The University of Manchester

Department of Physics and Astronomy

Postgraduate Project Booklet 2024/2025

Contents

ASTROPHYSICS

(THE JODRELL BANK CENTRE FOR ASTROPHYSICS)

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 five research groups within JBCA: Cosmology; Pulsars, Exoplanets and Transients; Extragalactic Astrophysics; Galactic Astrophysics and Solar Physics. 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

Cosmology: • Understanding the origins of the initial deviations for homogeneity that eventually lead to the formation of large scale structure; • The origins of the cosmic acceleration; • The nature of the dark matter thought to pervade the Universe; • The formation of galaxies and clusters of galaxies.
Pulsars, Exoplanets and Transients: • The origin of fast radio bursts and their use as cosmological probes; • Using pulsars as precision tools for testing gravity and studying extremes of plasma and magnetism, nuclear equations of state, and binary system evolution; • The structure of our galaxy as determined through microlensing; • The physics of planetary atmospheres; • The physics of explosive events such as novae.

Extragalactic Astrophysics: • Active galaxies and black holes; • Astrophysical magnetism; • Galactic interactions and clusters.
Galactic Astrophysics: • Star formation and interstellar medium; • Late stellar evolution; • Diffuse Galactic Radiation; • Galactic magnetism.
Solar Physics: • How is plasma in the solar corona heated to temperatures of millions of degrees? • How does the process of magnetic reconnection work in the solar corona and elsewhere? • What is the origin of high-energy charged particles in solar flares?

Project areas

The full list of our PhD projects are available below and also at the JBCA projects webpage
http://www.jodrellbank.manchester.ac.uk/study/postgraduate/phd-projects/

and at the MSc(R) projects webpage
https://www.jodrellbank.manchester.ac.uk/study/postgraduate/msc-projects/

Active and Passive Satellite Observations with e-MERLIN
Supervisory Team: Prof Michael Garrett and Prof Simon Garrington
Contact: michael.garrett@manchester.ac.uk

Space Situational Awareness (SSA) is now becoming an increasingly urgent aspect of Space Sustainability with the proliferation of low-Earth orbit (LEO) satellites for global internet provision and increased space debris populations. At the same time, the protection of important national assets in space, especially in geostationary orbit (GEO) is becoming more important. A related area is the study of Unidentified Anomalous Phenomena (UAP) with organisations like NASA and Project Galileo tasked with understanding their nature and origins, and their impact on national security and air traffic management.

Active satellites can be tracked using various telemetry methods and almost all objects in space (depending on size) can be tracked using radar and/or optical techniques.

Radar observations have the advantage of providing additional data on distance and velocity and are usually made using the same antenna to transmit and receive (monostatic). Because radar sensitivity scales with D4 tracking objects at GEO is much more challenging. Using large radio telescopes as the receivers in a bistatic configuration has significant advantages: large collecting area, highly sensitive and continually operating receivers, and the possibility to calibrate using astronomical sources. Initial experiments have already demonstrated the potential of this approach using transmitters at MIT (US) and FHR (Germany) and receiving antennas in the UK, Netherlands and Italy. In the UK, we have used antennas of the e-MERLIN array which comprises 7 large radio telescopes, including the 76-m at Jodrell Bank Observatory, and detected GEO satellites using both the MIT and TIRA transmitters. These observations include coherent processing to form range-Doppler 'maps' of clusters of satellites and to show the micro-Doppler signatures of tumbling space debris, such as rocket bodies. This Doppler signature can be inverted (using a range of techniques) to form high-resolution images (< 1m) of space debris in mid-Earth orbit (20,000km).

This project would build on this initial demonstration to use e-MERLIN as an array, combining the received signals from multiple telescopes to provide improved position and velocity measurements and to extend the observations to a wider range of targets. In particular it will exploit the capability of the e-MERLIN network to make synchronised and coherent measurements between antennas separated by up to 220km. The work may include: co-ordinating observations between transmitters in US and Germany with e-MERLIN (and potentially other European radio telescopes) ; simulating and processing radar data to derive ranges and velocities; synthesising data from multiple antennas; developing observing strategies to combine astronomical and radar observations to improve accuracy, coherence time and sensitivity and placing the results in a precise frame of reference; investigating novel cross-correlation techniques to augment current radar processing strategies; applying these techniques to passive observations of transmitting satellites and passive radar techniques using opportunistic transmissions. The techniques developed here could also be applied to studies of UAP and SETI (Search for Extraterrestrial Intelligence).

ALMAGAL: The ALMA Study of High Mass Protocluster Formation in the Milky Way
Supervisory Team: Prof. Gary Fuller and Dr Rowan Smith (St Andrews)
Contact: G.Fuller@manchester.ac.uk

Understanding the formation of massive stars is central to wide range of astrophysics, from the star formation history of the Universe to the physical and chemical evolution of galaxies and the origin of blackholes, pulsars and gamma ray bursts. ALMAGAL is an ALMA Large Programme to observe 1000 young, high mass regions to study the formation and evolution of high mass stars and their associated stellar clusters. This project will involve the analysis of the ALMAGAL observations, and observations from related ALMA projects, to study the properties of the sources detected, the dynamics of the regions and their environments, and the evolutionary status of the protostars. ALMAGAL is large international collaboration and there may be opportunities to spend time working at some of the partner institutions. There will also be opportunities to take part in, and potentially, lead follow-up observations of some of the sources studied with ALMAGAL. The results of the analysis of the ALMAGAL observations will be compared with numerical simulations of massive star formation to help constrain the initial conditions required to form the most massive stars.

Characterizing the dynamic magnetospheres of neutron stars
Supervisory team: Dr Patrick Weltevrede and Dr Mike Keith
Contact: patrick.weltevrede@manchester.ac.uk

Radio pulsars are highly magnetised neutron stars which rotate very rapidly: up to 100s of times per second. During each rotation, the radio emission beamed along the magnetic poles sweeps across the Earth and can be detected by very sensitive radio telescopes as a regular sequence of pulses. The rotation of the neutron stars can be extremely stable which makes them very accurate clocks allowing tests of the general theory of relativity.

However, for most pulsars the individual pulses of the observed sequence vary greatly in shape, intensity and polarization. These variations are caused by largely unknown physical processes in the magnetosphere of these stars. In some cases these variations happen in a coordinated fashion, which are known as drifting subpulses, indicative of regular dynamical changes in the magnetosphere.

In this project you will explore observational data from the "1000 Pulsar Array" project on the MeerKAT telescope in South Africa (a pre-cursor of the SKA: the Square Kilometre Array which will be the largest telescope in the world). This rich data-set has exquisite quality observations for many pulsars yet to be analysed in any detail. In this project you will characterize this variability seen in the pulse shapes and their polarization, and explore the implications for magnetospheric theories.

Where possible, we will supplement this data with observations from the Parkes radio telescope in Australia (a great instrument which has discovered more pulsars than any other radio telescope in the world) and the FAST radio telescope in China (largest single-dish telescope in the world).

CMB Spectral distortion anisotropies as a novel probe of cosmology
Supervisor: Prof Jens Chubla
Contact: jens.chluba@manchester.ac.uk

Spectral distortions of the cosmic microwave background (CMB) - tiny departure of the CMB energy spectrum from that of an equilibrium blackbody distribution - have now been recognized as one of the important future probes in cosmology and particle physics. While very challenging to observe, multiple experimental activities have started in the cosmology community with the big goal to improve the long-standing limits by COBE/FIRAS from the 1990s by orders of magnitudes. In addition to the average distortion signals in the CMB monopole spectrum, it has now been highlighted that anisotropic spectral distortions can be directly measured with existing and upcoming experiments (e.g., Planck, Litebird, The Simons Observatory, CMB-S4, the SKA). This directly links distortion science to studies of the CMB temperature and polarization anisotropies, and allows us to constrain new physics related to primordial black holes, primordial magnetic fields, axions, cosmic strings and textures as well as primordial non-Gaussianity.

In this project, you will work on the existing cosmological thermalization code CosmoTherm to develop novel tools for predicting and analysing spectral distortions signals (both average and anisotropic) in light of future CMB missions and experiments. This will identify novel methods for studying early-universe and particle physics in regimes that otherwise remain inaccessible. You bring a keen interest in theoretical physics / cosmology and experience with various modern coding languages (e.g., C++ and Python). The specifics of the project are open and multiple exciting possibilities are available, depending on the student's inclinations and strengths.

Commissioning the RHINO 21cm global signal experiment prototype at Jodrell Bank
Supervisor: Dr Phil Bull
Contact: phil.bull@manchester.ac.uk

Early in the Universe's history, before the first stars and galaxies had formed, the only significantly detectable EM radiation came from neutral hydrogen, which has a spin-flip transition deep in the radio part of the spectrum, at a rest-frame wavelength of 21cm. As galaxies began to switch on, the neutral hydrogen was heated and eventually re-ionised. By charting the brightness temperature of the 21cm line over time, we can learn about the magnitude and timing of these early heating processes, and thus learn about the very first stars and galaxies via their impact on their local environment.

The 21cm line is redshifted according to when in cosmic history its emission took place. To probe the time before the reionisation of the Universe, we must observe frequencies in the 70 - 100 MHz range, corresponding to emission from less than a billion years after the Big Bang. Observing this radiation is difficult however; it is faint, while other radio emission processes (such as Galactic synchrotron) occur nearby and can be several orders of magnitude brighter. Radio interference from human activity is also problematic in this part of the spectrum, e.g. FM radio. Instruments designed to observe the 21cm "global" signal in this range (its average over the whole sky) must therefore be calibrated extremely accurately, in order to make it possible for these spurious sources of emission to be subtracted from the data to uncover the 21cm signal itself.

In this project, you will work on designing and commissioning a new 21cm global signal experiment called RHINO, which currently exists as a scaled-down prototype at Jodrell Bank. The main RHINO telescope will be an extremely large (~15m high) horn antenna, which has excellent rejection of many of the systematic effects mentioned above, but will require a lot of infrastructure to build. The prototype is much more manageable however, at only ~3m in height, and can observe at ~350 MHz. The aim of this project is to demonstrate successful science observing with the prototype. This will require developing or refining some components of the receiver hardware, developing a statistics-based calibration pipeline, and observing and subsequently analysing seasons of data from the prototype telescope. The results of this project will then feed into development of the full-sized antenna. (Note: Existing knowledge of electronics/RF engineering is not necessary for this project.)

Discovering and Studying Pulsars and Fast Transients with SKA precursors: MeerKAT and LOFAR 2.0.
Main Supervisor: Prof Ben Stappers
Contact: Ben.Stappers@manchester.ac.uk

Pulsars and Fast transients represent some of the most extreme objects in the Universe. Pulsars are rapidly rotating neutron stars which have exceptionally strong magnetic fields. They have applications ranging from studying the extremes of matter through to their use as Galactic scale gravitational wave detectors. Recently we have discovered that there is a new population of very slowly rotating pulsars which challenge our ideas of how the evolve and how they generate their radio emission. Fast radio transients is a growing area of research and are epitomised by Fast Radio Bursts (FRBs), but their appear to be other manifestations too. FRBs are currently one of the most exciting and mysterious sources in astronomy. They are millisecond-long bursts of radio emission which are coming from sources that are distributed throughout the Universe: seen in our near neighbour galaxies and all the way to at least redshift 2. This combination of a burst of radio emission and large distances mean that they are excellent probes of the intervening medium and so can be used to investigate questions about the location and nature of the missing baryons and the material around, and within, galaxies.

While many hundreds of these sources are now known, the origin is still unclear. Some FRBs are known to repeat, but apparently not all do. So, is there more than one type? Proposed progenitors range from highly magnetised neutron stars to the merger of neutron stars. In this project you would be part of the LOFAR 2.0 and MeerTRAP teams which will use these precursors to the largest radio telescope every built, the Square Kilometre Array to find and study new pulsars and fast transients. These projects probe very different regions of the expected parameter space for pulsars and fast transients and so are nicely complementary. You would be involved in the search for these sources, studying their emission properties and also looking at the population.

Discovery and Study of the First Galaxies and Stars with the James Webb Space Telescope
Main Supervisor: Prof Christopher Conselice
Contact: conselice@manchester.ac.uk

Since its launch in late-2021 the James Webb Space Telescope has started a revolution in our understanding of the first galaxies and stars formed within 500 million years after the Big Bang. This update to the Hubble Space Telescope will observe for the first time the birth of galaxies in the universe. We will also observe some of the earliest stars when they explode as supernova and those seen as gravitationally lensed objects. I am co-leading a JWST guaranteed time observations (GTO) team who will obtain some of the earliest data from JWST for this project, in which these first galaxies and stars will be located and studied.

