in C/C++ and proficiency on Linux operating system. It also requires good communication skills in a collaborative environment.

Supervisors: ***Dr X Lu*** and ***Prof A Weber***
Email: ***xianguo.lu@physics.ox.ac.uk***

PP05 **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***

PP06 **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***

PP07 **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***

PP08 **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***

PP09 **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 Weatherall***
Email: ***daniel.weatherill@physics.ox.ac.uk***

PP10 **Optimisation of algorithm for longitudinal profile image reconstruction of femtosecond electron bunches**

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

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

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

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

PP11 **Theoretical and experimental studies of multi-cell asymmetric cavity for Energy Recovery Linac**

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

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

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

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

PP12 **Designing a future vertex detector for the LHC**

The LHCb detector at CERN is world-leading in its exploration of heavy quark decays. Building on this current success, a detector upgrade is under consideration for the late 2020s.

If this upgrade proceeds, the silicon vertex detector that the heart of the experiment, will be rebuilt with advanced pixellated sensors with high timing resolution.

This project offers a student the opportunity to author the key physics performance design studies that will guide the engineers in their conceptualisation. Using a fast simulation package, a simplified model of the LHCb vertex detector will be written and particle tracking parameterised. These tools would be used to characterise the physics performance as a function of design parameters (e.g. pixel size, location, clock-length and material). This work will be highly topical and visible in the collaboration. No prior experience is required but the 3rd yr lab “NP10: search for mesons containing b-quarks” provides a general introduction.

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

PP13 **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***

PP14 & PP15 **Higgs Self-Coupling and Search for New Physics with di-Higgs to final states with the ATLAS detector**

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

Depending on the interest of the student it could also involve phenomenological studies on the Higgs self-coupling measurement which the di-Higgs process is sensitive to.

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

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

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

PP016 **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***

PP17 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***

PP18 Absolute distance interferometry using a frequency comb

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

In 2015 FSI measurements were made at the German national institute of standards (PTB) in Braunschweig in which in addition to multiple gas absorption cells and a precision reference interferometer and a state of the art, high precision frequency comb was used to record beat patterns of the scanning lasers with the comb laser. This data has only been peripherally analysed yet and could lead to new methods for improving the spectroscopic methods used in FSI and hence improve the distance measurement accuracy.

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

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

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

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

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

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

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

The project is open ended and only a small fraction of data has been analysed been analysed in a summer project last year.

How many of the above points can be dealt with depends on the student and on the data.

The project is entirely analysis based and demands good analytical skills and good programming skills with some experience in Matlab or Java preferred.

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

PP19 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***

PP20 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***

PP21 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***

PP22 **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.

PP2201 **Using LHC measurements of precision ratios to search for new physics**

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

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

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

PP2202 **Precise measurement of the W boson mass**

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

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

PP2203 **Measurement of Higgs boson production in decays to W bosons**

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

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

Theoretical Physics projects

TP01 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***

TP02 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***

TP03 Dimer models on quasicrystals

Ionized gas, called plasma, generates and responds to How many ways are there of tiling a chess board with dominoes? This is an example of a classical dimer model. Removing one domino reveals the two squares it covered: one black, one white. These can be viewed as a particle-antiparticle pair. Further domino re-arrangements allow the particles to move around on the board. This simple model turns out to have deep implications for strongly-interacting theories of physics.

This project will consider dimer models on 'quasicrystals': aperiodic tilings which can be constructed as slices through higher-dimensional crystals. Can dominoes (dimers) be placed on the tiling's edges such that every vertex connects to one dimer? Or must there be a finite density of particle-like defects? The project will require some programming in python, but can be taken in either an analytical or numerical direction. For relevant background see arxiv.org/abs/1902.02799.

