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The Jodrell Bank Centre for Astrophysics (JBCA) is one of the largest astronomy groups in the UK. It hosts around 30 academic staff and a total of approximately 180 researchers, including around 60 research students, working across a wide range of topics in astrophysics.

The JBCA is based on two sites: the Alan Turing Building is sited within the central University city campus in Manchester and hosts the UK ALMA regional centre node. JBCA also encompasses the Jodrell Bank Observatory, home to the Lovell Telescope, the e-MERLIN/VLBI National Facility, and the international headquarters of the Square Kilometre Array (SKA).

There are three research groups within JBCA: Cosmology; Pulsars and Time Domain Astrophysics; and Sun, Stars and Galaxies. In addition to these research areas the Interferometry Centre of Excellence aims to bring together the significant expertise we have in state-of-the-art radio astronomy data analysis techniques utilised by e-MERLIN and ALMA, and which are being developed towards future projects such as the SKA.

Further information on our research can be found on the JBCA research webpage: http://www.jodrellbank.manchester.ac.uk/research/ General information on studying for a postgraduate degree within JBCA can be found at http://www.jodrellbank.manchester.ac.uk/study/postgraduate/

Research themes

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<th>Cosmology:</th>
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<td>• Understanding the origins of the initial deviations for homogeneity that eventually lead to the formation of large scale structure;</td>
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<td>• The origins of the cosmic acceleration;</td>
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<td>• The nature of the dark matter thought to pervade the Universe;</td>
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<th>Sun, stars and galaxies:</th>
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<td>• Solar plasmas, including understanding solar corona heating, magnetic reconnection, and the origin of high-energy charged particles in solar flares;</td>
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<td>• Astrophysical magnetism, masers and radiative transfer;</td>
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<td>• Star and planet formation, stellar evolution, circumstellar and interstellar processes;</td>
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| Pulsars and time-domain astrophysics: |
- Pulsar detection, characterisation and physics, including milli-second pulsars, pulsar timing, pulsar glitches, pulsar emission physics;
- Fast Radio Bursts (FRBs), including search techniques, and brightness and dispersion measures;
- Novae, including multi-frequency monitoring of outbursts, structural studies of ejecta, and hydrodynamic simulations of mass-loss;
- Extra-solar planets, including detection using the microlensing technique, and atmospheric detection and characterisation through transmission spectroscopy studies;
- SKA and next-generation instrumentation.

Project areas

Below are some examples of research areas and projects on offer for PhD study at JBCA in 2019. This is a non-exhaustive list and you are encouraged to look at the JBCA PhD projects webpage for further examples:

http://www.jodrellbank.manchester.ac.uk/study/postgraduate/phd-projects/

Please also feel free to make direct contact with members of JBCA staff to find out about projects they may be offering.

**ATOMIUM: ALMA Tracing the Origins of Molecules forming dust in oxygen-rich M-type stars**

**Dr Anita Richards, Dr Malcolm Gray (contact: a.m.s.richards@manchester.ac.uk)**

We stand on the 3rd rock from the Sun - but what made the grains of sand-like or soot-like dust which it formed from? "ATOMIUM: ALMA Tracing the Origins of Molecules forming dust in oxygen-rich M-type stars" will be observed during 12 months starting October 2018. These mm and submm wavelength radio interferometry observations will map the spectral lines from dozens of molecules around 22 cool, red giant and supergiant stars. The goal is to unravel the phase transition from gas-phase to dust species, pinpoint the chemical pathways, map the morphological structure, and study the interplay between dynamical and chemical phenomena. ATOMIUM is led by Prof. Leen Decin (Katholic University of Leuven, Belgium) with collaborators from 5 European countries, Taiwan and the US. Most of the lines detected will be due to thermal emission but some will be masers - the naturally-occurring radio analogue of lasers. The exponential nature of maser amplification produces very bright emission which allows mass ejected from these stars and the circumstellar envelopes to be explored at the resolution of individual clumps, shedding light on how the winds are driven and how dust forms. The PhD project will involve a contribution to the general work of processing ATOMIUM data and in particular to analysing the maser data (mostly from water and silicon monoxide). The project will include data processing, image reconstruction and analysis, modelling maser processes and organising the results in an accessible archive, as part of a friendly international collaboration; the student can concentrate on preferred aspects and, as ever in research, something unexpected may turn up.

**Timing of radio pulsars with Jodrell Bank and MeerKAT**

**Dr Michael Keith (contact: Michael.Keith@manchester.ac.uk)**

Pulsars are rapidly rotating neutron stars which sweep out beams of radiation along the
poles of their extremely strong magnetic fields. We observe a pulse of radio waves from the pulsar each time its beam of emission sweeps across the Earth. The most rapidly rotating pulsars, which have spin periods of a few milliseconds, provide insight into a wide range of physics and astrophysics, ranging from studies of general relativity, understanding the turbulent interstellar medium, unlocking the complex physics of the pulsar magnetosphere, or studying the superfluid interior of neutron stars.

This project may involve a wide range of pulsar related astrophysics using data from the Lovell telescope at Jodrell Bank Observatory and also the new MeerKAT radio telescope, which is one of the most powerful radio telescopes on Earth. The particular focus will depend on discussions with the prospective student and may evolve during the PhD, but typical topics involve study of relativistic binaries, precision timing of millisecond pulsars, understanding the long-term evolution of pulsars or exploring the unknown by determining the rotational and astrophysical properties of newly discovered radio pulsars.

**Constraining the physics of the early Universe with the Simons Observatory**

**Prof Michael Brown** (contact: m.l.brown@manchester.ac.uk)

The Simons Observatory is a next generation Cosmic Microwave Background (CMB) telescope to be located in Chile. The Simons Observatory’s primary goal is to detect a very specific pattern in the polarisation of the CMB radiation (termed B-modes) which will provide a unique observational window into the very early Universe and physics at GUT-scale energies. As part of our group you will have the opportunity to get involved with this state-of-the-art CMB experiment in a number of areas including investigating the best scanning strategies to use when conducting the observations and developing sophisticated analysis techniques to extract the extremely faint B-mode signal from the experimental data. This project would suit a student with keen analytic and computational skills.

**Gravitational lenses: finding and followup**

**Dr Neal Jackson** (contact: neal.jackson@manchester.ac.uk)

Strong gravitational lenses are systems in which a background source is multiply imaged by a foreground lensing mass (usually a galaxy or cluster of galaxies). They are important because they allow us (i) to study the background objects at higher resolution and/or sensitivity than would otherwise be possible, and (ii) to study the mass distribution of the lens, independent of the light that it emits. The subject is about to be revolutionised by future instruments such as the Euclid satellite, which will find hundreds of thousands of lens systems instead of the few hundred currently known. Radio lenses, historically the first to be found, are a particular area of interest.

We are involved in a number of investigations which could form the basis of a PhD project depending on interest and developments in the subject: (i) Calibration and results from the long-baseline surveys with the LOFAR low-frequency radio telescope - we are leading the calibrator survey and hope to use the survey to examine existing lenses at high resolution; (ii) other radio studies of interesting lensed objects such as radio-quiet quasars, to look at the mechanisms of radio emission; (iii) involvement in the Euclid lens searches, due to begin with the launch of the Euclid satellite in 2021, and (iv) modelling studies of strong lens systems.
Modelling and simulation of magnetic reconnection, solar flares and solar coronal heating

Prof Philippa Browning (contact: philippa.browning@manchester.ac.uk)

Research in solar plasma physics is concerned with modelling the complex interactions of magnetic field with plasma in the solar atmosphere, in the context of transformational new space and ground-based observations of our nearest star. There are synergies with magnetically-confined fusion plasmas, and there are opportunities for PhDs exploring both fusion and solar applications, in collaboration with Culham Centre for Fusion Energy. We are also interested in the physical processes underlying variable radio emission in young stars, building on understanding of solar flares.

A major unsolved problem is to explain why the solar coronal temperature is over a million degrees Kelvin. Coronal heating likely results from dissipation of stored magnetic energy, but the details remain controversial. A strong candidate for energy dissipation is the process of magnetic reconnection - which also operates in solar flares, and in many other space and astrophysical plasmas. One of the biggest challenges in flare physics is to explain the origin of the large numbers of high-energy electrons and ions, requiring integration of small-scale plasma kinetic models with large-scale fluid models.

PhD projects are available to explore the nature and consequences of magnetic reconnection in the solar atmosphere, using magnetohydrodynamic simulations, relaxation theory and kinetic plasma models. There is also likely to be a funded PhD project with Culham Centre for Fusion Energy studying magnetic reconnection in the core plasma of tokamaks.

The main applications are to the heating of the solar corona, and energy release and particle acceleration in solar flares. Models of energy release in unstable twisted coronal loops, and in current sheets in sheared magnetic fields, will be extended to more complex configurations, including interactions between magnetic flux ropes. Students may use a new “reduced kinetics” approach to develop self-consistent models including energetic electrons. An important aspect is “forward modelling” of observational signatures, with energetic particles potentially detected both through hard X-ray and radio emission.

Building Models of the Universe with Hydrodynamic Simulations

Dr Scott Kay (contact: Scott.Kay@manchester.ac.uk)

Hydrodynamic simulations have become the cosmologist's tool of choice for modelling the assembly of large-scale structure in the Universe, from galaxies to clusters to the cosmic web. The processes involved are highly non-linear, involving complex interactions between the baryonic and dark matter components. While such interactions are driven by gravity, astrophysical processes such as the formation of stars and super-massive black holes, and the feedback of energy from these sources to the surrounding gas (via powerful galactic outflows) also need to be incorporated to make realistic models of the observed galaxy and cluster population. As part of the Virgo consortium, an international collaboration of computational cosmologists, we are currently developing the next generation of these simulations that exploit recent advances in computing power and simulation codes. In this project, the student will have the opportunity to participate in the development of these new
simulations and exploit the resulting data to make new predictions for the properties of galaxy clusters, in particular how the feedback affects the properties of their galaxies and hot gas.

Beyond the Beam: Revealing Star Formation in Galaxies through Simulations and Observations

Dr Rowan Smith (contact: rowan.smith@manchester.ac.uk)

Stars form in dense clouds of molecular gas in galaxies, but how these clouds and the stars within them are formed is still not fully understood. Galactic forces are likely to play a role at some scale but the precise role of galactic environment still has to be determined. Observational surveys using revolutionary facilities such as ALMA, SOFIA, the upcoming SKA and its precursors are now able to observe the formation of the molecular clouds that are the birthplaces of stars all the way from atomic HI to dense star forming cores in other galactic systems for the first time. However, even the best observations are limited by resolution, sensitivity, projection effects and issues of optical depth. In this project we will seek to “translate” between simulations and observations to learn the key physical parameters that determine how molecular clouds and stars form in different galactic environments. We will do this by creating synthetic observations of gas-rich regions in cutting-edge high-resolution galaxy simulations using post-process radiative transfer. Uniquely these simulations resolve individual molecular clouds sub-structure while still capturing galactic forces on kpc scales. Our synthetic observations will focus on creating 1) HI maps in the 21 cm line for comparison to the THOR survey of the Milky Way, observations from MEERKAT, and predictions for the SKA, 2) CII emission maps for comparison to a SOFIA survey our team is a member of and 3) CO molecular line emission for comparison to ALMA observations. These will then be compared to the observational data sets to determine what parameters best reproduce the observations. This project will allow the prospective student to gain experience with both theoretical and observational data.

Design and realization of a wide-band sub quantum noise parametric amplifier (paramp) based on the non linear kinetic inductance property of superconductors

Prof. Lucio Piccirillo (contact: Lucio.Piccirillo@manchester.ac.uk)

This project involves the design and development of an ultra-low noise parametric amplifier for future radio astronomy observatories. It will consist of a superconducting thin film exhibiting highly non-linear kinetic inductance. When pumped with an external RF signal it
will be driven in a state of parametric amplification with potential sub-quantum noise characteristics. The student will be involved in all phases of the development work, from the theoretical basis to the computer simulation of the final devices as well as manufacturing in the Computer Science clean room and testing in our fRF facilities in Alan Turing Building.

**The Formation of Massive Stars in Our Galaxy and Other Galaxies**

Prof Gary Fuller (contact: G.Fuller@manchester.ac.uk)

The conversion of gas into stars is one of the fundamental processes in galaxies. With their prodigious luminosity, energetic winds and their ultimate demise as core collapse supernovae, the massive stars which result from this process dominate the physical and much of the chemical evolution of interstellar medium. Understanding how these stars with masses greater than 8 times the mass of our Sun form is therefore a key astrophysical problem. It impacts a wide range of astrophysical issues from the lifecycle of baryons in galaxies including the origin of heavy elements essential to the formation of rocky planets and life, to the birth-rate of supernovae, pulsars, black holes and gamma-ray bursts. Starburst galaxies host the most extreme star forming environments known. A single starburst region can be forming stars at rates 10 to 100 times more rapidly than the whole Milky Way galaxy. Understanding how these regions form and evolve is essential to understanding both the evolution of individual galaxies, including the formation and feeding of their central supermassive black holes, as well as the star formation history of the universe as a whole. The star formation group is focused on using a range of observations at infrared, millimetre/submillimetre and radio wavelengths from telescopes such as Herschel, ALMA and JVLA, and eventually SKA, together with numerical simulations, to study the formation and early evolution of massive stars in both our galaxy and starburst galaxies. The immediate aims are to understand the relative importance of the different physical processes involved in the formation of massive stars and the effect these forming massive stars have on their natal cocoons, as well as on larger scales. Ultimately the goal of this area of research is to build a predictive model of star formation. Since many of these projects are being carried out in collaboration with international colleagues, there is the possibility of placements at institutes overseas.