The student working on this project will lead the discovery of the first galaxies, and studying their properties including their masses, sizes, structures, and merger histories. We are currently obtaining ancillary data with the Hubble Space Telescope and the Very Large Telescope (VLT) in Chile. The student working on this project will take on a leadership role in investigating the stellar populations, ages, structures, and star formation rates of the first galaxies and stars using JWST imaging and spectroscopy. These observations will be interpreted in terms of theories of galaxies formation to test and exclude different ideas for how the first generations of galaxies and star formed.

Galactic radio emission – understanding our Galaxy for future cosmology missions
Supervisory team: Prof Clive Dickinson, Dr Stuart Harper, Dr Vasu Shaw, Dr Paddy Leahy and Prof Jens Chubla
Contact: clive.dickinson@manchester.ac.uk

JBCA has been at the forefront of studying diffuse Galactic radio emission since the very first days of radio astronomy. We've mapped the entire sky at low angular resolution with several "low" radio frequencies (< 5 GHz) and "high" radio frequencies (30-900 GHz) with the Planck space mission. However, we still do not have a full understanding of Galactic emission across the radio/microwave bands. There are many unanswered questions, including what causes the large radio loops that cover large fractions of the sky or the halo bubbles near the Galactic centre, what is the form of dust/molecules that is responsible for anomalous microwave emission – is it due to spinning dust grains? New polarization observations also reveal a very ordered Galactic magnetic field, both locally and across the Galaxy, but a detailed Galactic model is still missing.

In addition to Galactic science, detailed measurements of the Cosmic Microwave Background

(CMB) provide the strongest constraints on cosmological parameters. Future CMB polarization missions are aiming to constrain primordial B modes, caused by a background of gravitational waves, which would be a smoking gun signature that inflation happened in the first fractions of a second of the Universe. However, one of the major challenges is in quantifying and removing "foreground" emission, which for B modes, is at least an order of magnitude brighter than the cosmological signal we're trying to detect!

JBCA is involved in several world-leading experiments that are both trying to measure CMB B-modes and quantify the contaminating foreground emission, including:

- C-Band All-Sky Survey – 5 GHz all-sky survey to map synchrotron intensity and polarized emission with high sensitivity and fidelity, to provide a foreground template for future CMB missions. C-BASS is likely to be the key low frequency data for future missions, as it is at the ideal frequency and is able to map the sky with high sensitivity with minimal systematic errors. We have completed the northern survey and the southern survey will be starting in the near future.
- COMAP Galactic Plane Survey – 26-34 GHz survey of the northern Galactic plane with the COMAP instrument at 5 arcmin resolution to study Galactic emission, particularly AME/spinning dust near 30 GHz. Manchester is leading this sub-project for the COMAP collaboration. The survey is well underway and is expected to be completed ~2025.
- LiteBIRD – next generation Japanese-led space mission to provide the ultimate limits on inflationary B-modes. LiteBIRD is the successor to the immensely successful Planck space mission, to be launched ~2030, and could potentially provide the best limits on inflationary B-modes on large scales (r<0.001). As part of LiteBIRD UK, U. Manchester is responsible for analysis pipelines for component separation and systematic error mitigation.

We are looking for a PhD student that is interested in radio data analysis techniques, with the potential to work on both low level (e.g. improving calibration of C-BASS/COMAP data, data reduction etc.) and high level (e.g. CMB component separation, Galactic science) analyses. The exact nature of the PhD will depend on the experience and interests of the student. Much of the work will be aimed at preparation for the LiteBIRD space mission, including simulations of foregrounds and potential systematic effects. Some of the work may also be applicable to the Simons Observatory (SO) project that Manchester is also involved in.

HI Intensity Mapping with MeerKAT
Main Supervisor: Laura Wolz
Contact: Laura.wolz@manchester.ac.uk

A key goal of cosmology is to understand the accelerated expansion of the Universe, believed to be driven by a force called Dark Energy. Mapping the distribution of galaxies throughout the Universe’s lifetime can measure the expansion history and help us understand the nature of Dark Energy. Historically, cosmologists have successfully used the optical emission of stars located in galaxies to map the cosmic web over time. In the past decade, a new method called intensity mapping has emerged which uses the radio emission of gas (specifically the highly abundant Neutral Hydrogen gas) to trace the galaxy distribution. The future Square Kilometre Array (SKA) and its pre-cursor MeerKAT are enormous radio telescope arrays, capable of higher sensitivities and spatial resolution than any existing radio instrument. Intensity mapping is a unique probe, as it can be observed using the SKA as a single dish array, as well as in interferometric mode which gives much higher spatial resolution in the data. Both datasets are essential if we aim to acquire a complete understanding of how hydrogen traces dark matter and how gas and galaxies evolved with cosmic time.

PhD projects are available to work on the on-going MeerKAT data analysis, both in Single Dish as well as in interferometric mode, as well as the simulation of data including instrumental effects. Topics for exploration include optimisation of the HI and cosmology constraints by combining information from both data types, improvement of the data reduction pipelines as well as preparations and forecasts for SKA observations. Most project work will be computationally and the student will work within the teams of MeerKAT and SKA intensity mapping. Some background reading can be found here https://arxiv.org/pdf/2010.07985.pdf and https://arxiv.org/pdf/2206.01579.pdf.

Long term studies of star formation in M82
Supervisory team: Prof. Robert Beswick and Dr David Williams-Baldwin
Contact: Dr David Williams-Baldwin

Understanding the star formation rates of nearby galaxies is important for both galaxy evolution but also our knowledge of stellar physics. In an ideal world, star formation rates can be estimated from optical light received from a galaxy. However, this is complicated as the optical light from an active galactic nucleus must be taken into account, and large amounts of dust and gas can extinct or absorb optical light, biasing estimates. High-resolution radio observations provide the perfect probe of these different classes of object as radio waves are unaffected by this extinction and absorption. The radio waveband is especially useful as it traces both the thermal emission from HII regions of young massive stars, but also the non-thermal emission from the shells of supernova remnants. Radio observations of star forming galaxies are therefore an excellent independent probe of star formation rates which can be used to calibrate other star formation correlations.

The nearby supernova factory M82 has been intensely studied by e-MERLIN and other radio interferometers over the last 4 decades, owing to the high optical absorption which has prevented study of the supernovae, HII regions and exotic transient objects in this galaxy in optical bands. This project will concentrate on radio datasets of M82 over several decades to continue the long-term monitoring of this source and explore new areas such as widefield imaging now that higher performance computers are available. This project can take several different routes depending on the candidates preferred areas and interests, including e-MERLIN data analysis of similar star forming galaxies in the LeMMINGs survey, 10s mas resolution European VLBI Network data to resolve individual supernova remnants or more in depth coding to search for transients over the course of the last 40 year's worth of observations. The candidate should be able to use python and have an interest in radio astronomy on stellar objects.

Mining the Jodrell Bank Pulsar Timing Data Archive
Supervisory Team: Dr. Michael Keith and Dr. Patrick Weltevrede
Contact: Michael.keith@manchester.ac.uk / Patrick.Weltevrede@manchester.ac.uk

The pulsar group at Jodrell Bank has been studying pulsars for over 50 years, and regularly observes around 800 pulsars. These datasets usually stretch back to the discovery of the pulsar, and are therefore the most complete records of pulsar arrival times in the world. Using these data we can track the rotation of the pulsar, and in most cases this means that we unambiguously know when every rotation of the pulsar occurred since it was first observed.

These data are a valuable tool for understanding the complex physics that governs the rotation of pulsars. In particular, it is of great interest to understand how pulsar rotation evolves over time, and how we can characterise and understand the rotational instabilities in the pulsar. We also can use the data to track the position of pulsars over time, and hence get some understanding of the velocity distribution of the pulsars, which we can use to understand the processes leading to the birth of neutron stars.

In this project you will be tasked with extracting deeper understanding of pulsars by applying modern data science techniques such as Bayesian Analysis and Gaussian Processes to the Jodrell Bank pulsar timing database.

Modelling time domain radio emission in the circumstellar regions of protostars
Supervisory Team: Prof. Gary Fuller and Prof. Philippa Browning
Contact: G.Fuller@manchester.ac.uk

Understand how a forming star acquires its final mass is a fundamental issue for a building a comprehensive model of star formation. The time-dependent and transient nature of the process of mass accretion from the circumstellar disk to the protostar is difficult to study and poorly understood. However, this process can be diagnosed through variable emission it produces. Recently, we have developed new idealised models (Waterfall et al Mon Not Roy Astr Soc 483, 917, 2019; Waterfall et al. Mon Not Roy Astr Soc 496, 271, 2020) of this phenomenon in T-Tauri stars, in which magnetic large loops interconnecting the star and the accretion disk are filled with non-thermal electrons due to magnetic reconnection which emitting at radio wavelengths.

The aim of the current project will be to develop more sophisticated and realistic models of this process and predict its radio emission. This will be done using numerical resistive magnetohydrodynamic simulations of protostars, which will predict the energy release due to magnetic reconnection as the stellar magnetic field interacts with the disk. Then, the gyrosynchrotron radio emission due to electrons accelerated by the reconnection – similarly to solar flares – will be calculated, modelling both the intensity and polarization properties as a function of frequency as the accretion event progresses.

Comparison of the results of these models with observations will provide some of the first insights on this final stage of accretion on to protostars. The results will provide important constraints on the design the first large scale radio surveys of star forming regions with the world's largest radio telescope, the Square Kilometre Array (SKA) and there may be the opportunity to be involved in the comparison of the model predictions and observations made with current radio telescopes.

Next generation hydrodynamic simulations of galaxy clusters
Main supervisor: Prof Scott Kay
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Galaxy clusters host the most massive galaxies in the Universe, with stellar masses up to one trillion times the mass of the Sun. These galaxies are surrounded by huge reservoirs of hot, X-ray emitting plasma, with temperatures over 10 million Kelvin. A puzzling observation, however, is that this gas is not cooling down and forming new stars at the expected rate - why does star formation shut down in massive galaxies? One, currently favoured, answer is that the gas is being kept hot by an active galactic nucleus (AGN) through the emission of powerful jets of radio-bright relativistic plasma. The AGN, powered by accretion on to a super-massive black hole, is energetically capable of counteracting the radiative losses in the X-ray gas and can even drive some of the gas out of the system altogether.

Modern hydrodynamic simulations of galaxy clusters attempt to include the effects of this so-called AGN feedback process and can successfully model the shut-down of star formation in brightest cluster galaxies, while producing black holes with observationally-reasonable masses. However, these simulations currently struggle to reproduce the X-ray thermal properties of the gas, predicting material that tends to be too hot and diffuse in the cluster core. Such a discrepancy is likely the result of current models not capturing all the essential physics but may also be due to insufficient numerical resolution.

In this PhD project, the student will join ongoing collaborative efforts to develop a new generation of cluster simulations with improved resolution and physics modelling using the SWIFT hydrodynamics code (swift.dur.ac.uk). They will work on science projects involving the analysis of new simulation data as well as have the opportunity to help develop and test new simulation models. The student will join the Virgo consortium and use the DiRAC high performance computing facility (dirac.ac.uk).

Probing the Early Universe with Simons Observatory
Supervisory Team: Prof Michael Brown, Prof Richard Battye, Prof Jens Chluba and Prof Lucio Piccirillo
Contact: M.L.Brown@manchester.ac.uk, Richard.Battye@manchester.ac.uk, Jens.Chluba@manchester.ac.uk, Lucio.Piccirillo@manchester.ac.uk

Simons Observatory (SO) is a next-generation Cosmic Microwave Background (CMB) telescope to be located in Chile. Its primary objective is to make high fidelity images of the Cosmic Microwave Background which will allow constraints on fundamental physics. The University of Manchester leads a recently announced major UK contribution to SO (termed SO:UK) which will have a major impact on SO's ability to pursue this headline science goal. The UK team will provide: (i) two additional state-of-the-art telescopes for SO, (ii) a UK-based data centre for processing the large data volumes and (iii) a program of algorithm development aimed at turning the raw data from the ~80,000 detectors into higher-level data products and scientific results. The JBCA at The University of Manchester hosts the data centre and is delivering one of the two SO:UK telescopes. We are also playing a major role in the pipeline development work. As part of our group, you will have the opportunity to get involved with this state-of-the-art CMB experiment in multiple areas including contributing to the instrument development, developing data processing algorithms and in the scientific exploitation and interpretation of the data. There are three PhD projects available to work with the SO team at the JBCA which will be between 10 and 15 scientists. Each will become part of the team taking a general interest in the overall project but will also have specific responsibilities. Projects B & C should expect real SO data on the timescale of the PhD, while the delivery of the SO:UK SATs involved in project A is due during the timescale of the PhD.