Supervisor: ***Dr F Flicker***
Email: ***felix.flicker@physics.ox.ac.uk***

TP04 Dynamics and Substructure of the Milky Way Disk

With the advent of Gaia satellite data (kinematics and positions of stars throughout the disc) and Gaia's follow-up high-resolution spectroscopic surveys (giving us precise stellar abundances and ages), we can for the first time examine in detail the history and dynamics of the Milky Way. These data have revealed an impressive wave-like pattern of mean stellar motion vs. angular momentum

We can explain this wave-like pattern by the Galactic bar and spiral. The detailed structure observed in stellar kinematics contains much more information than that. It does not only betray what is responsible for this pattern, but it also gives detailed information about, e.g. the mass and precise pattern speed of the bar, or in the case of vertical waves of the disc, the mass and orbit of the satellite that fell into the disc, as well as the density and kinematic properties of the dark matter around the disc. The project will entail an investigation of the observed data in action space with the hope to identify signals of orbital resonances. We will also launch test particle simulations in a perturbed potential to examine resulting velocity substructure. Depending on how far you want to go in this research, these results again can be compared not only to the data, but also to analytic perturbation theory and/or full N-body simulations that incorportate the non-linear response of the disc.

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

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

_TP05_ Chemodynamical Evolution of the Milky Way Thick Disc

As kinematics, i.e. the motion of stars, change over their lifetime, the only information we have about the origin of a star, is its chemical composition together with some information on its age. This chemical composition is inherited from the gas cloud that collapses into the star, with very minor alterations afterwards. Understanding this information is key to quantify the history and dynamics of any stellar system, in our case the components of our Galaxy. One central question here is the origin of the Galactic thick disc, a chemically distinct population that has a larger vertical extent from the disc mid-plane, consists of older stars and appears to have a shorter radial extent. While the system is well-described, we currently do not know, what gave rise to the large vertical extent of this population.

The project will make use of an existing model of detailed chemical evolution of several elements, which is also capable of predicting kinematic information and modeling observations we compare to. From the current Gaia satellite mission and its follow-ups, we will have high-precision data to which we can compare. The most obvious task will be to compare the observed spatial extent of the thick disc to estimates for its size due to stellar radial migration, which can transport thick disc stars from the central regions to the outer disc. Depending on your skills and interests, we can also compare with results from N-body simulations.

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

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

_TP06_ Probabilistic Parameter Determinations of Stars or Galaxies

From the Gaia satellite mission and its follow-up surveys, we have a vast abundance of measurements on stellar parallaxes, proper motions, line-of-sight velocities, as well as spectra that provide temperatures, surface gravities and stellar abundances, from which again stellar ages can be determined. While this data is the greatest treasure of information that Galactic Astronomy has ever seen, it is also very dangerous to use. Having millions up to billions of stars, Poisson noise in the sample plays no role, and systematic biases dominate the scientific results. Whoever manages to control these biases gains access to reliable information on previously unexplored (or misunderstood) parts of the Galaxy. This project will make use of advanced statistical methods to gain improved information on stellar parameters. It can be played at different levels. In the simplest version, we will derive unbiased distances for combined parallax + spectroscopic data and use these to investigate the structure of the Milky Way halo and the galactic disc. For more engaged students, we can use our existing Bayesian parameter pipelines to derive full stellar parameter sets including e.g. stellar ages, which can then provide information on the history and structure of the Milky Way. Depending on interests, we can also use these data to measure the gravitational field and hence dark matter content of our Galaxy.

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

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

_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_ Modelling DNA

In this project you will use oxDNA to study either biophysical properties of DNA, or the physics of DNA nanostructures.

Look at dna.physics.ox.ac.uk for more information on the potential projects.

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

_TP09_ Physics of machine learning

In this project you will use concepts from statistical mechanics and algorithmic information theory (AIT) to understand why deep learning with neural networks works so well. See K. Dingle, C. Q. Camargo and A. A. Louis

Nature Comm. 9, 761 (2018) for background on AIT.

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

TP10 **Signature of spiral structure in Gaia data**

Density waves must be running through the disc of our Galaxy. There have been tentative detections in pre-Gaia data of the shift in mean stellar velocity caused by such waves, but these detections are far from secure. On 25/4/2018 the quality of the relevant data will increase dramatically when ESA releases the first major tranche of Gaia data. This project involves fitting not only the shifts in mean velocity but also changes in velocity dispersion that arise as the gravitational field compresses the stellar plasma, which has not been considered before. We would start by using test-particle simulations to check the correctness of a rather intricate analytic computation of the impact of a wave. Then the analytic formulae would be used to extract from Gaia data the amplitude and phase of the waves running through the solar neighbourhood. If time allowed, one would then connect the extracted values to what we know about the secular evolution of the Galactic disc.

Ability to program, preferably in C++, would be advantageous.

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

TP11 **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.

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TP12 **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.

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