**Example Projects:**

- Variable Radio Sources as Probes of Accretion and Outflow in Star Forming Regions
- The Structure, Kinematics and Evolution of Filamentary Molecular Clouds and Their Role in Massive Star Formation
- Using Dust Polarization to Probe the Magnetic Field in Massive Star Forming Regions
- Identifying the Precursors to Massive Stellar Clusters
- Connecting Star Formation in the Starburst Galaxy NGC253 and Star Forming Regions in the Milky Way Using The ALCHEMI Large Programme on ALMA
- Using The ALCHEMI Large Programme on ALMA to Study the Evolution of Starbursts in NGC253
- Vibrationally Excited Molecules as Probes of the Most Extreme Regions in Galaxies
Pushing the Noise Limit: Low Noise Amplifiers for Radio Telescopes

Prof. Gary Fuller (contact: G.Fuller@manchester.ac.uk), Prof. Danielle George (School of Electrical & Electronic Engineering)

Low noise amplifiers (LNAs) are critical components of receivers for radio telescopes. They offer a number of important advantages over competing technologies such as operating at 20K rather than 4K as well as being better suited for use in large scale imaging array receivers. Recent advances in technology have allowed the development of LNAs which operate at much higher frequencies than previously possible. This is an opportunity to join the Advanced Radio Instrumentation Group in the Schools of Physics & Astronomy and Electrical & Electronic Engineering and the newly established joint research laboratory for Radio Astronomy Advanced Instrumentation Research (RAAIR). There are three areas of research:

- The designing and testing high performance, wide bandwidth, LNAs at frequencies of up to 300 GHz, and beyond, for use in both single pixel and array receivers on the world’s biggest telescopes.
- New processes and materials for transistors for future, high performance generations of LNAs.
- Computer-aided LNA design optimisation.

In each of these areas there is the possibility of placements at various collaborating international institutions, including Caltech in Pasadena.

Onset of stellar mass loss and the kinematics of planetary nebulae

Prof Albert Zijlstra (contact: a.zijlstra@manchester.ac.uk)

Stars like the Sun end their lives with a phase of catastrophic mass loss. The so-called 'superwind' can remove between 50 and 80% of the star's mass, leaving only the degenerate, inert core. The ejected shell is briefly visible as a planetary nebula. The intricate shapes of the nebulae shows that the mass loss is far from spherically symmetric. The cause of this is not well known but interactions with binary stars or planetary systems seems most likely. We have started projects studying the onset of the mass loss using the nearby stars in this phase of evolution, and are studying the kinematics of the planetary nebulae. Several potential projects are available within this area of research, depending on the specific interest of the student.

Coherent alignment of radio sources axes

Emeritus Prof Ian Browne, Dr Scott Kay, Prof Michael Brown (contact: ian.browne@manchester.ac.uk)

The project gives an opportunity to be in at the beginning of something new and potentially very exciting. Marcha & Browne (in preparation) report a remarkable observational result. They find radio sources with flat radio spectra are apparently much more clustered on the sky than steep spectrum sources selected from the same catalogues. Why is this remarkable? This a completely new result, the measured degree of clustering is much greater than that for any other cosmological population and the angular scale over which it occurs implies coherence scales comparable or larger than that of any known structure. The observational result implies a coherent alignment of AGN axes within huge volumes of space.
offering a new probe for large-scale structure formation. The proposed PhD project has both data analysis, simulation, and perhaps theoretical, components. The work needs to be extended to more samples of radio sources and the clustering signal needs to be cross-correlated with other observables related to large-scale structure. Existing n-body simulations existing N-body simulations would be analysed to predict axis alignments in order to compare predictions with the observational results. The work would be done in collaboration with Maria Marcha (UCL).
The main research theme of the Biological Physics Group is to use multiple experimental and computational approaches to investigate the fundamental physics of biological problems. Postgraduate projects are therefore closely related to this main theme, covering the investigation of biological problems connecting structure to function at molecular, cellular, tissue and whole organ levels. Projects on translational studies linking basic scientific research to potential industrial and clinical applications are also available. Briefly the projects are focused on, but not limited to the following topics:

**Biointerface**: this topic involves studying molecular and cellular structure under conditions mimicking biological and biomedical applications and applying the latest physical techniques to access direct information at molecular and cellular levels from various bio-interfacial processes.

**Computational systems biology and medicine**: this topic aims to develop multi-scale and multi-physics computer models of biological systems. New ways of analysing and interpreting experimental data and complexity of nonlinear dynamics of biological systems will be developed.

**Biomolecular structure and dynamics**: this topic involves the study of water around DNA, proteins and biopolymers using various neutron sources around the world.

**Cellular tracking and self-assembly**: this topic develops a range of new tools to examine the behaviour of bacteria, human cells and biomacromolecular aggregates. Specifically, new microscopy and microrheology based approaches will be used, combined with mesoscopic models for the molecular behaviour.

**Projects**:

**Biointerface**

**Prof. Jian Lu** (j.lu@manchester.ac.uk)

**Neutron reflection study of protein adsorption.**

Proteins are large biomacromolecules that perform many functions in living systems. They are folded up from one or several polypeptide chains. In order to perform their functional roles, they must retain their 3D structures. Once exposed to surface or interface, protein
molecules tend to adsorb; some become struck and some could even desorb. These interfacial processes of adsorption and desorption tend to damage their 3D structures, deactivating them or causing adverse consequences. Neutron reflection could help determine the structural conformation of an adsorbed protein layer. The information could help us develop biocompatible surfaces and interfaces whilst improving our basic understanding. This project also has desire for computer modelling and is often developed in collaboration with scientists at Rutherford Laboratory and industry.

**Self-assembly of short peptide amphiphiles and their interactions with biointerfaces**

There are many natural and unnatural amino acids that are polar, apolar and charged. We can design short, simple peptide sequences from them that resemble conventional surfactants with distinct hydrophilic head and hydrophobic tail moieties. Unlike conventional surfactants, the properties of these peptide amphiphiles are strongly influenced by hydrogen bonding. Light scattering, neutron scattering and computer modelling are often used together to help understand how a give set of peptide amphiphiles self-assemble to form a range of nanostructures such as nanorods, nanotubes, nanobelts and larger structures templated from them.

**Interfacial processes underlying antimicrobial actions and biocompatibility.**

A major antimicrobial action is to kill bacteria by disrupting their membranes, but antibiotics or equivalent must target bacteria very selectively with minimal damage to mammalian cell hosts. In collaboration with colleagues in biology and medicine, we have developed physical models to help understand the key mechanistic events at molecular and cell levels, by seeking the combined studies utilising skills and tools from both biology and physics.

**Computational systems biology and medicine**

**Prof. Henggui Zhang** (henggui.zhang@manchester.ac.uk)

Development of the computer model of the heart for the study of electrical and mechanical dynamics of the heart.

A grand challenge for modern physics is to develop a biophysically detailed and accurate model for predicting the dynamical behaviours of the heart that paves the way leading to predictive life sciences. In collaboration with colleagues in biology and medicine, we aim to develop multi-scale physics models of the heart to investigate its nonlinear dynamics in electrical and mechanical behaviours ranging from molecular to cell and organ levels, by utilising combined skills of physics and high performance parallel computing.

**Novel non-invasive technology for diagnosing cardiac arrhythmic origins.**

Cardiac arrhythmias are the leading cause of sudden death. Current treatment of cardiac arrhythmias (e.g. atrial fibrillation) involves the use of catheter ablation. However, the success of catheter ablation relies on accurate identification of the cardiac arrhythmic origins, which is challenging at the moment. The aim of this project is to develop a new algorithm that solve the inverse problem of the heart, by which electrical excitation dynamics in the heart can be reconstructed from multi-channel ECG recordings from the human body surface. This will provide a new non-invasive technology for identifying the target for ablation, which will have significant practical values.
The virtual heart as a platform for new drug design and testing.

Cardiac arrhythmias are the leading cause of sudden death. Current treatment of cardiac arrhythmias by using of anti-arrhythmic drugs is unsatisfactory due to the toxic side effect of the drugs. The aim of this project is to develop a novel computer model of the heart for testing the efficacy and safety of the drugs. This will provide a new technology which has great potential application in the drug industry.

Artificial intelligence (AI) in diagnosing cardiac arrhythmias.

AI based on deep learning and machine learning may revolutionise the way of automatic clinical diagnosis. The aim of this project is to develop a new set of AI algorithms that analyse the nonlinear dynamics of heart from multi-channel ECG recordings from the human body surface. This will provide a new technology for accurate diagnosis of cardiac arrhythmias.

Biomolecular structure and dynamics

Dr. Jichen Li (j.c.li@manchester.ac.uk)

Water flow in confined nano graphene channels.

Water transport through nanoscale channel is fundamental importance for us to understand biological processes, such as the transportation of ion through protein channels and drug deliveries. It potentially has also industrial applications such as gas separations. It is known that water molecules are transported in and out of cells selectively through the nanopores such as transmembrane proteins, aquaporin, and so on. Unfortunately, biological water channels often contain specific and complex structures, exhibiting extraordinary transport properties that are far from being understood completely. In this sense, the study of water transportation in a structurally less complex and controllable carbon nanotube or graphene channel becomes a fascinating alternative, where the conditions and parameters can be conveniently tuned by experimental techniques [1] or theoretical methods [2,3]. In the project, we will combine inelastic neutron scattering (INS) and molecular dynamics simulation (MD) techniques to investigate the diffusion of water the in graphene channels as function of temperatures and pressures. Since INS is very sensitive to scattering on water hydrogen, we expect to get direct information on vibrational spectra of confined water, the translational and librational modes of which are strongly affected by the local geometries and thsesimulations will provide microscoptic details of the local water structures.


Cellular tracking and self-assembly

Dr. Thomas Waigh (t.a.waigh@manchester.ac.uk)

Super-resolution fluorescence imaging of bacterial biofilms (with Prof. Ian Roberts in Life Sciences)

A super-resolution fluorescence microscope (STORM) will be used to study biofilm formation in bacteria. Bacterial biofilms are a key issue in antibiotic resistance and are therefore a huge problem in modern medicine. Experiments in our laboratory have demonstrated bacteria can use electrical signalling during biofilm formation. Optogenetics methods are also possible to insert voltage sensitive fluorophores into bacteria to observe their activity.

Models for the creation of bacterial biofilms (with Prof. Ian Roberts in Life Sciences)

Statistical models to describe bacterial biofilms will be constructed. These will include ideas from agent based modelling, colloidal hydrodynamics and systems biology. Electrophysiological effects can also be incorporated into models to describe electrical signalling experiments. A range of medically important biofilms will be studied in collaboration with experimental physicists and microbiologists.

Optical coherence tomography to study the fluid mechanics of opaque solutions of DNA (with Dr Mark Dickinson)

Concentrated (opaque) DNA has a number of novel non-linear flow phenomena, such as turbulence at very low Reynolds number. This project will develop new optoelectronics equipment to study fluid mechanics based on optical fibre interferometry. It will then apply the techniques developed to medically important areas of research including the flow behaviour of DNA and bacteria.

Active cell movement in live tissue (with Dr Tom Millard in Life Sciences)

We want to understand how cells move inside complex living tissues and how the physical properties of the surrounding environment affect cell movement. Drosophila embryos are transparent and we will determine how cell motion is influenced by the spatial properties of the surrounding environment. New statistical tools will be developed to characterize the heterogeneous motility of immune cells.
COMPLEX SYSTEMS AND STATISTICAL PHYSICS

Dr. Tobias Galla (tobias.galla@manchester.ac.uk)

Complex systems are composed of many interacting components, giving rise to emergent phenomena which cannot be understood from analysing the individual components in isolation. Examples include the emergence of traffic jams, stock market crashes or the take-over of a population by an invading mutant.

In our work we study complex systems using the tools and ideas of theoretical physics. Specifically we focus on “individual-based systems”, where the word “individual” can represent stock market traders, players in a game, protein molecules, messenger RNA, members of a population in which a disease spreads or cancer cells in a tumour.

Many of these systems are modelled as random processes. We are interested in the mathematical theory for such systems, and in applying these methods to specific questions, often motivated in biology, evolutionary dynamics or game theory. Past PhD projects include path integral analyses to delay models in epidemiology and gene regulation, the statistical physics of fixation and equilibration in cancer populations, multi-player games, social learning in insects, the spread of languages, biological systems coupled to fast external environments, host-pathogen games, evolutionary dynamics in flows, etc.