*** Project A: (Piccirillo and Brown)**

This will be a technical project involving the build of the two SO:UK telescopes. Our group is in charge of the build and operation of a state-of-the-art telescopes dedicated to the observations of the CMB. It will be a vital part of the most sensitive experiment ever built in experimental cosmology. The student will play a major role in the assembly, testing and operations of the telescope first in the testing site at Jodrell Bank Observatory and then at the observing site in Atacama (Chile).

*** Project B: Constraining primordial gravitational waves (Brown and Battye)**

One of SO's primary goals 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. These B-modes can be created by primordial gravitational waves, but also by other non-standard physics such as birefringence. These signals are typically very weak and it will require exquisite control of systematics. The project will involve some work on the data pipeline working with the data centre staff, development of sophisticated mathematical algorithms to remove systematic effects and playing a role in the international SO working group on B-mode science.

*** Project C: Using the Sunyaev-Zeldovich effect to constrain fundamental physics (Battye and Chluba)**

The SZ effect is the inverse Compton scattering of CMB photons by the gas inside galaxy clusters along the line of sight. It has a unique spectral signature and it has been used to constrain cosmological parameters such as the matter density, the amplitude of perturbations and others including the properties of dark energy and neutrino masses. This is done using observables such as the number of clusters a function of redshift and the power spectrum fo the Compton y-parameter. The JBCA plays a significant role in the SZ working group. The objective of the PhD will be to work on the modelling of the SZ effect, which involves numerical simulations, modelling the observations and ultimately using the results to constrain cosmological models and the underlying astrophysics of clusters.

Probing the Galactic magnetic field with POSSUM
Supervisory Team: Dr Paddy Leahy and Prof Anna Scaife
Contact: J.p.leahy@manchester.ac.uk

Our Galaxy's magnetic field plays an important role in the interstellar medium, sometimes dominating the local dynamics and rarely negligible. It helps regulate star formation and accelerates some particles to relativistic energy, forming cosmic rays. These processes are not fully understood, and nor is the structure of the magnetic field, which is often described as turbulent although some organized patterns can also be discerned. There are many observational tracers of the interstellar field, but they all have severe limitations, and so we must make progress by using observational clues to guide theoretical and computational modelling.

One of the most important magnetic tracers is Faraday rotation: the plane of polarization of radio waves change with wavelength, at a rate proportional to the integral the magnetic field component along the line of sight, weighted by the free electron density. This can be relatively easily assessed using extragalactic radio sources, which give us the integrated Faraday rotation along the sight line through the Milky Way. Mapping this across the sky gives a weighted 2D projection of the 3D magnetic pattern. The quality of this information is about to be vastly increased by the Polarization Sky Survey of the Universe's Magnetism (POSSUM), an international project to measure the polarization of radio sources across most of the sky at 800-1088 MHz, using the Australian SKA Pathfinder (ASKAP), which will give a 10-fold increase in sampling of the Faraday rotation pattern. In addition to extragalactic sources, POSSUM will detect polarization from synchrotron emission in the interstellar medium, which in principle gives more direct information about the 3D field structure, although there are challenging instrumental issues that have to be overcome.

The aim of this PhD project is to study the statistical structure of the Faraday rotation and the underlying magnetic field. The primary observational input will be the POSSUM Faraday results: about one quarter of the sky will have been observed in time to use, including fields close to the Galactic plane with a long sight-line through the disk, and at high latitude where we are looking just through the local layer of the Galaxy. You will draw on other observational results as needed, for instance single-dish observations of the Galactic synchrotron emission at short wavelengths, where the polarization traces the field component in the sky plane. You will interpret your results using theories ranging from toy models that can be run on a laptop to the outputs of massive full-disk magneto-hydro-dynamic simulations being run by Rowan Smith and collaborators.

Pulsar Timing Arrays for the detection of Nanohertz Gravitational Waves
Supervisor: Dr. Michael Keith
Contact: Michael.keith@manchester.ac.uk

In June 2023 the European Pulsar Timing Array (EPTA) and collaborators around the world announced the first evidence for a background of ultra-low frequency gravitational waves from super-massive black hole binaries in the centres of distant galaxies. (Press release: https://www.manchester.ac.uk/discover/news/astronomers-find-first-evidence-for-new-class-of-gravitational-waves-which-could-unveil-origin-of-the-universe/).

A pulsar timing array makes use of high precision (<1 microsecond) timing measurements of the rotation of millisecond pulsars to form a galaxy-scale gravitational wave detector. We can directly detect the gravitational waves through the quadrupolar correlated variations in the arrival times of pulses from the pulsars.

The Lovell Telescope at Jodrell Bank has been observing these pulsars for decades, and these observations are a key part of the EPTA and International Pulsar Timing Array datasets. More recently new telescopes have also started contributing highly sensitive observations of additional pulsars. In Manchester we are continuing to provide data from the Lovell Telescopes, as well as from the MeerKAT telescope in South Africa, an important precursor telescope for the upcoming international Square Kilometre Array Telescope. We are also involved in studying the pulsars themselves, including the effort to better understand the ‘foreground’ pulsar noise which can mask the signal from the gravitational wave background.

This project will involve working with the observations from the Lovell Telescope and MeerKAT for Pulsar Timing Array work, and developing new data analysis techniques, with potential to explore ways to exploit recent developments in machine learning. The overall goal is to better understand the signals that we see in the pulsar timing array data, leading to a clear and unambiguous detection of the gravitational wave background.

Pushing the Noise Limit: Low Noise Amplifiers for Radio Telescopes
Supervisory team: Prof. Gary Fuller and Prof. Danielle George (Department of Electrical & Electronic Engineering)
Contact: G.Fuller@manchester.ac.uk

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 Departments of Physics & Astronomy and Electrical & Electronic Engineering. There are four possible areas of research:

1) 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.

2) The design and construction of receivers for current radio telescopes using new generation, high performance LNAs.

3) New processes and materials for transistors for future, high performance generations of LNAs.

4) Computer-aided LNA design optimisation.

In each of these areas there is the possibility of placements at various collaborating international institutions, including ESO in Germany and Bologna in Italy.

Searching for axions using neutron stars
Main Supervisor: Prof Richard Battye
Contact: Richard.Battye@manchester.ac.uk

Axions are one of the leading dark matter candidates and can be converted into photons in the magnetosphere of neutron stars. This can lead to a spectral line signature in the radio/mm waveband. In recent times we have developed techniques to predict the signal expected and have been applying these to observations made by the JVLA and Lovell Telescopes.

The aim of the project - which would likely involve collaboration with scientists in Louvain and Munich as well the JBCA pulsar observers - would be to refine these predictions, involving modelling axion electrodynamics in the magnetosphere, and compare to the most update to date observations. It will require a range of theoretical, numerical and data analysis related skills. At its most optimistic it could lead the detection of the dark matter axions, but more likely stringent upper bounds on their coupling to photons. It could also lead onto a study of the theoretical models for the production of axions.

Space-based exoplanet detection with microlensing
Supervisor: Dr Eamonn Kerins
Contact: Eamonn.Kerins@manchester.ac.uk

Microlensing is proving to be the most capable method to find cool low-mass planets, including planets around the most common types of star, and planetary architectures that most resemble that of our own solar system. The demographics of these planets is also crucial for testing planet formation theories.

In the next few years NASA will launch the Nancy Grace Roman Space Telescope (Roman) which will undertake a dedicated exoplanet microlensing survey. With a field of view 100 times greater than the Hubble Space Telescope and a data rate more than 20 times that of JWST, Roman will revolutionize our understanding of exoplanet demographics. The ESA Euclid mission may also undertake an exoplanet microlensing survey.

Manchester has developed the Galactic microlensing simulation framework that underpins the design of potential surveys for both Roman and Euclid. A PhD project is available to further develop this simulation framework to enable detailed optimization and analysis work that will be required for both missions.

The project will be computational in nature, both using existing codes and developing new ones. We have a dedicated 64-core AMD Threadripper machine dedicated to our exoplanet work. The exoplanet group working with Kerins currently comprises 5 PhD students and one MSc student. It is expected that this project will involve working closely with colleagues based in France and the US.

Testing models of relativistic jets with e-MERLIN
Supervisory Team: Dr Paddy Leahy and Dr Emmanuel Bempong-Manful
Contact: J.p.leahy@manchester.ac.uk

Many of the issues in understanding structure formation and black-hole growth are thought to be resolved by suitably-tuned feedback of energy and momentum from AGN activity – from dense to diffuse phases of matter. Relativistic plasma jets of radio-loud AGNs are particularly thought to be responsible for the production of the most energetic photons and hadrons in the observable Universe, thereby playing a key role in this feedback cycle. However, the physics driving the observed jet structure in these cosmic outflows remains an open question. To resolve them we need to quantify the mass, momentum and energy inputs from jets and to work out how they interact with their environment.

Here at Manchester we are leading an ambitious global effort (The e-MERLIN Jets Legacy programme) to resolve these and other key questions in extragalactic jet physics. The programme has been mapping a number of powerful radio galaxies and quasars, allowing us to study for example the detailed structure of magnetic field in relativistic jets (the synchrotron radiation polarisation) and in the foreground gas (via Faraday rotation). Deep LOFAR observations have also been acquired for the programme, providing us with the unique opportunity to probe the dynamics and energetics of relativistic jets over broad frequencies.

The goal of this PhD project will be to utilize these new radio observations to map the jet structure of some well known powerful radio galaxies in order to test the relativistic beaming model in jets. The student will join the e-MERLIN Jets Legacy collaboration and become a part of the LOFAR-VLBI Working Group. Depending on their interests, the project could be extended into a multiwavelength campaign with complementary observations at optical and X-ray wavebands, and/or perform numerical MHD simulations to model the jet kinematics and compare theory with observations.

The evolution of galaxies in the early universe with the next generation of telescopes
Supervisor: Dr. Rebecca Bowler
Contact: rebecca.bowler@manchester.ac.uk

At the cutting-edge of Astronomy research is the study of the formation and evolution of the first galaxies. Through breakthrough observations in the past 30 years it has been possible to identify galaxies from when the universe was less than 400 million years old. These galaxies have unusual properties compared to the local universe, showing low chemical enrichment and dust obscuration, and irregular morphologies. This project aims to exploit the new Vera Rubin Observatory (VRO) and Euclid space-mission to discover and analyse galaxies at very high-redshifts (probing the first few billion years). The goal of the project is to understand when and how the most star-forming galaxies formed in the Universe. The student will become an expert in the selection of high-redshift galaxies from multi-band photometry. They will then use the resulting samples to constrain the evolution of the number density of these sources (via the luminosity function). There is considerable flexibility in the direction of the project in later years, and the student would be encouraged to apply for follow-up data (e.g. with JWST, ALMA) as well as exploit archival data where available. At the end of the project the student would be in an excellent position to continue working with these next generation facilities.

VRO is an 8.4m diameter optical telescope that is being built in Chile. As well as surveying the entire southern sky it will also provide four deep fields which will contain many hundreds of thousands of distant galaxies: https://www.lsst.org/about

Euclid is an optical and near-infrared space mission. It is primarily a cosmology mission but it will discover many thousands of high-redshift galaxies. As Euclid has a near-infrared camera (like Hubble) it will be able to discover very distant galaxies (z = 7-10). https://www.euclid-ec.org

Is there a new radio background? The L-Band All-Sky Survey (L-BASS)
Supervisory team: Dr Paddy Leahy, Prof Ian Browne and Prof Peter Wilkinson
Contact: j.p.leahy@manchester.ac.uk

The aim of the L-BASS project is to map the intensity of the radio sky at ~1.4 GHz with unprecedented absolute accuracy (0.1K) – ten times better than achieved by Penzias and Wilson in their discovery of the cosmic microwave background radiation. There are several reasons to do this, the most exciting being that it should settle a current astrophysical puzzle about the reality of excess all-sky low frequency emission of unknown origin (the “ARCADE-2 controversy”). Such an excess might also help account for another recent controversial result which is the claimed detection of strong absorption arising in atomic hydrogen situated at a redshift of 17 (the “EDGES result”). In addition our sky map will have impact on Galactic astrophysics and our knowledge of the Cosmic Microwave Background.

During the PhD project the student will produce and interpret the first sky maps with the L-BASS telescope system which is situated at Jodrell Bank Observatory. The system, which is based on two large horn antennas, is now up and running. Commissioning observations are in progress. This PhD project involves a mixture of hands-on work to optimize the calibration of the system, making precisely calibrated observations and writing software for data analysis followed by the astrophysical interpretation of the results. To achieve the required accuracy

(0.1K) requires particularly careful calibration using a cryogenically cooled reference load of known physical temperature; the assembly and testing of this cryogenic calibration load will take place during the next two years and form a significant part of the project. In two years, the plan is to move the instrument to Tenerife, a site which enable us to map two thirds of the whole sky.

The Role of Magnetic Fields in the Formation of Massive Stars
Supervisory team: Prof. Gary Fuller and Dr. Rowan Smith (St Andrews)
Contact: G.Fuller@manchester.ac.uk

Magnetic fields are ubiquitous in the interstellar medium but their detailed role in the formation of stars is as yet unclear. In the dense star forming regions of molecular clouds the magnetic field can be traced through observations of the polarized continuum emission from dust grains which align with the magnetic field. However, to understand how magnetic fields affect the evolution of the gas, observations of the magnetic field must be combined with observations of the cold, molecular gas in the regions. This project will study the impact of the magnetic fields as gas flows from parcsec-scale clumps down to individual star forming cores and protostars. It will involve observations of polarization emission from dust and molecular lines to study the magnetic field and molecular gas covering a wide range of size scales in star forming regions. Part of the project will be developing new methods to compare the polarization and line observations with the results of state-of-the-art magneto-hydrodynamics simulations. This work will be carried out in part as part of the follow-up of ALMAGAL, the ALMA large programme studying the formation and evolution of high mass stars and the ERC Synergy project ECOGAL.

Tracing cosmic baryons with the Sunyaev-Zel'dovich effect
Supervisory team: Prof Scott Kay and Prof Jens Chluba
Contact: scott.kay@manchester.ac.uk

The Sunyaev-Zel'dovich (SZ) effect is the inverse-Compton scattering of CMB photons off free electrons, leading to a distortion in the CMB blackbody spectrum. At present, it is routinely used to measure the pressure profiles of hot (T~10^7K) gas in nearby, resolved galaxy clusters. On larger scales, it can also be used to find the missing baryons in the cosmic web. Future instruments at millimetre/sub-millimetre wavelengths will allow SZ observations to be made with even more accuracy, opening the door to additional measurements such as the temperature and velocity of the warm and hot cosmic gas, in clusters and beyond. In this project, the student will use a combination of the latest hydrodynamical simulations (see e.g. the FLAMINGO project here: https://flamingo.strw.leidenuniv.nl) and theoretical modelling tools to make predictions for future observations of these SZ signals. These can then be used to make quantitative predictions for the thermal and kinematic properties of the intergalactic and intracluster gas, and how these relate to the underlying dark matter distribution. Such models can also be used to inform requirements for future CMB instrumentation.

Topological defects at the electroweak phase transition
Main Supervisor: Prof Richard Battye
Contact: Richard.Battye@manchester.ac.uk

Topological defects can be formed at cosmological phase transitions where the vacuum manifold has non-trivial homotopy. The objective of this project is to explore the possibility that topological defects might be formed at the electroweak phase transition in extensions of the Standard Model of particle physics. We have bene studying the so-called two Higgs- Doublet model (2HDM) which is one of the most popular extension with Prof Apostolos Pilaftsis in the Manchester Particle Physics group.

The project will involve further developing the work often using large-scale computing resources based in the Manchester elsewhere in the UK. It will also develop the picture of cosmological evolution of such defects, and also consider how such a defect might be produced in a particle accelerator such as the LHC.

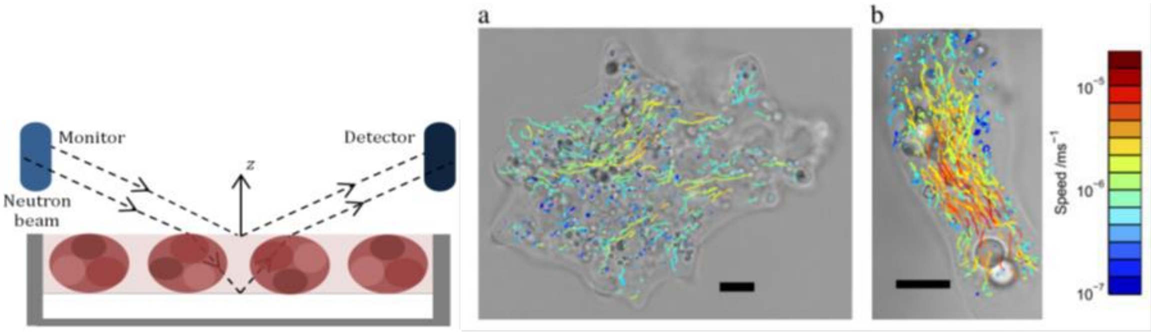
Unveiling Cosmic Dawn with the Hydrogen Epoch of Reionization Array
Supervisor: Dr Phil Bull
Contact: phil.bull@manchester.ac.uk

Cosmic Dawn - the time when the first stars and galaxies switched on - remains shrouded in mystery. While challenging to observe using optical and near-infrared telescopes due to the rareness and obscuration of bright sources, a series of radio telescopes (like HERA, the Hydrogen Epoch of Reionization Array, in South Africa) are being constructed that have the sensitivity to detect the presence of large amounts of neutral hydrogen during this epoch, via the 21cm emission line. This will allow us to map the neutral gas surrounding the first bright sources and understand how rapidly they reionised the Universe.

HERA is a large interferometric array that will have up to 350 receiving elements when fully completed. It is being built in stages and has already collected several seasons of data in a smaller configuration with between 50-100 receivers. Recent analyses of early seasons have produced the best upper limits on the power spectrum of 21cm fluctuations from the Cosmic Dawn and Epoch of Reionisation to date (see https://arxiv.org/abs/2108.02263), with significantly larger volumes of data well on the way.

In this project, you will develop and hone a set of advanced statistical analysis tools to recover the 21cm power spectrum from the available HERA data despite the presence of much brighter contamination ("radio foregrounds") and systematic effects due to the complexity of the instrument. These tools are based on a variety of techniques for high-dimensional Bayesian inference, a type of machine learning. Through this project, you will develop a mix of skills, including some analytic theoretical work on statistics, hands-on data analysis with a large, cutting-edge astronomical dataset, and high-performance computing, which may include some GPU programming. The student will be able to choose which of these areas to put more emphasis on.

BIOLOGICAL PHYSICS



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.

Biointerface

Prof. Jian Lu
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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, become deformed and then desorbed. During these interfacial processes of adsorption and desorption, protein molecules undergo different interactions that may damage their 3D structures and deactivate them. 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 involves computer modelling and 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 peptide sequences from these amino acids that resemble conventional surfactants with distinct hydrophilic head and hydrophobic tail moieties. Unlike conventional surfactants, however, 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 given set of peptide amphiphiles self-assemble to form a range of nanostructures such as nanorods, nanotubes, nanobelts and larger structures templated from them. Materials assembled from these nanostructures may have distinct mechanical, light, biological and piezoelectric functions.

Interfacial processes underlying antimicrobial actions and biocompatibility.

A distinct mode of 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. We have developed a range of antimicrobial peptides that can selectively bind to bacterial and fungal membranes whilst remaining benign to host cells. In collaboration with colleagues in biology and medicine, we have combined both physical and biological approaches to help understand the key mechanistic processes of antimicrobial action at molecular and cell levels. This collaborative study has led to important publications.

Computational cardiac physics and artificial intelligence in biology and medicine

Prof. Henggui Zhang
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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.

Inverse problem for 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.

Digital twins of the 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 deep 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.

Development of AI algorithm for searching for antimicrobial peptides (with Prof. Jian Lu)

Antibiotic resistance has fast become a global healthcare threat over the past two decades. Resistant microorganisms can compromise many antibiotics, making previously effective medical treatments less effective or ineffective. It is imperative to explore new alternatives that work differently from the current mainstream of antibiotics. Some antimicrobial peptides (AMPs) kill microorganisms by disrupting microbial membranes. This process of fast structural damage to the microbial membrane is widely thought to generate the much lower rate of resistance. Currently, thousands of these peptides have been reported. However, in vitro experimental screening of either rational or non-rational libraries is tedious, expensive, and often generates only a few AMP candidates, albeit most of them fail to show the required bioactivities and physicochemical properties for practical applications. In this project, we aim to develop an artificial intelligence algorithm to search for high-activity AMPs based on existing public databases. It is hoped that the outcome of the project will provide an AI-based algorithm for AMP screening, which helps to reduce required experimentation and increase the efficiency of high-activity AMP discovery.

Biomolecular structure and dynamics

Dr. Jichen Li
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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 the simulations will provide microscopic details of the local water structures.

1. Nair, R.R.; Wu, H.A.; Jayaram, P.N.; Grigorieva, I.V.; Geim, A.K. Unimpeded permeation of water through helium-leak-tight graphene-based membranes. Science 2012, 335, 442-444.

2. The Observation of the Oxygen-Oxygen Interactions in Ices - Redefine the term of hydrogen-bonding between water – water molecules, Shun Chen, Zhiping Xu and Jichen Li, New J. Phys. 18 023052-58 (2016).

3. Effect of layered water structure on the anomalous transport through nanoscale graphene channels. S. Chen; X.C. Nie; H.P. Fang; N.R. Walet, Shiwu Gao and J.C. Li, to be published (2017).

Cellular tracking and self-assembly

Dr. Thomas Waigh
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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
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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.

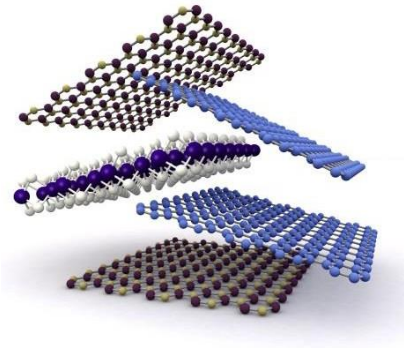
Most of our applicants have excellent marks, strong mathematical skills and programming experience. We are looking for energetic students with outstanding communication skills, and who are enthusiastic and able to drive this exciting field forward.

CONDENSED MATTER PHYSICS

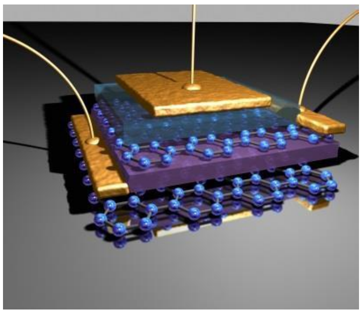
Research in the Condensed Matter physics group is exceptionally broad, from electronic, optical, mechanical and magnetic properties of a whole family of atomically thin, two-dimensional materials to the physics of quantum fluids, intercalation-induced superconductivity in layered and two-dimensional 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.

Rotating millikelvin cryostat that allows visualization of vortex lines in superfluid.



Layer-by-layer assembly of 2D heterostructures.



Graphene=based vertical transistor.

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 f 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
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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.

Control of electronic properties of 2D materials by intercalculation; superconductivity in layered and 2D materials

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

Prof Grigorieva's current research focuses on two main areas: (i) physics of alkali ion intercalation into 2D crystals and using intercalation as a tool to tuning tune electronic properties of layered crystals and heterostructures; (ii) unconventional superconductivity in materials with strong spin-orbit coupling.

Ion intercalation of layered van der Waals crystals underpins important applications, such as rechargeable Li ion batteries, and also provides a powerful tool to tune the material's chemical, electronic and optical properties. Yet, our understanding of the fundamentals of the intercalation process is poor: What controls the intercalation process? What determines the maximum possible concentration of the intercalating ions? How do the electronic properties of the host crystal (for example, few-layer graphene) influence the process of intercalation? In our projects we are trying to answer these fundamental questions.

In projects on superconductivity our aim is to understand how superconducting pairing works in materials with strong spin-orbit coupling. This is a little explored group of superconductors, where we recently observed signatures of unconventional (non-BCS) superconducting pairing. To this end we are using tunnelling spectroscopy and creating Josephson junctions that allow probing the symmetry of the superconducting order parameter.

Projects:

1. Understanding intercalation of 2D crystals: a physicist's approach.
2. Unconventional superconductivity in materials with strong spin-orbit coupling.

Programmable van der Waals materials

Dr Artem Mishchenko

(artem.mishchenko@manchester.ac.uk)

Reactions between solids are fundamental in areas as diverse as catalysis, information storage, pharmaceuticals, electronics manufacturing, advanced ceramics, to name just a few. Controlling the spatial extent of solid-state reactions at the nanoscale will enable development of materials, programmed on an atomic level, which will facilitate many emerging applications like bioinspired smart batteries and artificial synapses for future neuromorphic electronics. Our programmable matter research is centred on van der Waals materials – layer-by-layer assembled stacks of individual atomic planes, and aim to obtain a class of new materials through interplanar chemical reactions between highly-crystalline solids in precisely controllable conditions. We focus on the two main research directions: (i) discovery and programmable synthesis of novel van der Waals materials, and (ii) study their electronic and photonic properties for various applications. By combing machine learning with automated materials synthesis, we are working on a novel approach towards materials discovery to enable future cutting-edge quantum, electronic, and photonic technologies. More details are available on www.2Dmatters.com

Projects:

1. Development of autonomous materials discovery platform
2. Polariton chemistry in quantum van der Waals materials
3. Designer topology from 2.5-dimensional physics of graphene multilayers

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.