This is a fast-moving field and it is hard to say what exactly your project will be. This will also depend on your interests and preferences. We promise an exciting mix of theoretical analysis, computer simulation and interdisciplinary work with colleagues in the life sciences, mathematics, healthcare/medicine, computer science and even linguistics.

Most of our applicants have excellent marks, strong mathematical skills and programming experience. We are looking for energetic students with outstanding communication skills, and who are enthusiastic and able to drive this exciting field forward.
CONDENSED MATTER PHYSICS

Research in the Condensed Matter physics group is exceptionally broad, from electronic, optical, mechanical and magnetic properties of a whole family of atomically thin, two-dimensional materials to the physics of quantum fluids, intercalation-induced superconductivity in layered and two-dimensional materials and mass transport through atomically thin channels in 2D-materials based membranes. The focus in 2D materials research is currently shifting from studying the properties of graphene to other 2D crystals with a variety of electronic properties - insulators (hBN), semiconductors (phosphorene, MoS2, WSe2, etc.), superconductors (NbSe2), 2D magnets (CrI3) – and the so-called heterostructures, where atomically thin layers with different properties are assembled with monolayer precision to produce ‘materials by design’. Our research is supported by extensive cutting-edge facilities in the Schuster building and the National Graphene Institute, including clean-room microfabrication, measurements and characterisation. The quantum fluids research is supported by unique measurements systems, including ultra-low temperature rotating cryostats. More information is available at:

http://www.condmat.physics.manchester.ac.uk/ and
http://www.graphene.manchester.ac.uk/  Research areas led by individual academics are described in more detail below.

Physics and applications of 2D materials and their heterostructures
Prof Andre Geim (Andre.K.Geim@manchester.ac.uk)

Prof Geim’s current research focuses on developing van der Waals (vdW) heterostructures and smart Lego-style materials based on 2D crystals. This is a very broad field of research, encompassing many new systems that allow to access electronic, optical, transport and other properties not readily found in ‘natural’ materials. A number of current projects focus on exploiting non-trivial topology of graphene-based heterostructures, developing new systems that allow new types of measurements (for example, a recently developed technology for fabricating designer nanochannels with monolayer precision), and studying little explored properties of graphene, boron nitride and other atomically thin crystals for transport of subatomic particles (protons, deuterons). Available PhD projects are constantly
evolving and interested students are encouraged to contact Prof Geim for latest opportunities.

Quantum fluids

Professor Andrei Golov and Dr Paul Walmsley
(andrei.golov@manchester.ac.uk; paul.walmsley@manchester.ac.uk)

Currently, the Low Temperature Group (Prof. Andrei Golov, Dr. Paul Walmsley, Dr. Ivan Skachko) investigates turbulence in superfluid $^4$He in the limit of zero temperatures. For further details, see http://www.condmat.physics.manchester.ac.uk/researchthemes/quantumfluids/ and https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.118.134501.

Superfluid helium is an ordered inviscid liquid, capable of maintaining flow without dissipation. Yet, a tangle of quantized vortices (a.k.a. Quantum Turbulence) decays even at $T = 0$, the energy being lost to elementary excitations of the superfluid. There exist several competing theories of processes involving the emission of phonons, rotons and small quantized vortex rings after short-wavelength perturbations of the shape of vortex lines grow in amplitude. However, nobody yet knows – which of them is correct, if any. We are going to take photographs and videos of vortex lines, which will allow to learn about the amplitude and spectrum of waves along vortex lines and the dynamics of their evolution. We are also developing different types of detectors, capable of recording the emission of phonons, rotons and small quantized vortex rings.

Projects:
1. Visualization of vortex lines in superfluid $^4$He through fluorescence of molecules and nanoparticles, attached to vortices.
2. Investigation of elementary excitations in superfluid $^4$He responsible for the removal of energy from tangles of vortex lines in the T=0 limit.

2D plasmonics in thin atomic layers

Prof Sasha Grigorenko (Alexander.Grigorenko@manchester.ac.uk)

Recently, plasmons and polaritons in two-dimensional (2D) systems attracted a lot of attention due to isolation and availability of various 2D materials. Among these 2D materials one can easily find dielectrics (e.g., boron-nitride), semimetals (e.g., graphene) and semiconductors (various transitional metal dichalcogenides). At the same time, ultra-thin layers of metals down to single monolayer did not receive widespread attention despite they present an interesting and important part of LEGO-like van der Waals heterostructures. Recently, it was found that ultrathin layers of metals do possess nontrivial 2D plasmons, can show high temperature superconducting transition as well as truly 2D superconducting behaviour. The study of fascinating properties of ultrathin metals and their nanostructures is a timely and exciting topic in development of flatland optics and electronics.

In our group, we have all means necessary to fabricate, characterize and optimize thin layers of metals. Various fabrication technique will be used (deposition, cleaving, electrochemistry) with the objective to achieve extremely flat and homogenous films. Optical
and electrical properties will be studied using the existing equipment (spectroscopic ellipsometry, reflection and transmission spectroscopy, dc conductivity and Hall effect in large temperature and spectral ranges). New optical and electrical properties will be targeted – with emphasis on photo catalysis for green energy and high temperature superconductivity.

**Project: 2D plasmonics in thin atomic layers.**

**Superconductivity in layered and 2D materials; 2D materials for spintronics**

**Prof Irina Grigorieva** (irina.grigorieva@manchester.ac.uk)

Prof Grigorieva’s current research focuses on three main areas: (i) tuning electronic properties of layered materials or stacks of atomically thin layers by intercalation, including induced superconductivity; (ii) two-dimensional and non-trivial superconductors; (iii) applications of 2D materials in spintronics. Superconducting pairing in alkali-metal doped semiconductors or insulators often has a non-trivial nature either due to the interplay of the electronic states of the 2D layers and the intercalating metals or due to the non-trivial topology of the host material; there are also a number of bulk superconducting materials with non-trivial topology of electronic bands. We are looking for new experimental signatures of non-trivial superconductivity. In spintronics, the recently discovered possibility to make graphene ferromagnetic by proximity to known ferromagnetic materials can be exploited, for example, in magnetic tunnel junctions. We are currently looking for ways to either enhance this effect in graphene or find other promising 2D materials for such devices.

**Projects:**

1. **Superconductivity by alkali-metal doping/intercalation.**
2. **Superconductivity in topologically non-trivial materials.**
3. **2D materials for magnetic tunnel junctions and other spintronics applications.**

**Bridging electronics and mechanics at the nanoscale**

**Dr Artem Mishchenko** (artem.mishchenko@manchester.ac.uk)

Our research is centred on van der Waals heterostructures – layer-by-layer assembled stacks of individual atomic planes. “What could we do with layered structures with just the right layers? What would the properties of materials be if we could really arrange the atoms the way we want them?” asked Richard Feynman in his visionary lecture “There’s plenty of room at the bottom” back in 1959. In the light of a remarkable progress over the past few years, we are now on the verge of answering these questions. Currently, our research group focuses on the following main research directions within van der Waals heterostructures: (i) the nanoscale transport properties of novel materials and (ii) nanoscale electromechanical systems. The behaviour of charge carriers at the nanoscale is of paramount importance for a huge range of applications covering semiconductor industry, sensors, nanofluidics, and biophysics of living cells. Likewise, unravelling the interplay between mechanical and electronic domains at the atomic level will benefit all technology, especially in the fields of wearable computers, self-powered devices, smart materials, and medical and industrial nanorobots.

We work on advancing both of these directions by developing advanced measurement techniques, designing and prototyping a range of devices using cutting-edge
microfabrication technologies, and by exploring the interactions between mechanical and electronic domains at the atomic level.

Projects:

4. Developing an innovative nanoscale transport imaging platform to explore novel materials and new physics.
5. Piezoelectric properties of van der Waals heterostructures: actuation and energy harvesting
6. Electromagnetic and thermal actuation nanoelectromechanical systems
7. Friction, superlubricity and stick-slip motion in 2D materials

2D nanoelectronics beyond Moore’s law based on spintronics and thermoelectrics

Dr Ivan Vera Marun (ivan.veramarun@manchester.ac.uk)

Our basic research on 2D nanoelectronics paves the way towards alternative computing technologies beyond the use of charge in conventional electronics. In 1965 Gordon Moore made the observation that the number of components in an integrated circuit doubles every year. Fast forward to the present day and conventional electronics is expected to reach the atomic-scale limit by the next decade. To go beyond this limitation, we explore spin currents, heat transport, and other degrees of freedom to enable alternative logic and memory devices.

We use nanotechnology as an interface between the fields of magnetism, electronics, and thermal transport. Our work integrates spintronics (Nobel Prize in Physics 2007), nanoscale thermoelectrics, and graphene, the first two-dimensional material discovered in Manchester, to develop enhanced functionality, re-programmable and ‘green’ electronics.

Possible projects:

1. Spin transport in high-quality ballistic graphene transistors
2. Nanoscale thermoelectrics in van der Waals heterostructures.

Scanning probe microscopy of 2D materials and nanoconfined molecules

Dr Laura Fumagalli (laura.fumagalli@manchester.ac.uk)

Our group focuses on the study of the physical properties of matter at the nanoscale, mainly electrical and dielectric properties, by using scanning probe microscopy techniques. In recent years we have developed scanning dielectric microscopy which is able to probe electric polarizability on the nanoscale. This is a fundamental physical property with important implications in many disciplines, from physics to chemistry and biology, and yet it remains essentially unknown on such a small scale for lack of tools with sufficiently sensitivity. Hence, the applications of scanning dielectric microscopy are countless. Currently we are particularly interested in combining it with 2D materials and state-of-the-art 2D fabrication techniques to investigate the dielectric properties of fluids and solids under extreme confinement. We recently showed the power of this approach by succeeding in the long-standing challenge of probing the polarizability of few water layers confined into
nanochannels made of 2D materials. Available projects aim to continue this research to better understand the role of electric polarizability in phenomena such as surface hydration, ion solvation, molecular transport, macromolecular assembly and chemical reactions.

**Projects:**

1. Dielectric polarization properties of 2D confined water
2. Dielectric polarization properties of 2D confined macromolecules
3. Development of high-resolution dielectric microscopy

**Developing new techniques for fabrication of ultraclean 2D heterostructures and devices based on 2D materials**

**Dr Roman Gorbachev** ([roman@manchester.ac.uk](mailto:roman@manchester.ac.uk))

My research area is experimental condensed matter physics, with an emphasis on fabrication of nanoscale low-dimensional devices. The availability of novel nanoscale materials, such as nanowires and atomically thin 2-dimensional crystals is enabling the assembly and study of composite electronics and mechanical devices, as well as the exploration of fundamental physics in these low-dimensional systems. The use of modern state-of-the-art semiconductor device fabrication techniques and the development of new methods of material synthesis/manipulation are essential parts of this research, which gives an ample space to explore the new physical phenomena and can bring an impact to future technologies.

**Projects:**

1. Ultra-clean van der Waals heterostructures fabricated in high vacuum.
2. Scanning probe microscopy of atomically thin crystals in vacuum.

**One-atom-thick membranes**

**Dr. Marcelo Lozada-Hidalgo** ([marcelo.lozadahidalgo@manchester.ac.uk](mailto:marcelo.lozadahidalgo@manchester.ac.uk))

2D crystal membranes exhibit exotic phenomena. They are impermeable to all atoms and molecules but they are highly permeable to protons. They also display subatomic selectivity: deuterons, nuclei of hydrogen’s isotope deuterium, permeate ~10 times slower than protons. Unexpectedly, graphene membranes are also highly sensitive to solar light: A single photon impinging on graphene induces the transport of ~10,000 protons via a novel physical effect, the photo-proton effect. Encouragingly, these properties have been found using only a couple of 2D crystals – hundreds more remained unexplored. My research is focused both on finding more exotic properties and exploiting them in a number of energy applications such as fuel cells, photocatalytic water splitting or nuclear energy. PhD projects usually involve both fundamental science and industry applications.

**Angstrom-scale fluidics**

**Dr Radha Boya** ([radha.boya@manchester.ac.uk](mailto:radha.boya@manchester.ac.uk))

Our current research involves design and fabrication of capillary devices based on atomically thin 2D-materials assembled in 2D-heterostructures. The capillaries are layer-by-layer structures of 2D-materials such as graphene, with cavities running through the middle of a stack. To put it simply, we make atomic-scale channels with atomically smooth walls! This
novel architecture of capillaries provides atomic-scale tunability of the nanochannel dimensions and ensures atomically smooth walls. Despite the Ångstrom (Å) scale, this is essentially a top-down lithographic technique which ensures its high reproducibility and flexibility. Using these precise capillaries, we study effects of confinement on water, ion, and gas flows which can impact the fields of molecular separation and membrane-based water desalination. For further details, please see https://radhaboya.weebly.com/.

Projects:

1. Gate-voltage controlled ionic and mass transport of capillaries
2. Biomolecular sequencing using angstrom-capillaries
QUANTUM THEORY OF LIGHT AND MATTER

We study a broad range of topics within the framework of the Theory Division that spans from the electronic, magnetic and optical properties of 2D materials, topological order and superconductivity, to the development of the theory of quantum transport and strongly-coupled non-equilibrium phenomena, quantum thermodynamics, quantum noise, open quantum systems, nanoplasmonics and nanophotonics. The study of complex quantum systems involves a diverse array of tools, including advanced quantum-field-theoretical techniques (Feynman diagrams, path integrals, non-equilibrium Green’s functions), quantum kinetic and transport theory, master equations, and group theory, using both numerical and analytical approaches. The strong connection to experimental groups at the School of Physics and Astronomy and the National Graphene Institute allows immediate testing of newly developed theories, especially in relation to studies of physical phenomena occurring in two-dimensional materials, which remain a distinctive research beacon of the University of Manchester and were the subject of the 2010 Nobel Prize in Physics.

Possible projects are available on topics similar to those listed below under the individual members of staff. Other projects may be available. Some projects will involve joint supervision between two or more members of staff.

Theory of Quantum Nanomaterials

Prof. Vladimir Fal’ko (vladimir.falko@manchester.ac.uk)

Professor Vladimir Fal’ko studies electronic and optical properties of two-dimensional 2D materials and their heterostructures. 2D materials are atomically thin crystals which electronic and optical properties are dominated by quantum physics not only in cryogenic conditions, but even at the room temperature. The projects he offers include:

- many-body phases of electronic liquids in various 2D materials, including the quantum Hall effect in 2D materials with multi-valley spectra (where electrons are characterised by quantum numbers additional to their spin state);
- quantum properties of minibands generated by moiré superlattices characteristic for heterostructures of 2D materials with slightly incommensurate periods and in twisted homobilayers of 2D materials;
- quantum optics of 2D materials, from TH range (intersubband transitions in few-layer films and modelling of new types of cascade lasers) to single photon emissions from excitonic complexes (trions, biexcitons, quintons, etc) in heterostructures of two-dimensional semiconductors and their applications in quantum technologies.

These projects will enable students to learn field theoretical methods in condensed matter theory; analytical and computational quantum transport theory; group theory and symmetry applications in solid state physics. The studies will be carried out in collaboration with experimental groups involved in the European Graphene Flagship at Manchester, Geneva,
Quantum theory of strong interactions in low-dimensional systems

Dr. Alessandro Principi (alessandro.principi@manchester.ac.uk)

Dr. Alessandro Principi offers projects which involve the study of interactions and many-body physics (electron-electron, electron-phonon, electron-impurity, etc.) and their impact on the non-equilibrium properties of 2D systems. Examples range from electronic and thermal transport in graphene, where electrons can behave as a very viscous fluid thanks to the strong electron-electron interactions, to topological materials and 2D systems featuring both itinerant electrons and various forms of (topological and not) magnetism or superconductivity. The main approach is analytical, with numerical techniques used for the resulting integrations and linear algebra, etc. We make use of advanced techniques taken from quantum field theory (such as Feynman diagrams, path integrals, non-equilibrium Green's functions, quantum kinetic equation). These are applied to problems arising in 2D systems. Examples of research projects include:

- Quantum electron hydrodynamics in topological materials: the interplay between topology, Berry curvature, quantum Hall effects and electron-electron interactions;
- Polaron, polaron superfluidity and bi-polaron superconductivity in twisted bilayer graphene as an alternative explanation of unconventional superconductivity;
- Topological collective excitations (plasmons) in 2D superlattices and gratings. Their impact on resonant photodetection, vertical tunnelling, and nanoplasmonics.
- Electrical/optical control of order parameters and of their excitations. Applications to topological superconductivity, magnetism, quantum spin liquids and topological-quantum computation;
- Plasmon-enabled quantum entanglement and entangled two-photon nanosources in van-der-Waals heterostructures;

The projects will enable students to learn advanced analytical and numerical quantum-field theoretical, group theory and quantum transport methods. They offer the possibility of co-supervision by other members of staff, as well collaborations with theoretical and experimental groups in Manchester, Lancaster, Cambridge, ICFO&ICN2 (Barcelona), Pisa, MIT/Harvard (USA), Singapore.

www.alessandroprincipi.com
Thermodynamics and non-equilibrium dynamics of open quantum systems

Dr. Ahsan Nazir (ahsan.nazir@manchester.ac.uk)

Dr. Ahsan Nazir offers theoretical projects on the thermodynamics and non-equilibrium dynamics of open quantum systems. Open quantum systems theory describes the behaviour of quantum systems that are not isolated, but instead in contact with their surrounding environmental degrees of freedom. It is a topic of primary importance in physics and chemistry, and is becoming increasingly relevant in biology as well. Dr. Nazir develops new theoretical techniques to understand the behaviour of open quantum systems both in and out of equilibrium. Applications range from quantum thermodynamics to solid-state quantum technology, quantum transport, and the behaviour of molecular nanosystems. Potential projects include:

- fundamental developments in the theory of open quantum systems and applications to many-body systems;
- the impact of quantum correlations on the laws of thermodynamics and quantum scale thermal machines;
- the effects of environmental interactions in solid-state quantum technology (with established experimental collaborations);
- strong light-matter interactions in quantum electrodynamics;
- vibrational influences in the optical and electronic properties of natural and artificial molecular aggregates, with applications to solar energy harvesting.

http://personalpages.manchester.ac.uk/staff/ahsan.nazir/

Novel aspects of two-dimensional materials

Prof. Paco Guinea (francisco.guinea@manchester.ac.uk)

Professor Francisco Guinea works on problems in condensed matter theory with emphasis on novel aspects of two-dimensional systems. The emphasis is on topics with interesting fundamental content, and those which are at the interface between different disciplines. Some selected problems are:

- Electronic structure, superconductivity, and interactions in twisted bilayer graphene and related materials.
- Effects of the geometry of two-dimensional materials on their electronic and optical properties.
- Topological superconductivity. Macroscopic properties, role of defects.
- Interplay between atomic interaction and macroscopic shapes in membranes. Anharmonicity, formation of bubbles, ripples, and other curved structures.
- Novel properties of electronic states confined to defects, edges, and internal boundaries in two dimensional materials.
Theoretical and computational approaches to 2D materials

Prof. Niels Walet (niels.walet@manchester.ac.uk)

Professor Walet has broad interest in condensed matter physics, ranging from the study of many-body effects in strongly correlated systems to the description of the properties of graphene. His work is characterised by a mixture between theoretical and computational approaches, where computation is used to understand the theory. Computationally intensive projects are available as well.

A large variety of projects are available, largely in collaboration with other theorists in the group. Examples of possible research projects include:

- the study of Majorana edge states in novel devices
- the development of practical approaches for quantum information processing with such devices
- A description of the distortion of layered materials with approximate alignment
- a correct description of flat bands and twisted bilayer graphene
- the nature of topological effects in graphene heterostructures,
- electronic structure of superconductivity in 2D materials
- development of many-body theory (coupled cluster and the functional renormalisation group) for the study of strongly interacting systems.

Training in the relevant techniques, as well as in advanced computational methods, if applicable, will be provided.

https://www.research.manchester.ac.uk/portal/niels.walet.html

Quantum many-body theories and their applications in condensed matter physics

Dr. Yang Xian (yang.xian@manchester.ac.uk)

Dr. Yang Xian offers projects on quantum many-body theories and their applications in condensed matter physics. Many interesting physical phenomena are often the results of a combination of dynamic interaction between particles and their quantum mechanical nature. Magnetism, superfluidity, superconductivity, and fractional quantum Hall effects are such examples. Project are available on the following topics:

- Applications of quantum many-body theories to the ground and excited states of strongly correlated systems such as high-Tc superconductors (cuprates and iron pnictides) and quantum spin liquids (two-dimensional frustrated antiferromagnetic spin lattices such as RuCl3), with emphasis in the further improvement of the variational coupled-cluster method initially developed in our group;
- Dynamics of strongly correlated systems such as low-dimensional antiferromagnetic lattices, graphene ribbons and allied materials, with particular emphasis on their longitudinal modes;
- Topological properties, including the thermal Hall effect, of two-dimensional layered ferromagnets (chromium trihalides) and antiferromagnets with a Dzyaloshinskii-Moriya interaction and/or Kekule distortions. The aim is to provide quantitative support for development of magnon-based devices.

During the project, the student will learn several quantum many-body theories, particularly the coupled-cluster methods (CCM) and its extensions, and apply these techniques to find the physical properties of the relevant physical systems.

http://www.theory.physics.manchester.ac.uk/~xian/

**Glassy materials**

**Dr. Mike Godfrey** (michael.j.godfrey@manchester.ac.uk)

Glasses are poorly understood amorphous materials that share features of both solids and liquids: at low temperatures, a glass becomes rigid like a solid, while its microscopic structure remains virtually identical to that of a liquid. Yet how can a material with a liquid-like structure be rigid? It is a fundamental unsolved problem in physics, which also has practical importance for many technologies, the food and pharmaceutical industries, and even for the understanding of the structure of proteins and the development of organs within embryos. Potential areas of research for a student include:

- Investigation of the connections between local microscopic structure and dynamics in glasses.
- Development and application of linear algebra techniques for computing the properties of disordered materials in low dimensions.
- Study of the so-called “Gardner transition”, which has been predicted to exist deep inside the glass phase, and at which glasses might lose their brittleness and become malleable, like metals.
3D printing to improve patient dosimetry in Molecular radiotherapy (MRT). Our collaboration with the nuclear-medicine group at The Christie NHS Foundation Trust has established a fruitful interdisciplinary research program (2 pdras and 3 PhD students) which seeks to address the complex and interconnected problem of providing accurate patient specific dosimetry in MRT. This work has attracted continued STFC funding to develop more realistic 3D-printed patient-specific organs to allow more accurate patient dosimetry to be performed at the Christie.

**Improved Identification of illicit materials using an X-ray Backscattering technique.**
This research aims to demonstrate the potential improvements that can be made in X-ray backscattering techniques to better identify illicitly smuggled material in cargo / baggage. The will be achieved by combining a detailed understanding of the X-ray scattering processes and Monte-Carlo modelling with experimental results from poly-energetic X-ray sources and new high-efficiency, high-resolution CZT detectors. The project has Rapiscan Systems as industrial partner and currently funds (STFC) 1 pdra plus 1 PhD student.

A project using novel ion manipulation techniques (Paul traps, electrostatic traps and RF coolers) in conjunction with precision laser spectroscopy is available.
Dr. Paul Campbell (paul.campbell-3@manchester.ac.uk)

Aims: this STFC funded project aims to measure fundamental nuclear properties in exotic super-asymmetric fission fragments and atomic-nuclear processes in ultra-low lying nuclear excited states.

Details: The project is to be based at the IGISOL facility, JYFL, Jyvaskyla, Finland and ISOLDE, CERN. The research will exploit a recently constructed electrostatic ConeTrap and use it, for the first time, to facilitate high efficiency laser spectroscopy and then to use the developed spectroscopy to make precision measurements of nuclear parameters via the hyperfine structure and isotope shift.

The project is based at facilities where the University of Manchester and our national and international collaborators, from the UK, Belgium, Finland, Germany, Russia and Japan, have performed successful nuclear structure (and atomic) studies for many years. In the new work our objective is however to achieve spectroscopic efficiencies at an order of magnitude higher than that we have previously attained. Historical efficiencies have permitted in-flight studies of short-lived radioactive ions with lifetimes as short as 10 ms and production rates as low as 10 ions per second. We now intend to supersede these efficiencies and be capable of studying the most weakly produced and highest Z systems available at our on-line isotope separators.

**Laser Spectroscopy at the limits of nuclear existence**

Dr. Kieran Flanagan (keiran.flanagan-2@manchester.ac.uk)

How three-nucleon forces influence nuclear structure and the limits of nuclear existence remains a compelling question in nuclear physics. There are currently many different approaches being utilized around the world to measure the properties of nuclei that may help answer this question. Since laser spectroscopy measures nuclear observables without introducing any assumptions associated with a particular nuclear model it has become a very popular method. Until recently it could only be used to study isotopes that are produced in relatively large amounts, which has limited its application. Over the last 5 years the CRIS collaboration at CERN has developed new techniques in laser spectroscopy that have permitted measurements on beams of less than 10 atoms per second. This has greatly extended the reach of laser spectroscopy and has allowed it to study the most exotic nuclei for the first time. The project will be carried out at the ISOLDE facility, CERN, which is the premier radioactive beam facility at the precision frontier. There are currently PhD student projects in the area of ion trapping, production and application of negative ions for nuclear research and atomic physics. There is an opportunity in the project for students to spend a large fraction of their PhD at CERN.