Projects:

1. Spin transport in high-quality ballistic graphene transistors.
2. Nanoscale thermoelectrics in van der Waals heterostructures.
3. Spin-hall effect and related spin-orbit phenomena in 2D materials.

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.

Ultraclean heterostructures and devices based on 2D materials.

Dr Roman Gorbachev
(roman@manchester.ac.uk)

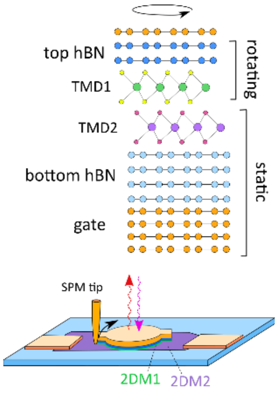
My research area is experimental condensed matter physics, with an emphasis on fabrication of nanoscale low-dimensional devices. The availability of novel nanoscale materials, such as nanowires and atomically thin 2-dimensional crystals is enabling the assembly and study of composite electronics and 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.

Significant part of our work is dedicated to van der Waals heterostructures assembled from 2D materials layer-by-atomic-layer, which offer unprecedented opportunities for solid state research. An important degree of freedom in 2DMH is the relative crystal rotation or ***twist*** between different atomic layers. Together with the lattice mismatch of the adjacent 2D crystals, the twist gives rise to the moiré superlattice (mSL): a long-range periodic variation of the local atomic positions with the length scale controlled by the twist angle. Before 2019 experimental twistronic investigations were largely confined to graphene/hBN, but recently other materials have gained a lot of attention.

Projects offered to PhD students continuously evolve due to fast pace of the field, at the moment:

1. Ultra-clean van der Waals heterostructures fabricated in high vacuum. To access the fascinating physics of these air sensitive 2D crystals, our team has recently built the first in the world "UHV 2D Press" that allows the heterostructure assembly and characterisation in ultra-high vacuum. In this project you will develop UHV technology and acquire a broad range of semiconductor nanofabrication skills including robotics, UHV equipment, as well as electron and scanning probe microscopies.

2. Dynamic twist in 2D materials. This project sets to explore twisted bilayers of 2D materials that exhibit correlated electronic states. The core idea here is to employ moiré superlattice to control magnetism or superconductivity with nanometre resolution, creating periodic textures of these ground states. This project has emphasis on cutting-edge solid-state physics, nano-mechanics, robotics, optical and electronic measurements.



One-atom-thick membranes

Dr. Marcelo Lozada-Hidalgo
(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 for molecular and ion transport

Dr Radha Boya
(radha.boya@manchester.ac.uk)

Our current research relates to sub-nanoscale aka angstrom-scale channels made from atomically thin 2D-materials assembled in 2D-heterostructures. The channels are akin to 3-layer sandwich (top/spacer/bottom layers, refer to the figure inset) 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! Using these precise channels held firmly on silicon chips, we study effects of confinement on water, ion, and gas flows which can impact the fields of molecular separation and membrane-based water desalination. We also have work ongoing on the translocation of biomolecules like DNA, proteins in such channels. Recently, we found the emergence of ionic memory and synapse-like dynamics from simple salt solutions as electrolytes confined in 2D-channels. For further details, please see https://radhaboya.weebly.com/.

We have setup a new instrument on thermal scanning probe lithography in National Graphene institute, which can do precisely pattern sub-50 nm features using simply heat, and we will be recruiting a new PhD student to work with this technique.

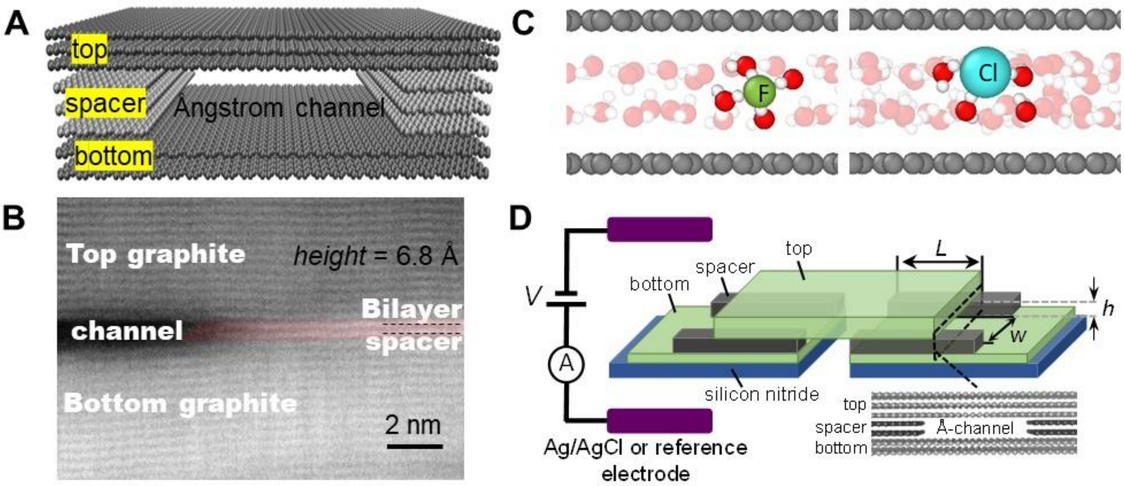


Figure: A) Angstrom-channels made from graphene in a three-layer sandwich (top/bottom/spacer). B) Transmission electron microscopy image of the angstrom-channel. The individual atomic layers of top, bottom and spacer layer are visible as horizontal lines. The dark region is the angstrom-channel with a height of 6.8 angstroms, which is the thickness of two graphene layers. C) Water molecules (red is oxygen, white balls are hydrogens) and ions (fluoride, chloride as examples) are shown inside the channels. D) The angstrom-channels on the silicon chips used for ion measurements.

Projects:

Project 1: Ionic memory in confined nanochannels

Project 2: Thermal scanning probe lithography as a tool for fabrication of 2D material devices

Project 2: Biomolecular sequencing using nanochannels.

Project 3: Confined material growth for new types of 2D materials

Water at the nanoscale

Dr Qian Yang
(qian.yang@manchester.ac.uk)

Water is essential to all life forms and carries enormous energy – 70% of solar radiation that reaches the surface of earth gets absorbed by water. This energy circulates with water around the globe and transfers into other forms of energy to be used. Most of the energy stored in water, so far, is not exploited. Our research aims at such fundamental questions as the structure and behaviour of water at the molecular level to provide means towards more efficient water-energy nexus. To this end, we explore water inside two-dimensional nanocapillaries and the water-graphene interface to clarify the mass transport and charge transfer processes, respectively. Using combined nanocapillary devices with microfluidics system, together with precise electrical measurements, we currently examine the following directions: (i) capillary condensation inside nanocavities and modulated ionic transport; (ii) electricity generation induced by liquid flow through graphene surface; (iii) nanoconfined water structure and their properties. Our research will enable technologies in a wide range of fields, including single molecular sensing, medical diagnostics and energy harvesting.

Projects:

1. nanoconfined molecules and their characterization
2. electrokinetic phenomena at the water-graphene interface for energy harvesting
3. dynamics of the capillary condensation process

QUANTUM THEORY OF LIGHT AND MATTER

We study a broad range of topics within the framework of Theory Division, spanning from the electronic, magnetic and optical properties of low-dimensional quantum materials to topological quantum phases and superconductivity and from the development of the theory of quantum transport and strongly-coupled non-equilibrium phenomena to quantum thermodynamics, quantum noise, open quantum systems, nanoplasmonics and nanophotonics. The study of complex quantum systems involves a diverse array of tools, including advanced first-principles modelling techniques, quantum-field-theoretical methods (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 prompt testing of newly developed theories, especially in relation to studies of physical phenomena 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.

Potential projects are offered in alignment with the areas listed below by individual members of staff. Some projects may involve joint supervision between two or more members of staff.

Condensed matter theory

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. His current projects include:

- many-body phases of electronic liquids in 2D materials, including the quantum Hall effect in 2D materials with multi-valley spectra, where electrons are characterised by valley quantum numbers additional to their spin state;
- quantum properties of minibands generated by moiré superlattices generic for heterostructures of 2D materials with slightly incommensurate periods and for twisted homo-bilayers of all 2D materials;
- modelling optical properties of 2D materials, from THz 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, including the influence of moiré superlattice effects.

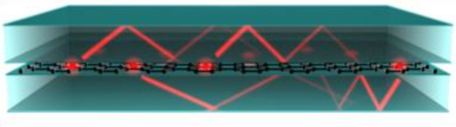
- Modelling heat transport in 2D materials and related thermoelectric properties.

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, ETH Zurich, LNCMI-CNRS in Grenoble, and our partners in the European Quantum Technologies Flagship at Cambridge and ICFO in Barcelona.

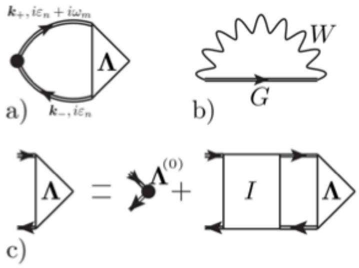
http://www.graphene.manchester.ac.uk/discover/the-people/vladimir-falko/
http://www.royce.ac.uk/about-us/professor-vladimir-falko/

Strongly interacting quantum many-body systems

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



I study the impact of many-body interactions on equilibrium and non-equilibrium properties of quantum materials. For example, the impact of viscous electron flow on charge, spin, orbital and thermal transport in 2D materials; the interplay between electronic and magnetic degrees of freedom; topological quantum order (e.g., quantum spin liquids) or superconductivity. I am also interested in studying applications of many-body systems and topological matter to quantum technologies (e.g., topological quantum computation), as well as their behaviour when coupled to quantized electromagnetic radiation (together with Dr. Ahsan Nazir).



The approach to these problems is mainly analytical. Numerical techniques are used to confirm/guide analytical results, numerically evaluate integrals, perform linear algebra manipulations, etc. The analytical techniques used are those of quantum field theory (Feynman diagrams, path integrals, non-equilibrium Green's functions, quantum kinetic equation, etc.) but applied to many-body problems in 2D systems.

Examples of my research interests include (please contact me for more details):

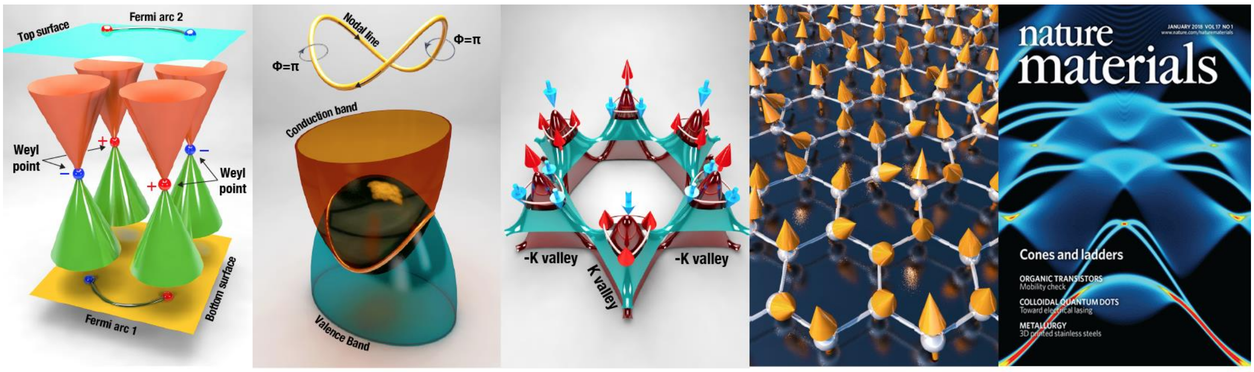
- Quantum magnetism and topological matter, in particular quantum spin liquids.
- Detecting and controlling emergent quasiparticles with anyonic statistics, with application to topological quantum computation.
- Twisted strongly-correlated 2D materials.
- The charge, spin, orbital, thermal, and thermoelectric transport in the hydrodynamic regime of electronic transport.
- The complex interplay between topology, Berry curvature and strong electron-electron interactions.

Students will learn and use advanced quantum field theory techniques. Co-supervision with other group members is possible, as well collaborations with theoretical and experimental groups in Manchester, Lancaster, Cambridge, ICFO&ICN2 (Barcelona), Pisa, MIT/Harvard (USA), Singapore.