**Fission dynamics and nuclear astrophysics measurements at CERN**

Dr. Gavin Smith (gavin.smith@manchester.ac.uk)

Projects involve the measurement of fission data from the Neutron Time-of-flight (n_TOF) facility at CERN. Neutrons of a broad spectrum of energies are produced by spallation of protons on a lead target. The neutrons are timed relative to the proton pulse and are used to induce fission on an actinide target in experimental area of the n_TOF facility. The
SpectromeTer for Exotic Fission Fragments (STEFF) is a 2E-2v detector system, developed at the University of Manchester, which used to study the resulting fission fragments. It allows measurement of the velocities and energies of both fragments from the fission event. Mass may be measured independently in each arm. STEFF includes an array of 12 (5”x4”) NaI scintillation detectors for gamma-ray detection. The fission fragments stop in Bragg detectors, the outputs of which are digitized as a function of time and are used to measure energy loss (dE/dx) and range; and hence are used to determine atomic-number distributions. The measured properties of fission and fission-fragment gamma decay are used in studies of the dynamics of the process and have applications in the nuclear-energy sector. A new programme is commencing to use the ISS facility at CERN to use (d,p) reactions in inverse kinematic to induce fission.

Exploring the Changing Shell Structure of Nuclei

Prof. Sean J Freeman (sean.freeman@manchester.ac.uk)
The introduction of the spin-orbit interaction by Maier and Jensen led to an understanding of the observed shell gaps and magic numbers in near-stable nuclei. The appearance of these ideas in undergraduate textbooks gives the impression of solidity and permanence to the well-known sequence of magic numbers. Recent observations, however, have challenged this basic assumption by suggesting that the sequence of single-particle states observed near stability is actually quite fragile; studies of nuclei far from the line of β stability have begun to indicate that the familiar shell gaps do not persist in exotic systems. Instead, shifts in the sequence of single-particle levels conspire to give gaps that change with changing nucleon number, fundamentally reshaping the basis of nuclear structure and producing new and unexpected phenomena. The reasons for these alterations to one of the basic tenets of nuclear physics are currently being debated and are of paramount interest in the development of the understanding of atomic nuclei.

PhD projects in this area will involve using transfer reactions with radioactive beams to investigate the evolution of single-particle structure in to exotic regions of the nuclear chart. This work will predominantly take place at HIE-ISOLDE, CERN using the newly commissioned ISOLDE Solenoidal Spectrometer (ISS).
NUCLEAR THEORY

The Nuclear Theory at Manchester is interested in the connections between nuclear physics and the underlying theory of the strong interaction, Quantum Chromodynamics (QCD), and also in descriptions of nuclei from first principles. Our work ranges from studies of the properties of a single nucleon, through descriptions of the forces between two or three nucleons, to calculations of heavier nuclei. Key tools in this work are effective field theories (EFTs). These theories are expressed in terms of the relevant low-energy degrees of freedom, such as nucleons, pions and photons. They incorporate the symmetries of QCD including a chiral symmetry which reflects the existence of almost massless up and down quarks inside hadrons. This symmetry places important constraints on the interactions of pions with other particles. The work combines ideas from quantum field theory with methods for treating few- and many-body systems. It involves a combination of analytic and numerical calculations, the exact balance depending on the particular project. Possible projects are available on all of the topics listed below for individual members of staff.

Dr Judith McGovern's current interests are focussed on applications of chiral EFTs to the properties of protons and neutrons, and in particular to their electromagnetic polarisabilities. These quantities describe the response of a nucleon to external fields. Recent work has been on analyses of Compton scattering data for the proton and deuteron; extensions will determine the full range of proton and neutron polarisabilities from new experiments on protons and light nuclei. The same approach can be used to determine the contribution of two-photon exchange to the Lamb shift in muonic atoms. In work with Mike Birse, it has been applied to muonic hydrogen, and further work is needed to analyse recent experiments on other muonic atoms. The results of this will help to shed light on the "proton radius puzzle".

Prof Mike Birse works on nuclear forces within the framework of EFTs, and their applications to few-nucleon systems. A particular interest is the use of the renormalisation group to analyse the scaling behaviour of the interactions. In collaboration with Niels Walet, he is also developing an approach to many-body systems based on a functional version of the renormalisation group. This provides a tool for handling strongly interacting systems that does not rely on diagrammatic expansions.

Prof Niels Walet has expertise with a variety of first principles approaches to many-body systems, in particular the coupled-cluster method. In work with Mike Birse, he has implemented a stochastic variational method to calculate the properties of few-nucleon systems. First applications of this have been made using simpler EFT without pions to describe nuclei with up to eight nucleons.
PARTICLE PHYSICS - ACCELERATOR

The Particle Accelerator Physics group studies the interactions between charged particle and electromagnetic fields. We are involved with a number of collaborations. In particular, we work on the High-Luminosity LHC upgrade, Anti-Matter research as part of ALPHA, acceleration through plasma as part of AWAKE at CERN, High Gradient acceleration through CLIC, THz radiation, and medical accelerators (both proton and high energy electron). This research has theoretical and experimental aspects to it. We conduct experiments at Daresbury laboratory (as part of the Cockcroft Institute), at CERN in Switzerland, The Christie and the Photon Science Institute in Manchester, XFEL in Hamburg, and FNAL in Illinois.

We have a strong connection to the Cockcroft Institute, which is a unique collaboration between academia, national laboratories and industry with the goal of bringing together the best accelerator scientists, engineers, educators and industrialists to conceive, design, construct and use innovative instruments of discovery and lead the UKs participation in flagship international experiments. Our group has 6 active academics who usually have funded Ph.D. opportunities.

Some details of current projects and future projects are indicated below. Students are encouraged to contact potential supervisors directly, or Dr. Guoxing Xia (guoxing.xia@manchester.ac.uk) for an overview of research opportunities.

"NEG Coating Impact on Future Particle Accelerators"
https://www.findaphd.com/search/ProjectDetails.aspx?PJID=102276

"Advanced Dielectric Structure Based Particle Accelerators"
https://www.findaphd.com/search/ProjectDetails.aspx?PJID=102012

"A dispersive bunch decompressor and its potential"
https://www.findaphd.com/search/ProjectDetails.aspx?PJID=102015

"Super-macro-particles"
https://www.findaphd.com/search/ProjectDetails.aspx?PJID=101658
**Fundamental tests of antimatter gravitation with antihydrogen accelerators**

**Dr. William Bertsche** ([william.bertsche@manchester.ac.uk](mailto:william.bertsche@manchester.ac.uk))

One of the outstanding grand challenges in physics is to understand the fundamental differences between matter and antimatter that have left us with a universe that is largely composed of matter. The ALPHA experiment at CERN seeks to address this question by performing precise atomic physics measurements on trapped antihydrogen atoms in order to seek minute differences with equivalent measurements in hydrogen. The collaboration is building ALPHA-g, the next generation of antihydrogen traps intended to measure antimatter gravitation.

We are seeking a PhD student to design and perform gravitational free-fall measurements on antihydrogen atoms in order to directly measure antimatter gravitational acceleration as a test of the weak equivalence principle. The student will design and analyse experimental protocol and diagnostic technique for use in ALPHA-g intended to measure the gravitational acceleration $g$ of antimatter on Earth. The student will also be expected to participate in ALPHA’s general experimental programme with trapped antihydrogen atoms.

This is an interdisciplinary experimental project based at CERN with underpinnings spanning plasma, atomic and particle physics. The successful realisation of this project will require both experimental efforts as well as development of diagnostic tools for measuring and controlling the probe and background magnetic fields in the experiment. Particle and field behaviour will be modelled using software such as GPT, Opera, ANSYS and COMSOL. This is a 3.5 – year fully-funded PhD studentship with the University of Manchester where the majority of the studentship would be based at CERN in Geneva, Switzerland.

**Terahertz driven linac: Shrinking the size and cost of particle accelerators**

**Dr Darren Graham** ([darren.graham@manchester.ac.uk](mailto:darren.graham@manchester.ac.uk)) and **Dr. Robert Appleby** ([robert.appleby@manchester.ac.uk](mailto:robert.appleby@manchester.ac.uk))

Terahertz radiation, which sits between infrared and microwave radiation on the electromagnetic spectrum, has the potential to reduce the size and cost of particle accelerators, opening the door to new applications in compact medical therapy, security screening, and fundamental materials science with ultrafast electron or x-ray pulses. We are seeking PhD students to work on terahertz driven particle beam acceleration, joining a collaborative project at the Cockcroft Institute. The primary objective of this project will be to optimise high power ultrafast laser based terahertz radiation sources and investigate novel concepts for terahertz-based manipulation of the 5-50 MeV relativistic electron beams provided by the VELA accelerator at STFC Daresbury Laboratory. By developing new concepts for acceleration we seek to enable a new generation of table-top particle accelerators.

The Institute has been heavily involved in the design, commissioning and operation of the Versatile Electron Linear Accelerator (VELA) facility which is capable of delivering a highly stable, highly customisable, short pulse, high quality electron beam to a series of test enclosures.
This project will involve using a number of high-power ultrafast lasers, including state-of-the-art femtosecond laser systems in Dr Graham’s lab at the Photon Science Institute, a Terawatt laser system at the Cockcroft Institute, and high-energy particle accelerators at STFC Daresbury Laboratory. Hands-on experience in the use of lasers and optical components is not essential, but the student is expected to have a keen interest in experimental physics.

Recent publication:
Nature Communications 8, Article number: 421 (2017) DOI:10.1038/s41467-017-00490-y

Novel Acceleration-Miniaturizing the Next Generation Energy Frontier Accelerators

Dr. Guoxing Xia (guoxing.xia@manchester.ac.uk)

The development of plasma accelerators has achieved significant breakthroughs in the last three decades. Nowadays, the laser wakefield accelerator can routinely produce ~GeV level electron beam with percentage energy spread within only a few centimetre plasma cell and the accelerating gradient (~100 GeV/m) achieved is over three orders of magnitude higher than the fields in conventional RF based structures (in general less than 100 MeV/m). The electron beam driven plasma wakefield acceleration has successfully demonstrated the energy doubling of the electron beam (from an initial 42 GeV to a final 85 GeV) at the Stanford Linear Collider-SLC within an 85 cm plasma channel. A very recent proton driven plasma wakefield acceleration-AWAKE experiment at CERN has achieved for the first time ever the electron acceleration in a proton-driven plasma wakefield [1]. All these achievements will revolutionize today’s conventional particle acceleration technology and will be paving the way for next generation very compact and cost effective energy frontier particle accelerators or colliders based on this enabling plasma technology.

Our group is one of the first few proponents to propose the proton driven plasma wakefield acceleration experiment (CERN AWAKE). Currently we are focusing on several exciting research activities including proton beam, electron beam and laser driven plasma wakefield acceleration and advanced dielectric structure based particle accelerators. Through collaboration with CERN (on AWAKE), Daresbury Laboratory (electron driven plasma wakefield acceleration) and DESY in Germany (through the EU-funded EuPRAXIA project on laser wakefield acceleration) and other international labs, we are working on various topics related to plasma and dielectric structure based novel particle accelerators and radiation sources.

Projects:

- Proton-driven plasma wakefield acceleration - AWAKE at CERN
- Key issues in electron driven plasma wakefield acceleration - Daresbury Lab
- A compact plasma beam dump for next generation particle accelerators
- Ultrashort electron beam driven dielectric wakefield acceleration
- Smith-Purcell radiation based on ultrashort electron beam in grating structures
- Accelerator on a chip - laser driven dielectric accelerator
- Compact radiation sources (x-rays and gamma-rays) based on intense laser plasma interaction.

Very high energy electrons (VHEE) have the potential to deliver radiotherapy rapidly, in a well-controlled manner, and with a more favourable dose distribution than conventional photon therapy, or indeed extant radiotherapy techniques. In addition, the technological advantages of rapid dose delivery, there may well be significant radiobiological advantages in terms more efficacious tumor control or indeed other target control for similar doses as that used in conventional radiotherapy. It is important to realize that VHEE can effectively "freeze" the patient motion, as the beam can be steered rapidly using deflectors familiar to those in RF engineering. This Ph.D. project will have analytical, simulation, and experimental aspects. It will necessarily entail both mathematical physics and medical physics.

In order to assess the potential benefits of VHEE over extant methods we need to investigate the dose distribution in phantoms, and the applicability of beam steering focussing and various other beam delivery aspects. In each case, this necessitates intensive computing, based upon application of Monte Carlo methods to track the particles within the media. Here we will utilize the well-known and well-validated code Geant4, Topas, and related codes to investigate the dose distribution in heterogenous media. We plan to capitalize on massively parallel computing and special dose collation techniques.

Our short-term plans entail validating the dose delivery to water phantoms—with the experimental component being obtained via the unique facility in Daresbury laboratory known as VELA/CLARA (which is anticipated to allow experiments at 50 MeV in 2018). We will also consolidate initial experiments made by our students in this area with additional experiments at 250 MeV with the CALIFES (recently renamed CLEAR) facility at CERN. Based on these validations on dose-depth delivery we will also proceed to investigate, both with intensive simulations and with experiments at the aforementioned facilities, focusing within water phantoms. Initial simulations indicate that VHEE radiotherapy is insensitive to media intervening in between the path of the particle beam and that of the intended dose delivery point of cancerous tissue—i.e. it is insensitive to heterogeneities such as bone tissue, air bubbles and related materials. This is a significant advantage for particular radiotherapy treatments (such as lung and bowel for example) over extant radiotherapy treatments.

High-energy electron radiation therapy has important implications for a novel radiation treatment system for cancer. It may have significant benefits over other means of radiotherapy treatment. The CLARA facility at Daresbury Laboratory (DL) provides a unique facility to provide ground-breaking experiments in this area. There is opportunity for publication in high quality journals in this area.

Proton Radiotherapy & Synchrotron Radiation

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My work is focussed in two main areas: proton radiotherapy and synchrotron radiation facilities. Recent developments for the delivery of proton and ion beam therapy have been
significant, and a number of technological solutions now exist for the creation and utilisation of these particles for the treatment of cancer. There is nonetheless the need for the development of particle accelerators used for external beam radiotherapy and more capable and cost-effective sources of particles. On-going projects entails gantry design and cyclotron design (the RF source to accelerate protons). Utilisation of massively parallel computation, and using the cloud services for example, could have impact on treatment planning.

An additional area of interest lies in the area of synchrotron radiation facilities, which demand progressively brighter sources of electron bunches to drive both spontaneous photon output and free-electron lasers, both storage rings and linear accelerators. Many physical phenomena must be understood to design such facilities, and this is a fertile area of research.

LHC

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We are very excited to design and build an upgraded Large Hadron Collider to make proton-proton collisions at a much higher collision rate, to probe the fundamental structure of matter, measure the Higgs boson and other new particles to an unprecedented level of precision and search for undiscovered particles of nature. There are often opportunities for students to participate in research in this area, on novel new cavities, such as crabbing cavities, on collimation, and on the beam dynamics of transporting high energy beam throughout the LHC. This research has analytical, simulation and experimental aspects to it.
PARTICLE PHYSICS: EXPERIMENTAL

Flavour Physics

The group has a range of involvements in flavour physics experiments. PhD projects are possible within each of them, but can also span more than one project.

Project: LHCb: The charm and beauty of antimatter

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Manchester is one of the larger university groups working on the LHCb experiment and is involved in all current and future aspects of the experiment. This experiment is designed to search for physics from beyond the Standard Model through the analysis of matter-antimatter differences and rare decays of hadrons involving bottom and charm quarks. The group has been responsible for world leading analyses in both areas. We are involved in running the vertex detector of the experiment, the highest precision detector at the LHC, and in the design and construction of an upgraded detector for much higher luminosity.

We aim to give students a broad education and therefore they would be typically involved in two of the following areas. In most cases, the project will have a physics analysis as the main activity, but it may equally be focusing on technical aspects.

Flavour Physics:

There are research projects in both of our main areas of focus: matter anti-matter asymmetries (CP violation) and rare decays. Our group is leading CP violation measurements in charm hadrons and has produced the world’s most precise charm CP violation measurement. In bottom hadrons we are involved in measurements using semi-leptonic B meson decays, which tackle one of the largest discrepancies with the Standard Model of particle physics. Among rare decays our general focus is on lepton-flavour violating processes, which we study in tau lepton decays as well as in bottom and charm hadron decays to a mixture of electrons and muons. The group also performs a number of tests of lepton universality – a fundamental symmetry under tension from recent results.

Many different measurements can be made in the rich field of quark and lepton flavour physics, and it is important to establish whether they can all be explained by the Standard
Model or whether the hints of small differences turn out to be the first signs of some new physics. Our group drives innovation of analysis methods and we have been the first to exploit Graphical Processing Units (GPUs) in an LHCb analysis.

**Detector operation:**

In addition to data analysis the group has major responsibilities in the operation of the LHCb Vertex Locator, in particular its spatial alignment and data quality monitoring. Our group is responsible for the study of radiation damage, which is world-leading research as no silicon detector has been operated in a similar high-radiation environment to date. We also have a leading role in the implementation of LHCb’s real-time alignment and calibration system, which is a novel approach that permits the acquisition of ready-for-analysis data straight out of the detector. Future projects in this area will focus on assessing the final detector performance and translating the lessons learned to the upgraded experiment.

Preparing for the next-generation experiment:

The LHCb experiment will be upgraded to a new detector for higher luminosity operation in 2018. One of our key work areas over the coming years will be the design, construction, commissioning, and operation of the upgraded LHCb vertex detector. Our group is carrying out the assembly of the individual modules (see figure) of what will be the highest precision detector at the LHC. The detectors are based on 55 by 55 micron pitch silicon pixel detectors. They use an innovative micro-channel cooling system using liquid CO₂. Research projects in this area span the full range of high-technology detector work. This includes the assembly and related testing systems to ensure spatial accuracy at the micron level, stability under temperature and pressure variations, and functioning of the electronic elements.

The second area of our involvement is readout electronics performed with dedicated configurable integrated circuits (FPGAs). Research projects cover the design of the algorithms, their tests with test-beam experiments, and their emulation in software. In the long run, these algorithms will be tuned based on data taken with the upgraded LHCb detector. The third area that our group contributes to is the software of the vertex detector where we hold responsibilities for the reconstruction, simulation and data quality monitoring. Research projects focus in particular on an accurate simulation of radiation damage effects and on the monitoring of their impact on data acquisition.

**Designing the long-term future of LHCb:**

Particle physics experiments operate on long timescales and our group is consequently also involved in developing crucial future detector systems. One is a new semiconductor detector to be used in the innermost regions of the tracking stations following the LHCb dipole magnet. The system should be installed around 2025. The second system is a novel vertex detector that, in addition to high position resolution, can also deliver precise timing.
information. This requires an ambitious R&D project to deliver a system that can cope with a factor ten more particles compared to the upgraded LHCb VELO.

**Project: BESIII: The Chinese flavour factory**

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The BESIII experiment is a flavour physics experiment at the electron-positron BEPC II collider at IHEP, Beijing, China. The experiment has been designed to operate in the tau-charm energy region and it a broad physics program that includes QCD tests, tau-physics, light hadron spectroscopy, electroweak interactions and lepton universality tests, charmonium production and decay properties, charm physics and searches for physics beyond the Standard Model. The Manchester group is involved in the latter two. A unique feature of the experiment is the coherent production of quantum-entangled D0 anti-D0 meson states at the (3770) resonance threshold with no additional hadrons. This unique production mechanism is very powerful for identifying the flavour and separating the different CP eigenstates.

Key attributes of the decays of the D mesons cannot be determined from the LHCb data; they require the use of quantum-entangled states that are accessible at BESIII. The quantum correlation of the charm pairs allows unique access to quantities such as relative strong phase variation across the phase space of the decays of the charm meson and its antimatter partner. Such measurements have an important impact on understanding the different behaviour of matter and anti-matter. The synergy of BESIII and LHCb physics programmes carries a great potential to reduce to the minimum the limiting systematics in measurements of charm mixing parameters and CKM angle at LHCb due to model or external inputs.

The production mechanism of the charm particles and the low-background environment makes the experiment particularly attractive for precise measurements of the absolute branching fractions, lepton universality tests and searches for dark matter candidates. Students are expected to focus on a physics analysis but contributions to service tasks and detector operation and data taking are also expected.

**Project: Mu2e: Precision muons at Fermilab**

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The Mu2e experiment at Fermilab aims to improve the sensitivity in the search for neutrinoless muon-to-electron conversions (in nuclei) by four orders of magnitude. The rate is such conversions is essentially zero in the Standard Model and thus any observation would be a signal of new physics. The experiment is sensitive to a wide variety of new physics phenomena many of which cannot be directly detected at the LHC.

Our group is responsible for delivering a detector to record the number of muons captured by the target (in excess of $10^8$/sec) in collaboration with other UK groups. The project will involve the simulation, construction and commissioning of the collimator system for the detector and the integration of the detector with the rest of the experiment.

In parallel, the project will contain a significant analysis component i.e. the precise determination of the muon flux and the comparison of this determination with other detectors and the optimization of the performance of the tracking detectors to maximise the experiment’s sensitivity to new physics phenomena.

Students in this project will play a central role both on the technical side and analysis of one of the most ambitious particle physics experiments on the horizon.

**Project: g-2: The anomalous magnetic moment of the muon**

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The interaction of a muon's spin with a magnetic field defines its magnetic moment in terms of the gyromagnetic ratio, $g$. In the Dirac equation, $g$ is exactly 2, but additional higher order QED, electroweak and strong interactions increase its value by $\sim 0.1\%$ such that $g-2$ is predicted to be: $0.0023318364(7)$. $g$ of the electron is the most accurately predicted and measured quantity in physics and $g$ of the muon is the most accurately measured quantity using a particle accelerator storage ring.

The Fermilab Muon ($g$-2) experiment is seeking to measure ($g$-2) of the muon with a factor of 4 improvement in precision to understand whether the current disagreement between the previous measurement: $0.0023318418(13)$ and the above theoretical value which differ by 3.5 standard deviations is an indication of new physics or not.

The experiment has the potential to establish new physics at the level of significance of more than 7 standard deviations. The experiment is presently accumulating a data sample x20 that of the previous experiment. A student on this project will be involved in the final year of the 3-year data taking campaign at Fermilab and the analysis of the data from the experiment. Particularly the evaluation of the systematic uncertainties due to the vertical harmonic motion of the beam and the variance in the beam momentum.
The results from this experiment are one of the most eagerly anticipated in particle physics.

**Neutrino Physics**

Neutrinos have already taken us beyond the Standard Model of Particle Physics, and may well be ready to reveal yet more new physics beyond the Standard Model. Our group is active in several key areas of neutrino research. We are involved in the US-based liquid argon programme, which includes the Short Baseline Neutrino (SBN) Programme that is searching for the sterile neutrino - a completely new particle; and DUNE, a long-baseline experiment with a cathedral-sized detector, which aims to explain the matter-antimatter asymmetry of the University through observations of neutrino oscillations. Another important question is whether the neutrino can be its own antiparticle, a so-called Majorana fermion. In this case it should be possible to observe an extremely rare radioactive decay called neutrinoless double-beta decay, which would violate lepton number conservation - we are searching for this process with the SuperNEMO detector in France.

**Project: The SBN Programme**

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![One of the first neutrino events observed by the MicroBooNE detector at Fermilab.](image-url)

The SBN Programme will combine three international experiments in order to perform the world's most sensitive search for sterile neutrinos, using the phenomenon of neutrino oscillation. Sterile neutrinos are hypothesized, new neutrino flavours, which do not interact via the weak force; they are only observable through their oscillations. SBN aims to search for such oscillations by placing three liquid argon TPC (LArTPC) detectors (MicroBooNE, SBND, and ICARUS T600) at short baselines along the Fermilab Booster Neutrino Beam.
and studying how the rates of different neutrino flavours vary as a function of the neutrino travel distance. This project will involve the analysis of data from the already running MicroBooNE experiment, and the SBND experiment, which is currently being constructed. Our group's focus is on reconstructing electromagnetic showers to measure the interaction probability of electron-neutrinos, looking for alternative signatures of physics beyond the Standard Model, and improving the uses of argon scintillation light in LArTPCs. The project could also have a small hardware component through involvement in the construction and commissioning of the SBND detector.

**Project: LArTPC Detector Development**

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Silicon photomultiplier and cryogenic photomultiplier covered in a blue-emitting wavelength-shifter under UV lamp light.

Current and future neutrino experiments propose to employ liquid argon time projection chambers (LArTPCs) to probe neutrino properties with unprecedented precision. Several small-scale LArTPC experiments are currently under construction or operating in neutrino beams, providing opportunities for physics measurements. At the same time, they are leading R&D for future-generation experiments, such as DUNE, which aims to search for CP violation in the neutrino sector, and determine the neutrino mass hierarchy.

Light collection systems for LArTPCs are the most rapidly developing component of this technology. In addition to providing triggering for the experiment, and allowing for the identification of beam neutrino events from cosmic ray backgrounds, their applications are quickly expanding to include energy reconstruction and particle identification. This can enable new opportunities for physics measurements, e.g. supernova core collapse neutrino measurements and understanding of nuclear effects in neutrino interactions. This project will focus on development of light collection systems for LArTPC's. This will involve data analysis...
from test-beam experiments such as LArIAT and protoDUNE as well as Fermilab SBN experiments, developing simulations and working with small scale prototypes in the laboratory.

**Project: SuperNEMO**

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SuperNEMO is a new international project that is beginning data-taking in 2018. The experiment will search for neutrinoless double-beta decay, a process that is only possible if neutrinos have mass and are their own antiparticles. Discovery of neutrinoless double-beta decay would be ground-breaking, requiring us to change the Standard Model of Particle Physics, and potentially opening a path to explain the existence, and the small size, of neutrino mass. This PhD project will begin a few months after the experiment begins physics data-taking, at a point when the collaboration is working hard to understand the new detector, reconstruct the data, and develop physics analyses. The student will take a role in both the detector characterization and the development of the very first physics analyses from SuperNEMO. In addition to the search for neutrinoless double-beta decay, the data will be sensitive to a wide range of beyond-the-Standard-Model physics, including lepton flavour violation, right-handed W bosons and Majoron exchange.

**Dark matter direct detection**

**Project: DarkSide-20k**

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The DarkSide-20k experiment is a new experiment aiming to detect dark matter via elastic scattering of dark matter particles from space on argon nuclei in the detector.