Personal webpage; Full list of publications

First-principles modelling of emergent quantum phenomena in cross-correlated materials

Dr Mohammad Saeed Bahramy (m.saeed.bahramy@manchester.ac.uk)



Topological Weyl semimetals and related quantum phenomena | Topological Nodal semimetals and related quantum phenomena | Valleytronic properties of transition metal dichalcogenides | Magnetism in two-dimensional vdW materails

Dr Mohammad Saeed Bahramy's research is focused on the study of exotic states of quantum matter using a range of computational techniques based on density functional theory, dynamical mean field theory, tight-binding modelling and, lately, machine learning. He is particularly interested in studying topological phases of matter, quantum confinement phenomena at the interface of heterogeneous materials, thermopower generation and manipulation in low-dimensional systems, strongly correlated electron systems, and superconductivity. He also seeks to understand how rich collective properties of materials, such as symmetry breaking, structural phase transition, and many-body effects, can lead to new phases of quantum matter. The ultimate goal of Dr Bahramy's research is to develop new guiding principles for the study and design of next-generation quantum materials with advanced functionalities suitable for future energy and information technologies.

Bahramy lab's current projects include:

- Development of machine-learning-based methods for designing artificial two-dimensional materials and superstructures.
- Theoretical study and design of functional materials with non-trivial topological properties.
- First-principles modelling of exotic superconductivity and magnetism in strongly correlated materials.
- Quantum simulation of quasiparticle interferences in structurally-frustrated electronic systems.
- Thermopower generation and waste heat harvesting in low-dimensional materials.

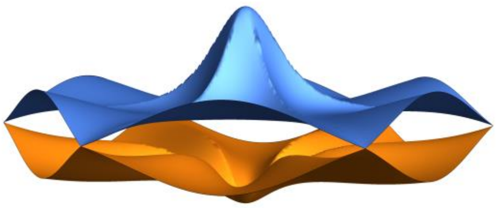
These projects will be performed in close collaboration with experimental groups in Japan (Univ. Tokyo, Univ. Osaka and RIKEN), the UK (Univ. St. Andrews, Diamond and UoM), China (Nanjing Univ.) and the USA (Stanford and Delaware Univ.).

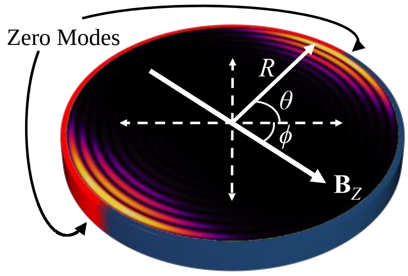
BAHRAMY LAB's Webpage   Full list of publications

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 novels 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.

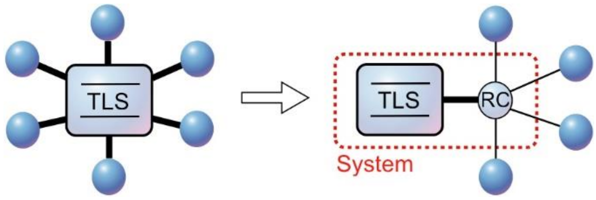
Training in the relevant techniques, as well as in advanced computational methods, if applicable, will be provided.

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

Non-equilibrium quantum physics

Theory of open quantum systems: non-equilibrium dynamics and thermodynamics

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/

Open quantum systems theory and quantum technologies

Dr. Jake Iles-Smith (jake.iles-smith@manchester.ac.uk)

Dr. Jake Iles-Smith studies the behaviour of quantum systems interacting with their environment, with particular focus on emerging quantum technologies.

All quantum systems are in principle 'open': that is, a quantum system is influenced in some way by its external environment. In many cases this induces complex behaviour that cannot be captured using traditional theoretical methods. Dr. Iles-Smith develops novel analytic and computational methods capable of describing the behaviour of open quantum systems that are strongly coupled to their environment. These tools are used to understand how environmental interactions impact emerging quantum technologies (e.g. nitrogen vacancy centres in diamond), with the overarching goal of developing novel quantum technologies that are robust against noise. Potential projects include:

- Development of analytic methods to describe open quantum systems in strong coupling regimes.

- Tensor network methods for describing nonequilibrium open quantum systems.
- Developing new quantum optics methods for solid-state quantum emitters (with established experimental collaborations).
- Methods to engineer an environment to enhance quantum technologies.

These projects will provide students with the opportunity to learn advanced numerical and analytic methods, along with the possibility of collaborating with leading experimental groups in Copenhagen, Bristol, Imperial, and Sheffield.

https://www.research.manchester.ac.uk/portal/jake.iles-smith.html

Structured quantum dynamics and the physics of quantum information

Dr Thomas Elliott (thomas.elliott@manchester.ac.uk)

Dr Thomas Elliott's research explores complex structure in quantum dynamics – and how this complexity can be harnessed – using tools from quantum information theory.

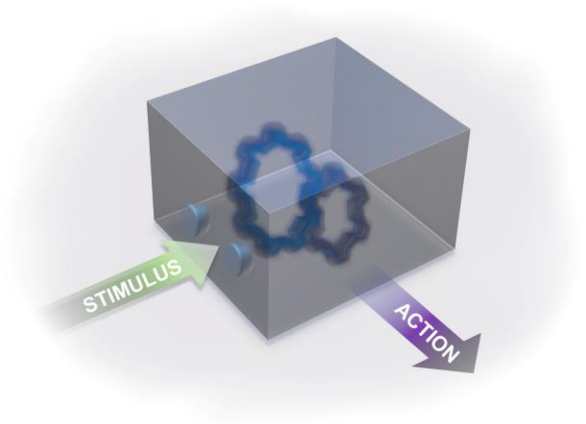
Even the smallest of quantum systems can give rise to seemingly complex behaviours. While this can make such systems hard to model with classical computers, it presents a valuable opportunity – to use quantum technologies to efficiently model and simulate other complex systems. Recently, Dr Elliott's research has focussed on how quantum computers can be used to simulate highly non-Markovian (i.e., memoryful) stochastic processes with a considerably smaller memory overhead than classically possible, and extending these results to the richer domain of adaptive agents – systems that modify their behaviour in response to environmental stimuli. Potential project directions include:

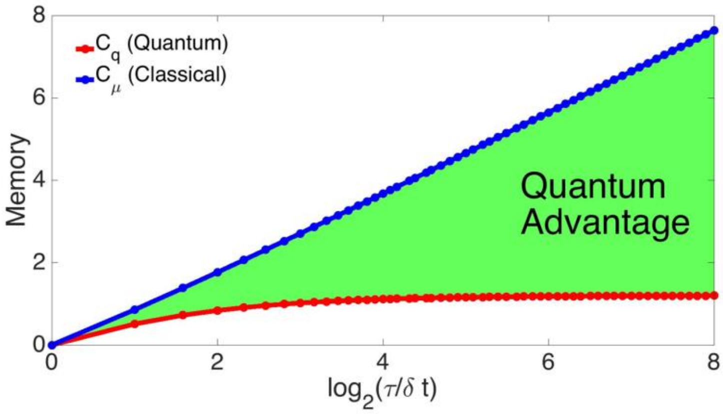
- Exploring the interplay between quantum memory advantages and increased thermal efficiency, to e.g., design quantum protocols for extracting work from stochastic processes.
- Improving and extending the design of quantum-enhanced adaptive agents, and/or developing their potential areas of application.
- Using machine learning and related tools to enhance quantum memory advantages in stochastic simulation.
- Identifying and characterising the features of complex structure in quantum dynamics, and/or developing techniques for their efficient simulation.

The projects will be mostly analytical, with scope for a significant numerical/computational element. Students will develop a strong background in quantum information theory, and one or more of: open quantum systems; quantum stochastic processes; tensor networks; quantum thermodynamics; and quantum machine learning.

https://www.research.manchester.ac.uk/portal/thomas.elliott.html

https://scholar.google.co.uk/citations?user=sDInixMAAAAJ





Quantum thermodynamics and optimal control

Dr. Harry J. D. Miller (harry.miller@manchester.ac.uk)

Dr. Harry Miller explores ways to optimise the thermodynamic behaviour of quantum systems driven far from equilibrium, with an aim to uncover universal design principles for energy-efficient quantum thermal machines and devices. This is addressed from a foundational perspective by merging ideas from stochastic thermodynamics, differential geometry and information theory. Potential projects include:

- Developing novel theoretical methods for reducing dissipation and irreversibility in small-scale thermal processes.
- Practical applications to improve designs of quantum thermal machines such as heat engines, batteries and refrigerators.
- Optimising the energetic costs of quantum computation (eg. Information erasure, state preparation, error correction)
- Searching for quantum advantages in thermodynamic tasks (eg. Entanglement, coherence & collective effects as resources)

These projects will provide students with the opportunity to explore a wide range of topics from quantum thermodynamics, information-geometry, statistical mechanics and optimal control theory, as well a chance for collaborations with international groups from Barcelona, Pavia and Ireland.

Personal page: http://harryjdmiller.com

Complex systems and statistical physics

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.

NUCLEAR PHYSICS

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 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.

Exploring the Changing Shell Structure of Nuclei

Dr David Sharp
David.sharp@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.

Single-nucleon transfer reactions offer a suitable probe of the single-particle characteristics via the spectroscopic factor (SF), measuring the overlap of the wave function of a state with simple single-particle configurations. Being subject to sum rules, SFs allow access to the occupancies of underlying single-particle orbits.

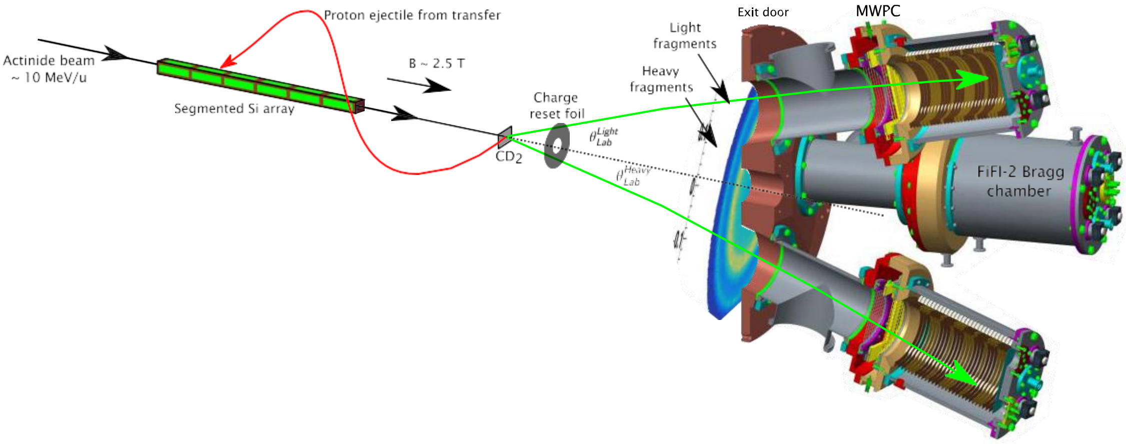
PhD projects in this area will involve using transfer reactions with radioactive beams to investigate the evolution of single-particle structure in to exotic regions of the nuclear chart. his work will predominantly take place at HIE-ISOLDE, CERN using the newly commissioned ISOLDE Solenoidal Spectrometer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

Fission Measurements in Direct and Inverse Kinematics

Prof. Gavin Smith, (gavin.smith@manchester.ac.uk), Dr Tobias Wright (tobias.wright@manchester.ac.uk) and Dr David Sharp (david.sharp@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. TheSpectrometeTer 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 ISOLDE Solenoidal Spectrometer facility at CERN to use (d,p) reactions in inverse kinematic to induce fission in previously unaccessible systems to neutron irradiation techniques.



Nuclear Data Measurements for Advanced Nuclear Technologies

Dr Tobias Wright
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The process of nuclear fission has been exploited as a virtually carbon-free energy source for many decades and it is set to play a major role within future global energy supplies. Advanced Nuclear Technologies (ANTs) are being developed which will serve to provide cheaper, safer and more efficient energy from nuclear fission. These advanced technologies will use new forms of nuclear fuel and designs of reactor which bring inherent technical and scientific challenges which must be tackled to ensure success. Specifically, a complete understanding of the physics governing the many processes involved within these technologies must be obtained. This understanding will come from detailed simulations and calculations and underlying these are the input of nuclear data. These nuclear data quantify all the associated nuclear reactions that occur and govern the functionality of these systems. These data sets typically arise from detailed experiments which measure individual quantities to appropriate accuracies. It is acknowledged that the current nuclear data is not of adequate accuracy for ANTs.