DarkSide-20k is designed for a sensitivity reach more than two orders of magnitude beyond current searches at dark matter masses of 1 TeV and to have leading sensitivity to masses above the energy scale accessible at the LHC. This experiment is in the R&D phase and is expected to begin taking data at the Laboratori Nazionali del Gran Sasso in Italy in 2022. Manchester will be responsible for various aspects of the experiment, including the design and instrumentation of the critical neutron veto system used to discriminate dark matter signals against natural radioactive background processes.

As well as enabling the sensitivity of the dark matter search, this veto system may be used to perform other physics measurements, including measurements of neutrinos from supernova explosions. PhD project work can combine aspects of detector design, simulation, and physics sensitivity studies.

ATLAS Experiment

Project: The ATLAS Experiment (LHC)

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Manchester group members play leading roles in the ATLAS experiment, the largest particle physics experiment at the Large Hadron Collider (LHC) in Geneva, Switzerland. They coordinate international research teams in data analysis and in the development of new detectors and algorithms. ATLAS has collected 150 fb⁻¹ of proton-proton collisions at a centre of mass energy of 13 TeV. This provides a data set that is unprecedented in size and energy in the history of particle physics colliders for testing the Standard Model with precise measurements and searching for signs of new physics phenomena beyond the Standard Model.

Our goals with these data include the search for: dark matter, extra dimensions, additional Higgs bosons, heavy Majorana neutrinos, supersymmetry, or new TeV-scale particles such as gravitons, leptoquarks, or new vector bosons (possible massive partners of the W and Z bosons). We perform this research from multiple angles. We search directly for these new physics phenomena as predicted by specific theories. We also make precise tests of the predictions of the Standard Model, in particular measurements of the properties of the recently-discovered Higgs boson. Such measurements are sensitive to potential differences that could provide the first hints of something completely new and unexpected.

The Manchester group offers a broad range of projects involving the analysis of a wide range of different types of events or `final states' at the LHC. We study, for example, events containing Higgs bosons, top and beauty quarks, multiple vector bosons (including events produced by the collision or `fusion' of two vector bosons), hadronic jets, and `missing transverse momentum'. The latter is a signature of weakly interacting particles that escape direct detection in the experiment (for example, neutrinos, but possibly also dark matter). A few more details of some of these possibilities are given in the following paragraphs, but cannot do justice to our full programme. Please get in touch with us.

Following the discovery of a Higgs boson in July 2012, the LHC experiments have focused on determining its properties. The Manchester group has led the way in model-independent analysis of the Higgs boson production in proton-proton collisions, including the first-ever measurements of the Higgs boson differential cross sections using data in the diphoton
decay channel. The group continues to make major contributions to the ongoing LHC Run-II model-independent Higgs analysis programme and is leading the effort to search for New Physics in the Higgs sector using this model-independent approach. This includes searches for CP-violation in the Higgs sector as well as searching for Higgs boson interactions with Dark Matter. Because of its large mass the top quark has a special place in our understanding of the Higgs mechanism. It is extremely important to measure directly the coupling of the Higgs boson to the top quark. Manchester is very active in searches for the associated production of Higgs bosons and top quarks, with Higgs decays to b quarks and also to multi-lepton final states (via the Higgs to WW decay). These events provide additional sensitivity to CP-violation in the Higgs sector. Many other properties of the top quark are being studied in Manchester, such as correlations between the final state particles that arise from the spin dependence of the weak interaction and the effects of the strong interaction between the quarks produced in top quark decays. We are also active in the search for events containing pairs of Higgs bosons in the \( \tau \nu b \) final state that could be produced, e.g., in models containing Gravitons. The search for events containing four top quarks is another area of interest.

Processes in which both of the incoming protons emit a Standard Model vector boson (a W or Z boson) produce a very distinctive experimental signature and are particularly suited to studies of weakly interacting particles. In studying such `Vector Boson Fusion' (VBF) processes, the Manchester group has led the way within ATLAS: making the first observations of the VBF production of both W bosons and Z bosons in their decays to electrons and muons, as well as conducting novel searches for the VBF production of beyond the Standard Model dark matter particles. One of the novel features of this latter analysis was that the numbers of candidate events and their kinematic distributions were expressed as ratios to the already established SM VBF production of Z boson decays to electrons and muons. This `cross section ratio' approach has helped to minimise the effect of both experimental and phenomenological systematic uncertainties on the measurements. Looking to the future, as well as benefitting from the increased data set, we are extending this programme to include a wider range of possible final states, such as events containing b quarks, and tau leptons, and extending the range of possible new physics models that we can investigate.

We search for the direct production of new heavy, weakly interacting, particles also in two boson final states, as predicted by models that contain, e.g., Randall-Sundrum Gravitons or an extended gauge sector. Manchester has significantly contributed to the ATLAS search for Gravitons and lead the combination of leptonic and hadronic decay channels. Currently, we are optimising our searches with the complete run-2 data set to gain an even better sensitivity to new physics that might be just round the corner.

Very few particle physics groups in this country or the rest of Europe can boast of such close and long-standing connections between the experimental and theoretical particle physicists. This provides plenty of fruitful opportunities for joint experiment-theory collaborations in LHC physics. We have had a number of very successful examples of PhD students developing a piece of phenomenology or a novel analysis technique in collaboration with the particle theory group, which they have then applied to the analysis of ATLAS data.

In addition to data analysis, the Manchester group has long-term involvement and leadership of the development of experimental triggers and data acquisition algorithms, measurement
of the luminosity, calibration of the detector response, and we are strongly involved in upgrading the ATLAS pixel detector for data-taking through to 2035. Detector research and development include cutting-edge semi-conductor technologies like 3D silicon and 3D diamond. Manchester led the qualification and industrialisation of 3D silicon for the first ATLAS detector upgrade.

3D diamond detectors have evolved from an idea to an actual proven concept. The key point is to combine radiation hard detector material with in-bulk electrodes (called 3D). The Manchester group is leading the development of this novel technology, being the first to successfully produce the first ever prototype of such a detector in single crystalline and poly crystalline CVD diamond. For this project the Particle Physics group strongly collaborates with the Laser Processing Research Centre at the University of Manchester.

A SEM close-up picture of a 3D diamond test detector with metallisation pattern (left) and schematic of the metallisation-structure with hexagonal, rectangular and quadratic test structures and a test strip detector on a 4.5x4.5mm² area (right). The cell width of the 3D detector is 100m.

One application of this new technology would be in the field of particle physics, specifically for the Phase-2 upgrade of the detectors at the Large Hadron Collider or at a future linear collider for a beam-calorimeter application. We also collaborate with The Christie Hospital to apply this technology to challenges in radiology. The objective is to use 3D diamond dosimeters for in vivo dosimetry applications for photon and proton beam therapy.

Possible PhD projects can combine activities from multiple of the above ATLAS research areas.
PARTICLE PHYSICS - THEORY

The Group has particular expertise in almost all aspects of Collider Physics phenomenology, in the Physics of the Early Universe, in Higgs and Neutrino Physics and in Physics Beyond the Standard Model. Our projects are often focused on aspects of theoretical physics that can be tested in ongoing or future experiments. Consequently we are especially interested in physics that is explored at the world’s colliders, both present and future, and work closely with the experimental particle physicists both in the group and at laboratories around the world. Opportunities exist for PhD work in almost all of our research areas and projects are generally tailored to the evolving interests of individual students and their supervisors. The group’s theorists regularly collaborate with each other, reflecting the fact that there is considerable overlap between the different areas of particle physics phenomenology. As a result it is usual that PhD students in this area will develop a good breadth of understanding during the course of their studies.

Beyond the Standard Model and Particle Cosmology

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The Standard Model of particle physics has been extremely successful in describing all current experiments, but it leaves many questions unanswered, like why particles have the masses and other quantum numbers that they do, why there are three generations of
elementary particles, why there is more matter than antimatter in the universe, what the ‘dark matter’ of the universe is made of, whether the three fundamental forces of particle physics can be unified, and whether this can be further unified with a quantum theory of gravity. To try to answer these questions, we bring together progress in theories Beyond the Standard Model (BSM) with a phenomenological understanding of how those theories could be tested in future experiments and how we can constrain them using the existing data. A recent exciting development is the application of ideas from particle theory to cosmology, the physics of the early universe, and the realization that cosmological data are becoming precise enough to constrain the structure of BSM physics. The group has strong links with Jodrell Bank’s Theoretical Astrophysics and Cosmology Group for research in this direction.

Early Universe and Particle Physics

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Modern physics has an excellent and precisely tested theory, Standard Model (SM) of particle physics, which explains all the modern laboratory experiments. With addition of the general theory of relativity the model allows also to describe the evolution of our Universe. However, here comes the problems—several observations that are part of the Standard Cosmological Model, LambdaCDM, cannot be explained within the SM of Particle physics, making cosmology now the main reason to search for physics beyond the SM. The major tasks are to explain are the inflation, Dark Matter, and Baryon asymmetry of the Universe.

We are focusing on the study the inflationary models and relation to the properties of particle physics. The interesting questions include models with modified coupling of fields and gravity, scale invariant theories. At the same time, the models studied are relevant for Dark Matter generation, provide predictions for new physics searches in the laboratory. Collaboration with other groups within the School of Physics and Astronomy is crucial for the project.

Using QCD to explore the TeV scale at the Large Hadron Collider

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Quantum Chromodynamics (QCD) has been established at collider experiments as the theory of strong interactions, which are responsible for binding elementary quarks and gluons into nucleons. It has emerged that QCD is a remarkable theory with a split personality, possessing a friendly regime where one can do calculations using perturbative techniques (Feynman Graphs) and a more challenging non-perturbative region beyond the control of any methods that derive directly from the QCD Lagrangian,and hence still ill-understood. Additionally, while calculations in QCD perturbation theory are in principle well defined, in practice carrying out such calculations at the level of precision required by most experimental data from particle colliders is also a formidable challenge. Moreover due to the fact that non-perturbative effects are always present, devising techniques to better understand the non-perturbative region is critical to the accurate description of data from colliders such as the LHC. We have played a leading role in developing the current theoretical picture of QCD radiation and non-perturbative effects. Our present focus is on the Large Hadron Collider (LHC) experiments and the search for new physics. Since the LHC collides strongly interacting particles (protons), QCD radiation affects all LHC processes and understanding it in detail is of great importance to enable discoveries of new physics at the
TeV scale. Our current research is playing a vital role in bringing a deep understanding of QCD to bear on developing precision tools to hunt for new physics such as supersymmetry, dark matter or extra dimensions, at the LHC.

**Automating QCD calculations**

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Almost all of the measurements at contemporary colliders, including the LHC, depend on precise theoretical calculations of the QCD “radiation” of quarks and gluons. That is because this radiation is ubiquitous in collisions involving coloured particles. The relatively strong coupling in QCD means that this physics is remarkably interesting because it cannot be captured by simple fixed-order perturbation theory. Instead “all orders” algorithms need to be developed and implemented. Here in Manchester, we are world-leading experts in all-orders QCD and this PhD project will involve joining a pre-existing team of researchers to work on the theoretical development and/or computational implementation of a new algorithm which will significantly improve upon anything that has gone before. Apart from its tremendous utility, this project involves analytic work in a problem of fundamental theoretical interest.

**Monte Carlo Modelling of QCD Interactions**

**Prof. Michael H. Seymour** ([michael.seymour@manchester.ac.uk](mailto:michael.seymour@manchester.ac.uk))

In high energy physics we are usually interested in interactions between partons (quarks and gluons) with high momentum transfer, producing new particles like the Higgs boson or supersymmetric partners, or more familiar ones like the top quark. These decay to produce further partons. However, partons cannot propagate freely but are confined into hadrons, the particles that interact with the detectors around the collision region. This process by which a few hard partons evolve into a system of hundreds of hadrons is far too complicated to calculate analytically and must be modelled numerically, with Monte Carlo techniques. Any attempt to understand the data from the LHC or other high energy collider experiments would be completely impossible without Monte Carlo event generators that simulate them.

Professor Seymour is a senior author of Herwig, one of the three general purpose event generators used by the LHC experiments. He is currently working on theoretical projects to improve the formal accuracy of the approximations used in event generators, called parton shower algorithms, and on more phenomenological projects, to use current data to validate and tune the modelling in the event generators to provide LHC predictions with quantified accuracy. He also works closely with experimenters using event generators to optimize their analyses and get the maximum value out of their data.
PHOTON PHYSICS

The Photon Physics group studies the interactions between light and matter and uses light to investigate a range of novel and important systems. The scope of the work ranges from improving our theoretical understanding of the quantum nature of these interactions to developing new spectroscopic and microscopic techniques for material science, medicine and biology.

Our experimental work utilises light in its broadest sense, exploiting the electromagnetic spectrum from x-rays to THz frequencies and we employ the cutting-edge facilities available in the Photon Science Institute, as well as developing new light sources ourselves. This work often studies the physical processes that underpin applications with important real-world impact, such as the development of efficient new solar cells and LEDs for low-energy lighting.

**Carrier dynamics in GaN films and InGaN/GaN Quantum Wells**

**Dr. David Binks** (david.binks@manchester.ac.uk)

LEDs based on InGaN/GaN quantum wells are revolutionising the efficiency of lighting, leading to a significant reduction in global power consumption and consequent impact on the environment. However, while these LEDs work well in the blue spectral region, they are much less efficient at other wavelengths. This necessitates the combination of a blue LED...
with a yellow phosphor to produce light that is sufficiently ‘white’ for the illumination of homes and offices, even though this involves an inherent energy loss. A much more efficient and controllable approach would be to make white light by combining the output of different coloured LEDs.

One reason why InGaN/GaN quantum wells become less efficient for emission at longer wavelengths is that obtaining LEDs that emit at these colours involves increasing the indium concentration in the quantum wells. This results in a stronger electric field across the well separates the electron and hole wavefunctions, reducing the rate at which they recombine radiatively so that it is less competitive with non-radiative processes. This electric field largely originates as a consequence of the hexagonal crystal phase of typical InGaN/GaN quantum wells.

Currently we are investigating carrier recombination processes in GaN films and InGaN/GaN quantum wells grown in the cubic crystal phase, the greater crystal symmetry of which greatly reduces the field across the quantum well. This work is supported by a recently-awarded EPSRC research grant to investigate cubic GaN material systems in collaboration with the Department of Materials and Metallurgy at the University Cambridge. We use a suite of spectroscopic techniques on cryogenically-cooled samples in well-equipped, established laboratories. In particular, photoluminescence (PL) and PL excitation spectroscopies are used to determine how carrier recombination is affected by the structure and composition of the samples, with PL decay measurements used to measure the characteristic lifetimes of the underlying processes. Raman spectroscopy is also an important technique because it yields insight in the crystal structure purity of the samples.

Project:

**Investigating the cubic phase of GaN films and InGaN/GaN Quantum Wells.**

**Optical techniques as medical diagnosis tools**

**Dr. Mark Dickinson** (mark.dickinson@manchester.ac.uk) in collaboration with **Dr. Andrea Murray** (andrea.murray@manchester.ac.uk)

There is a long standing collaboration between the Photon Physics Research group at the University of Manchester and Salford Royal NHS trust, looking at mainly optical techniques for investigating Systemic Sclerosis (SSc) and Raynaud’s phenomenon. Both of these conditions affect the microcirculation of the peripheral limbs, and we have been using these techniques as a window into the disease diagnosis and progression. It is anticipated that some of the projects will involve collaboration with industrial partners and may lead to CASE awards.

Projects:

- Advanced imaging, such as photo-acoustics
- Using mobile devices for patient self-monitoring of disease progression
- Functional imaging of the microvasculature

Using our techniques as an adjunct to MRI, microCT and biopsy.
Understanding photovoltaics and photocatalysts at the atomic scale

Prof. Wendy Flavell (wendy.flavell@manchester.ac.uk)

There is an urgent need to make better use of the 120,000 TW of power provided by the Sun, by using it to generate power. Alternatively, we can use its energy directly to make useful chemicals (so-called 'solar fuel' - one goal is to produce the world's fertiliser through photofixing nitrogen). In my current research, I am working to develop an understanding of how photoactive junctions work at the atomic scale. The transport of charge across interfaces is fundamentally important in this, but the processes occurring immediately after the absorption of light are poorly understood. Improving our understanding will help us to answer questions such as 'how can we make solar cells cheaper and more efficient?'

How do we do this? My group uses world synchrotron facilities for surface spectroscopies (such as photoemission) to study light-harvesting quantum dots, organometal halide perovskites and heterojunctions for next-generation solar cells. Currently we are developing time-resolved measurements using laser-synchrotron pump-probe spectroscopy in order to probe the charge transport in real time at these interfaces. We also use advanced spectroscopies in the Photon Science Institute at UoM, including near-ambient pressure X-ray photoelectron spectroscopy (one of only around 30 machines available in the world). This helps us to understand the reactions of just the topmost few atomic layers of our nanomaterials with the atmosphere - critical to the long-term stability of solar cell devices containing them. In late 2018, we will also take delivery of a world-first instrument for Hard X-ray PhotoElectron Spectroscopy (HAXPES), that will allow us to probe buried interfaces in device structures.

35 PhD students of 10 nationalities have graduated under my supervision.

Some recent papers: DOI:10.1039/c7nr00672a; DOI:10.1039/c7cc01538k; DOI:10.1063/1.4943077; DOI:10.1021/acs.langmuir.8b01453

Projects:

- **Understanding novel solid state photovoltaic cells**
- **Surface properties of quantum dots for next generation solar cells**
- **Ultrafast measurements of charge transport in nanoparticles for solar nanocells**
- **Degradation and surface passivation of halide perovskite light harvesters**
- **Designing new catalysts for nitrogen photofixation**

Ultrafast laser-driven sources of terahertz radiation

Dr Darren Graham (darren.graham@manchester.ac.uk)

Terahertz radiation, which sits between infrared and microwave radiation on the electromagnetic spectrum has historically been very difficult to utilise, and yet this last unexplored region of the spectrum has the potential to transform a diverse range of fields.
My group’s research interests are focused primarily on the development and exploitation of novel terahertz radiation sources. I address challenges both within the fields of photon physics and accelerator physics. Within the field of photon physics, my group uses ultrafast laser spectroscopic techniques to develop novel sources of terahertz (THz) radiation utilising the state-of-the-art laser facilities at the Photon Science Institute (PSI), and working closely with industrial partners. Further information about the work of my group can be found at https://personalpages.manchester.ac.uk/staff/Darren.Graham/

PhD projects include (but not limited to):

- **Ultrafast Spintronics** – Recently, the emission of extremely broadband electromagnetic radiation, spanning from the mid- to far-infrared spectral regime and covering the so-called ‘terahertz gap’ in the spectrum, from ferromagnetic structures has led to an exciting new route for the generation of terahertz radiation. The ability to control the properties of the emitted THz radiation also has the potential to facilitate a wide range of diverse, technologically demanding scientific applications, from improved medical diagnosis to non-destructive testing and advanced airport security scanners. Furthermore, by understanding the fundamental emission process we will be able to establish new characterisation tools for use in developing the next generation of spintronic devices, where ultrafast spin processes are being investigated for data storage and manipulation.

- **Ultrafast Terahertz Spectroscopy of GaN Semiconductor Structures** – The 2014 Nobel prize in Physics was awarded for the invention of the efficient blue light-emitting diodes (LEDs) that have enabled the development of bright and energy-saving white light sources. This breakthrough in the blue part of the spectrum has spurred interest around the world in exploiting GaN semiconductor quantum wells, the material at the heart of blue LEDs, in other regions of the electromagnetic spectrum. One region of particular interest is the terahertz region. To realise the potential of this region we require compact, efficient and powerful sources of terahertz radiation and the fundamental properties of GaN semiconductors make this a tantalising possibility. In this project the student will use the state-of-the-art laser facilities within the Photon Science Institute to reveal the physics that governs the properties of this remarkable materials system and optimise GaN-based quantum well structures for terahertz sources and detectors. This work will be carried out in close collaboration with the Materials Science Department at the University of Cambridge. The opportunity to work in collaboration with international renowned academics will provide training in cutting-edge experimental physics techniques. The skills gained will provide a solid foundation for a future career in industry or academia.

**Atomic collision physics using combined electron and laser beams**

**Prof. Andrew Murray** (andrew.murray@manchester.ac.uk)

Our research combines electron and laser interactions with atomic and molecular targets to study the fundamental processes that lead to excitation and ionization. This research is important in fields ranging from understanding energy loss mechanisms in Tokomaks, through to studying how low-energy electrons cause DNA breaks in cells leading to cancer. We combine high-resolution laser and electron beams to probe these interactions. Laser beams are used to cool, trap and excite atoms before an electron beam further excites, de-excites or ionizes the target under study. In this way we precisely control their quantum
state, with the results from our measurements being compared to models developed by colleagues in Europe, the USA, Australia and the UK. We are the leading group in the world in this area of research, with all experiments conducted using custom-built spectrometers in Manchester together with the laser facilities in the Photon Science Institute. We operate five different experiments that study electron-impact excitation and ionization from laser-excited atoms and molecules, the production of cold electrons from cold atoms, and the production and study of highly excited neutral Rydberg atoms (whose diameters are up to 10% that of a human hair) for possible use in future quantum computers.

Projects:

- Electron impact ionization and excitation of atoms and molecules
- Looking for quantum interface in two-colour photoionization pathways
- Studying highly excited Rydberg atoms to produce q-bits
- Producing cold electrons from cold atoms for diffraction experiments and for injection into future accelerators

Spectro-microscopy of nanostructured materials

Dr. Patrick Parkinson (patrick.parkinson@manchester.ac.uk)

Over the past two decades, developments in nanostructured materials have enabled huge progress in electronics and optoelectronic devices. However, novel materials, particularly those with nanoscale dimensions present unique challenges for characterisation, where surface-effects become dominant and light-matter interactions can be modified by wavelength-scale geometry.

My group is primarily concerned with how energy moves in nanostructured materials for optoelectronics applications (LEDs, lasers and photovoltaics). To study this, my group is developing automated spectro-microscopy techniques coupled to femtosecond lasers to allow the controlled study of carrier dynamics at the sub-micron length scale and sub-picosecond timescale. By combining advanced photonic characterisation with machine vision, we seek to take advantage of added information revealed through big-data approaches.

Typical PhD projects include:

1) Statistical approaches for nanotechnology (large measurement ensembles)
   Nanotechnology components are of great interest for applications, however, while geometrical size provides many opportunities in tuning electronic properties it also presents a challenge in terms of homogeneity of functional performance. My group have developed new methods to study nanomaterials across inhomogeneous ensembles, and use this to understand how optoelectronic materials behave on the nanoscale. A project exists to extend the theoretical basis our understanding, making use of big-data and Bayesian methods.

2) Single photon techniques (optical, SPAD and software development with novel materials)
   Single photon detection represents the ultimate limit for sensitive in photonics experiments, and is critical for quantum communication based on photon technologies. However, at present these techniques are limited primarily to visible bands. By making
use of absorption in 2D materials, we seek to extend the room-temperature single photon detection processes into the near-infrared and telecoms bands.

3) Silicon integrable nanolaser structures
   Chip-to-chip communication using light is a fundamental goal for low-energy and large scale computing. However, Silicon devices are poor emitters of light, and conventional off-chip approaches require inefficient copper interconnects. We are interested in using III-V nanowires as Silicon integrable nanolasers structures for high-efficiency and ultrafast data communication. This requires understanding of light emission processes on the micro to nanoscale.
PHYSICS OF FLUIDS AND SOFT MATTER

Prof. Anne Juel (anne.juel@manchester.ac.uk) Dr. Draga Pihler-Puzovic (draga.pihler-puzovic@manchester.ac.uk)

Research in Physics of Fluids and Soft Matter is focused on the dynamics and instabilities of complex systems, from bubble flows to soft tissues, and encompasses both curiosity-driven and industrially-relevant phenomena. Our group currently consists of 10 members including two permanent members of academic staff (Prof Anne Juel and Dr Draga Pihler-Puzović). Laboratory-based research into nonlinear phenomena often reveals unexpected findings, which in turn requires interpretation via mathematical modelling.

Our group houses the laboratories of the Manchester Centre for Nonlinear Dynamics (MCND, http://www.mcnd.manchester.ac.uk), founded in 2000 by the Schools of Physics and Mathematics to ally quantitative experimental investigations, with cutting edge approaches in mathematical and numerical modelling of complex systems. MCND builds on Manchester’s outstanding pedigree in fundamental fluid mechanics to provide a modern, multidisciplinary training environment of high international profile, which is unique in the UK.

Current research themes in our group include:

- Instabilities and pattern formation on the pore scale (AJ, DPP).
- Droplet microfluidics (AJ, DPP).
- Instabilities in soft materials (DPP).
- The dynamics of wetting (AJ).
- Yield phenomena in complex materials (AJ).

If you would like to know more, please contact anne.juel@manchester.ac.uk or draga.pihler-puzovic@manchester.ac.uk. PhD funding is available through EPSRC Doctoral Training Awards and CASE studentships.
Our group primarily performs experimental research in different areas of soft condensed matter, liquid crystals, polymer modified liquid crystal composites, nanoparticle dispersions in anisotropic fluids and liquid crystal phases formed by colloidal materials, especially graphene oxide. Investigations range from fundamental physical questions to studies which are of relevance to the applications.

We use a range of in house experimental optic, electric and electro-optic techniques. For some specialized techniques and material synthesis, we collaborate with different groups world-wide.

Possible projects:
- Myelin figures in the presence of nanomaterials
- Photo-responsive ferroelectric and frustrated liquid crystals
- Dispersions of liquid crystals with magnetic nanoparticles and ferrofluids
- Mixing spheres, rods and discs: inorganic liquid crystals
- Motion of spherical and elongated microparticles in liquid crystals
- From dissolved polymer liquid crystals to polymer stabilized liquid crystals