Uranium Nitride fuel is being considered as an Accident Tolerant Fuel for use in GenIV reactors and there is a requirement to improve the nuclear data on nitrogen. In particular, nitrogen enriched in 15N is being considered which is a poorly-studied isotope from a nuclear data perspective. Measurements of the neutron scattering, capture and n,p cross sections on 15N will improve this. The neutron time-of-flight facility n_TOF, CERN, is a world-leading cross section measurement facility and well-suited to performing these types of measurement of neutron-induced cross sections in the required energy region. Further, the neutron source ISIS at the Rutherford Appleton Laboratory is well suited for performing neutrons scattering measurements so use of this will be pursued. Projects will also investigate nuclear data measurements of importance to ANTs on neutron capture and fission.

Examining the Shape of Proton Emitting Nuclei

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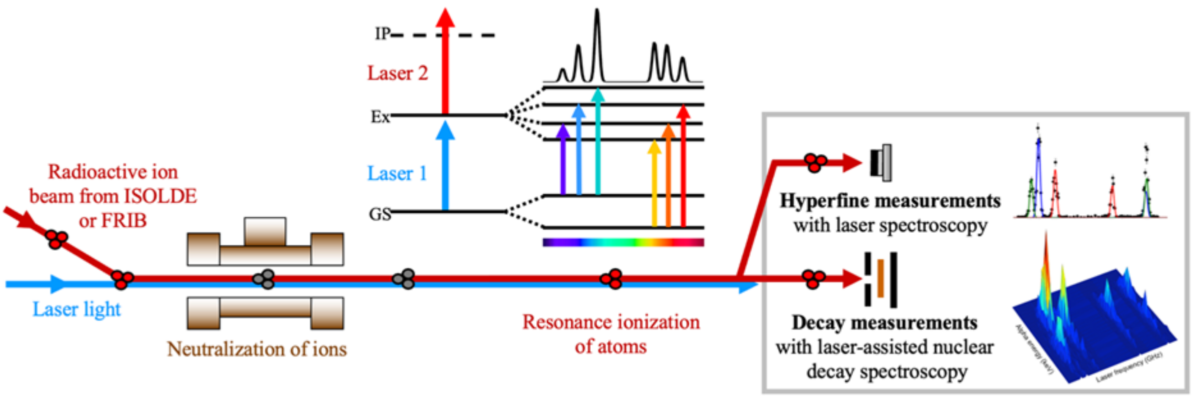
What is the shape of the nucleus in the moments before it emits a proton? How does the shape of the nucleus change when the proton becomes unbound?

Aim: This project aims to perform the first laser spectroscopy studies on proton-emitting nuclei, in order to measure the shape and other nuclear properties of these exotic species.

Details: At the edges of the nuclear landscape, a rare form of radioactive decay occurs where the nucleus emits a proton. Studying proton-emitting nuclei with laser spectroscopy provides an opportunity to measure their nuclear properties and understand the behaviour of nuclei right at the limits of nuclear existence.

Laser spectroscopy measures the hyperfine structure of atoms, an atomic fingerprint that allows nuclear properties (e.g. spin, electromagnetic moments and charge radii) to be measured in a nuclear-model-independent way. For example, the charge radius tells us about the proton distribution in the nucleus i.e. its shape. By measuring nuclei across the proton-drip line (beyond which proton decay occurs), we can understand the effect of the proton on the nucleus before it is emitted and gain a unique insight into how this single proton can influence the behaviour of the whole nucleus.

This project will be carried out at ISOLDE (CERN) and a new facility at Michigan State University (USA). It will use state-of-the-art laser spectroscopy techniques, such as Collinear Resonance Ionization Spectroscopy (CRIS) and the newly developed PI-LIST setup, to measure the properties of proton-rich nuclei. There are Ph.D. studentships available in the areas of laser spectroscopy and decay spectroscopy. There is an opportunity in the project for students to spend a large fraction of their time at CERN.



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.

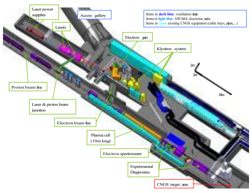
Prof Niels Walet has expertise with a variety of first principles approaches to many-body systems, in particular the coupled-cluster method. In work with Mike Birse, he has implemented a stochastic variational method to calculate the properties of few-nucleon systems. First applications of this have 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.

ALPHA Apparatus at CERN's Antiproton Decelerator facility.

Ultrafast laser systems at PSI.



AWAKE experiment at CERN.

VELA facility at Daresbury laboratory.

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
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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 and Dr. Robert Appleby
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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] [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.

[1] AWAKE Collaboration, E. Adli, et al., Nature, 561, 363-368 (2018).

VHEE Radiotherapy at The Christie and CERN: Investigation of Dose Delivery Aspects and a Potential New Paradigm in Cancer Treatment

Prof. Roger M. Jones
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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 heterogeneous 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.

LHC

Dr. Robert Appleby
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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

The Experimental Particle Physics group performs world-leading research at a wide range of experimental facilities. Potential projects are available in the following areas:

- Flavour physics
  - LHCb: The charm and beauty of antimatter
  - BESIII: The Chinese flavor factory
  - Mu2e: Precision muons at Fermilab
  - g-2: The anomalous magnetic moment of the muon
- Neutrino Physics:
  - The SBN Programme (MicroBooNE and SBND)
  - Deep Underground Neutrino Experiment (DUNE)
  - The NEXT experiment
- Dark matter detection:
  - The search for dark matter with the DarkSide-20k experiment
- Energy Frontier Physics:
  - The ATLAS Experiment at the Large Hadron Collider
- 3D diamond detector R&D:
  - Development of a beam conditions monitor with 3D diamond for the ATLAS experiment

In some cases, it is possible for the above projects to include a component of theoretical research. Please indicate in your application if this would be of interest to you.

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.

<u>Project: LHCb: The charm and beauty of antimatter</u>

Main contact:

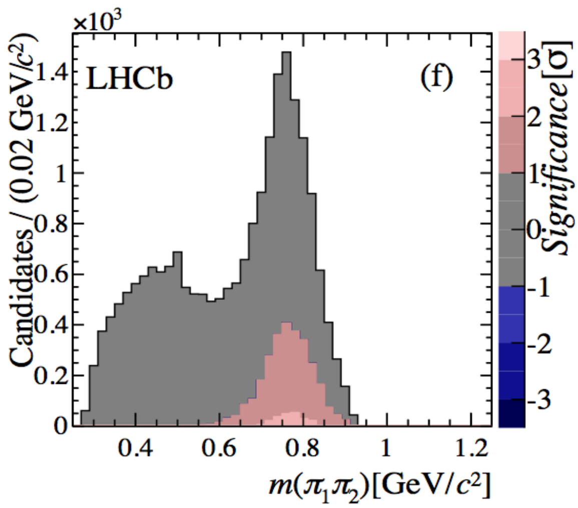
Prof. Marco Gersabeck (marco.gersabeck@manchester.ac.uk)

Other contacts:

Dr. Conor Fitzpatrick (conor.fitzpatrick@cern.ch)

Dr. Evelina Gersabeck (evelina.gersabeck@manchester.ac.uk)

Prof. Chris Parkes (chris.parkes@manchester.ac.uk)



Led by Manchester:
Hints of matter-antimatter asymmetries in charm?

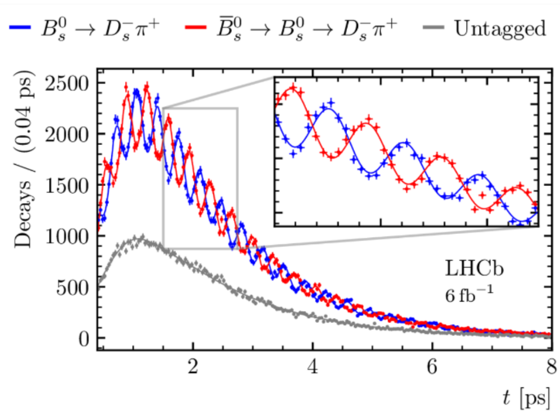
Manchester is one of the larger university groups working on the LHCb experiment and is involved in all current and future aspects of the experiment. This experiment is designed to search for physics from beyond the Standard Model through the analysis of matter-antimatter differences and rare decays of hadrons involving bottom and charm quarks. The group has been responsible for world leading analyses in both areas. We have been 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 all our main areas of focus: matter anti-matter asymmetries (CP violation), precision tests with semi-leptonic decays, and rare decays. Our group is leading CP violation measurements in charm hadrons. The group's work has been instrumental in the 2019 landmark discovery of CP violation in charm decays. Our CP violation studies with bottom hadrons focus on two areas: searches for CP violation in baryons and CP violation measurements of B hadron decays to final states involving charm hadrons. Many of these are sensitive to the CKM angle gamma, but we also exploit these final states to determine other parameters.

The figure below shows our group's measurement of the world's fastest particle-antiparticle oscillations. Some of the measurements within our group are performed exploiting synergies with the BESIII experiment.



The world's most precise measurement of Bs anti-Bs oscillations [Nature Physics 18 (2022) 1]

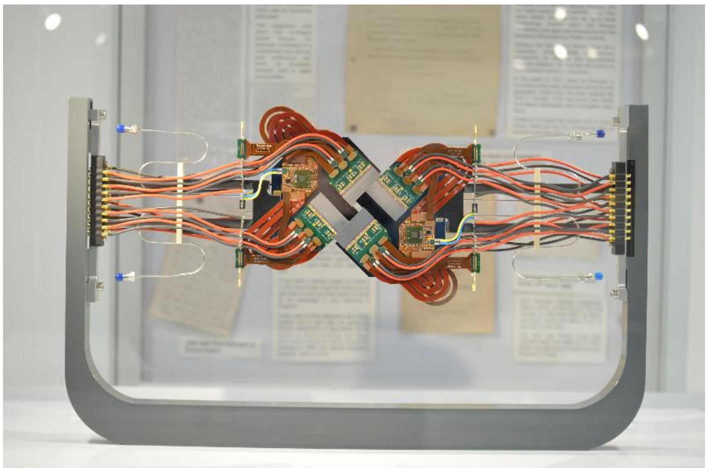
Another area of significant interest are measurements using semi-leptonic decays of charm and B hadrons, which primarily focus on tests of lepton universality, a fundamental principle of the Standard Model that has seen increasing tensions in a number of recent measurements.

Among rare decays our general focus is on lepton-flavour violating processes, which we study in tau lepton decays as well as in B and charm hadron decays to a mixture of electrons and muons. A recent study of charm decays led to over 20 world's best limits.

Our group drives innovation of analysis methods and we have been the first to exploit Graphical Processing Units (GPUs) in an LHCb analysis and have pioneered a fast simulation method that is now responsible for most simulated events in LHCb. In addition, we have had leading involvement in LHCb's Real-Time Analysis from the outset and remain committed driving novel analysis approaches. In general, all our projects include a high degree of data science applications and training.

We are also in close contact with theory colleagues who work on the phenomenology of the LHCb physics programme. With Dr Stefan Schacht being part of the High-Energy Physics group, this also offers the opportunity of informal theory projects or even a joint experiment-theory PhD.

Preparing for the next-generation experiment:



LHCb Vertex Locator modules built in Manchester and exhibited in the Schuster laboratory

The LHCb experiment has recently been upgraded to a new detector for higher luminosity operation and our group has strong involvement in commissioning and operation of the experiment, especially of the LHCb Vertex Locator (VELO). Our group built about 80% of the individual VELO modules (see figure), which now form 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 CO_2. Research projects in this area will focus on the commissioning and operation of the detector in areas in which the group has long-standing involvement through the decade-long operation of the predecessor vertex detector. This includes monitoring the data quality, including studies of radiation damage effects in particular, as well as studies of the data reconstruction and simulation.

We also have a leading role in the implementation of LHCb's real-time trigger, 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 achieving an optimal trigger quality, efficiency and throughput, as well as the required micron-level alignment of the detector components.

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. Future projects in this area will play a key role in the R&D phase and in the construction and evaluation of prototype detector elements.
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. Future projects will focus on R&D of advanced sensor technology, of novel cooling and support structures, as well as of the 4D reconstruction of particle tracks with this detector.

Project: BESIII: The Chinese flavour factory

Main contact:

Dr. Evelina Gersabeck

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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.

BESIII detector

Key attributes of the decays of the D mesons cannot be determined from other flavour physics experiments such as LHCb and Belle II; 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 the 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 complementarity and 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 done at LHCb due to model or external inputs. Manchester is one of the two UK groups involved in both LHCb and BESIII.

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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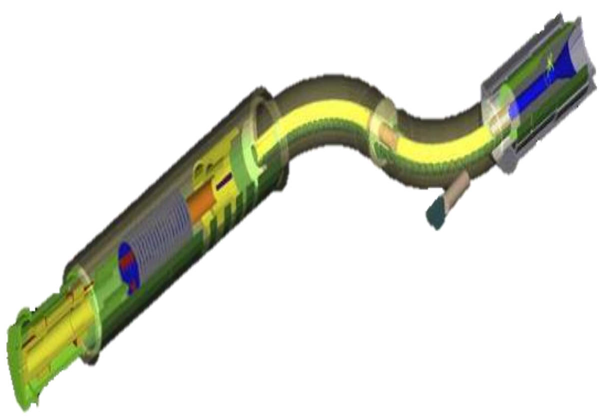
Prof. Marco Gersabeck (marco.gersabeck@manchester.ac.uk)

Dr. Alex Keshavarzi (alexander.keshavarzi@manchester.ac.uk)

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 and is particularly timely given hints from the Fermilab muon (g-2) experiment and LHCb that muons are perhaps not quite behaving as predicted by the SM.

Our group is responsible for commissioning and operating an X-ray detector to record the number of muons captured by the target (in excess of 10^8/sec) in collaboration with other UK groups.



The FNAL Mu2e Experiment

In this project, a student will be commissioning the X-ray detector with the first muon beam and optimising its performance and making a precise determination of the muon flux: without which, the rate or limit of new interactions beyond the SM cannot be determined. In parallel, the project will involve optimising the performance of the straw-tracking detectors to maximise the experiment's sensitivity to new physics phenomena and thus establishing the world's most sensitive search for charged-lepton flavour-violation.

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

Main contact:

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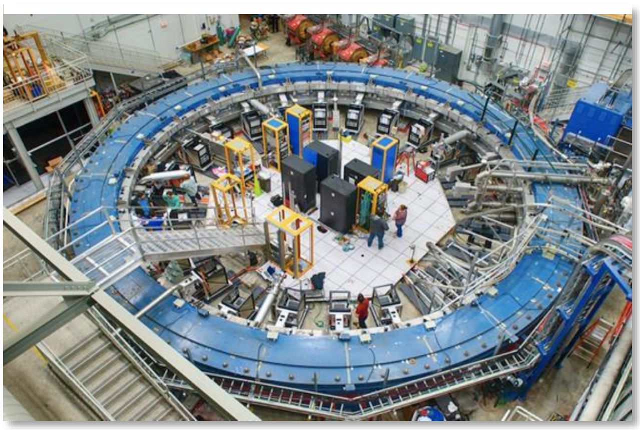
Other Contacts:

Dr. Alex Keshavarzi (alexander.keshavarzi@manchester.ac.uk)

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 ~ 0.1% such that in the Standard Model (SM),g-2 is predicted to be: 0.0023318362(9). g-2of the electron is the most accurately predicted and measured quantity in physics and g-2of the muon is the most accurately measured quantity using a particle accelerator storage ring.

The Fermilab (FNAL) Muon (g-2) experiment has recently published an analysis of less than 10% of its data and confirms a previous measurement made at the Brookhaven National Laboratory(BNL)almost 20 years ago. Together these two measurements measure g-2 to be: 0.0023318412(8):different from the SM prediction by 4.2 standard deviations. This is presently the largest difference between a SM prediction and a measurement, and is perhaps a sign of a new interaction beyond the SM. Results from the LHCb experiment that muons do not behave the same way as electrons also hint that muons are perhaps anomalous. With the data already accrued, the FNAL Muon (g-2) experiment can establish evidence for new physics with a significance of more than 5 standard deviations should the FNAL and BNL measurements be further confirmed with the higher statistics analysis.


The FNAL Muon g-2 Experiment

A student on this project will be involved in the final year of the 6-year data taking campaign at FNAL, where data with a μ-beam will be taken, and the analysis of the final, highest-statistics data from the experiment that will establish the definitive measurement of g- 2 of the muon. Particular focus will be on the evaluation of the systematic uncertainties due to the harmonic motion of the beam and the variance in the beam momentum.

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 and with NEXT in Spain. We also have an active detector instrumentation efforts that aim to enhance noble element detectors for future experiments.

Project: The SBN Programme (MicroBooNE and SBND)

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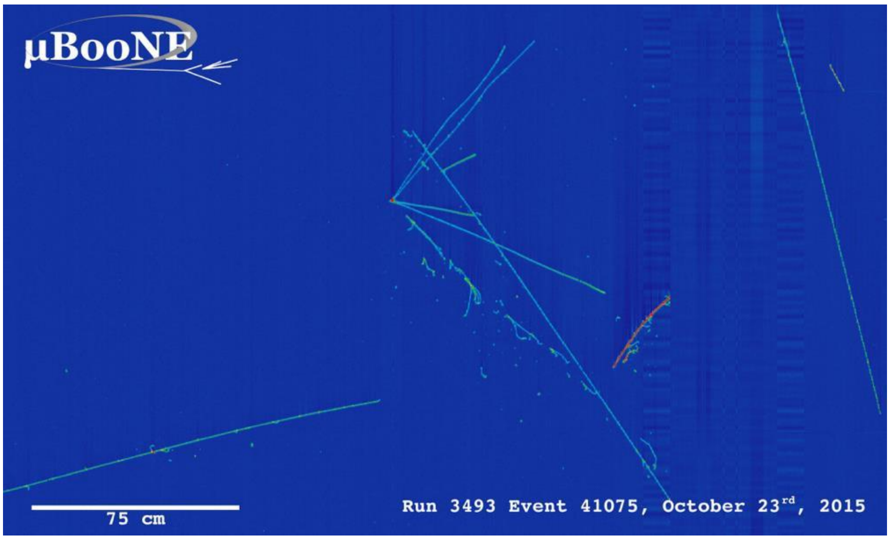

One of the first neutrino events observed by the MicroBooNE detector at Fermilab.

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, as well as the commissioning of the SBND experiment, which is currently being constructed. Our group's focus is on reconstructing electromagnetic showers to search for neutrino oscillations, measuring neutrino cross sections and looking for alternative signatures of physics beyond the Standard Model. The project could also have a small hardware component through involvement in the commissioning of the SBND detector.

Project: Deep Underground Neutrino Experiment

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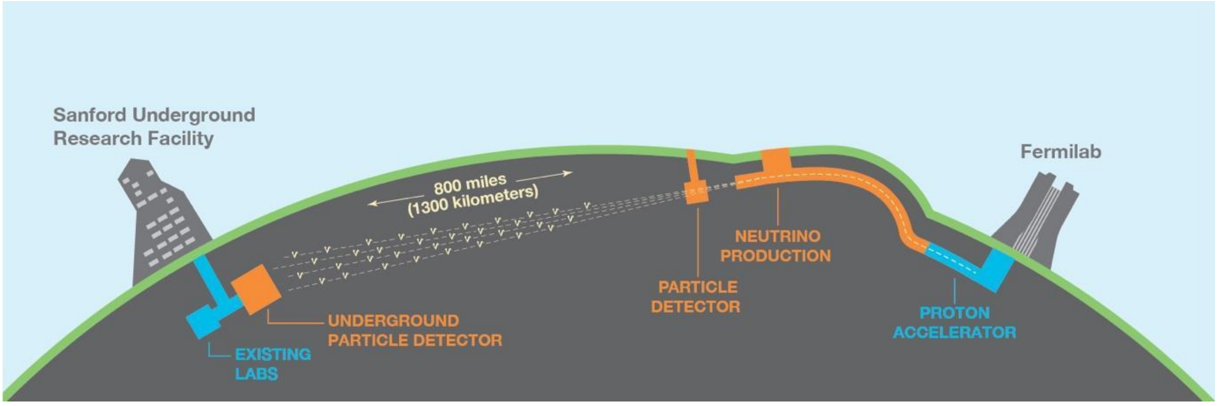

DUNE is an international, next-generation neutrino science project with the goal to discover CP violation in the lepton sector, study neutrino oscillations, and to record neutrinos from a supernova explosion. The neutrino beam produced at Fermilab near to Chicago will be measured in a Near Detector on-site and at a large underground facility in South Dakota.

The Deep Underground Neutrino Experiment (DUNE) is an international collaboration of scientists from more than 30 countries with the goal to study neutrino interaction and to discover CP violation in the lepton sector of the Standard Model, addressing the fundamental question of matter dominance in the Universe. It will also study neutrinos from supernova explosions and search for other non-standard physics phenomena, such as proton decay.

Our group plays a leading role on the project: we are responsible for building one of the largest components of the detectors, large wire planes (called Anode Plane Assemblies) that will read out the charge produced by neutrino interactions in the liquid argon of the DUNE far detectors located in South Dakota. We are also starting a programme to develop the next-generation charge readout designs, using a pixel design that will allow us to measure "true" 3D images of the interaction (see SoLAr and QPix in the R&D session). Potential PhD projects could be related to the optimisation of the design of such a detector, building and testing of detector components, or the developments of algorithms for the reconstruction of the images. Another important aspect is the development of physics analyses using machine learning techniques. As we are also collaborate on the short-baseline neutrino programme (see separate section), which uses similar detector techniques, data from these detectors could be used to validate and further develop physics analyses with a focus on searches for physics beyond the Standard Model.

Project: NEXT experiment

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The NEXT high pressure xenon gas detector, located underground at Canfranc, searches for Majorana neutrinos.

The NEXT experiment uses a high-pressure xenon gas time projection chamber to search for Majorana neutrinos. This type of detectors allows for great energy resolution and offers imaging capabilities that can help reduce background, two essential ingredients for identifying the extremely neutrinoless double beta decay process. We are currently constructing a new phase of the experiment at the Laboratorio Subterráneo de Canfranc in Spain, NEXT-100 which will take data for the next few years, providing competitive limits on the neutrinoless double beta decay half-life and demonstrating the capability of the technology at larger scale. Our group will play an active role in the detector commissioning and will perform several data analyses. We will also work on developing a new readout plane for the future ton-scale phase of the project.

Dark matter direct detection searches

Project: The search for dark matter: DarkSide-20k

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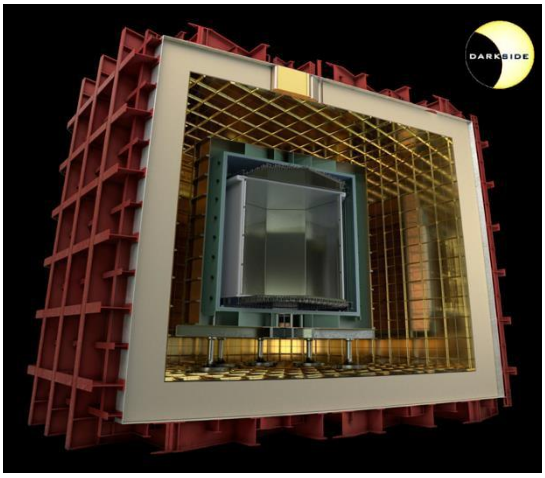

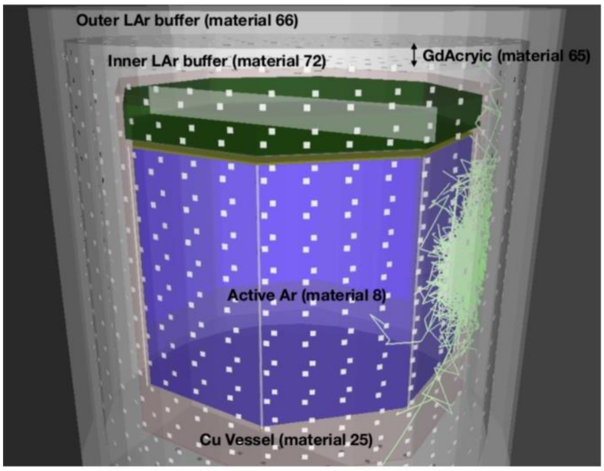

A simulation of the DarkSide-20k experiment and tests of the readout of the silicon photosensors in the neutron veto

The DarkSide-20k experiment aims to discover dark matter via the elastic scattering of dark matter particles from space on argon nuclei in a 50-tonne detector instrumented with over 11,000 cutting-edge silicon photosensors operating at cryogenic temperatures.

DarkSide-20k is designed for a sensitivity reach to dark matter interaction rates 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 2023.

Manchester holds key responsibilities within the experiment. These include the construction of the high efficiency low radioactivity cryogenic silicon photosensor modules for the outer detector, and the design electrical tests and performance characterisation of these sensors, critical to enable discriminate dark matter signals from natural radioactive background processes. The Manchester group plays a central role in algorithm development, detector simulations, and the analysis of data from prototype detectors. The group plays a central role in the expansion of the science programme of DarkSide, publishing innovative studies in conjunction with theorists exploring prospects and strategies for studying non-standard dark matter models, expanding dark matter mass sensitivity down to the tens-of-MeV range, and exploration of neutrino physics opportunities with this detector.

Potential PhD project work can combine aspects of detector design/construction, computer simulations, data analysis, and physics sensitivity studies.

ATLAS Experiment

Project: The ATLAS Experiment at the Large Hadron Collider (CERN)

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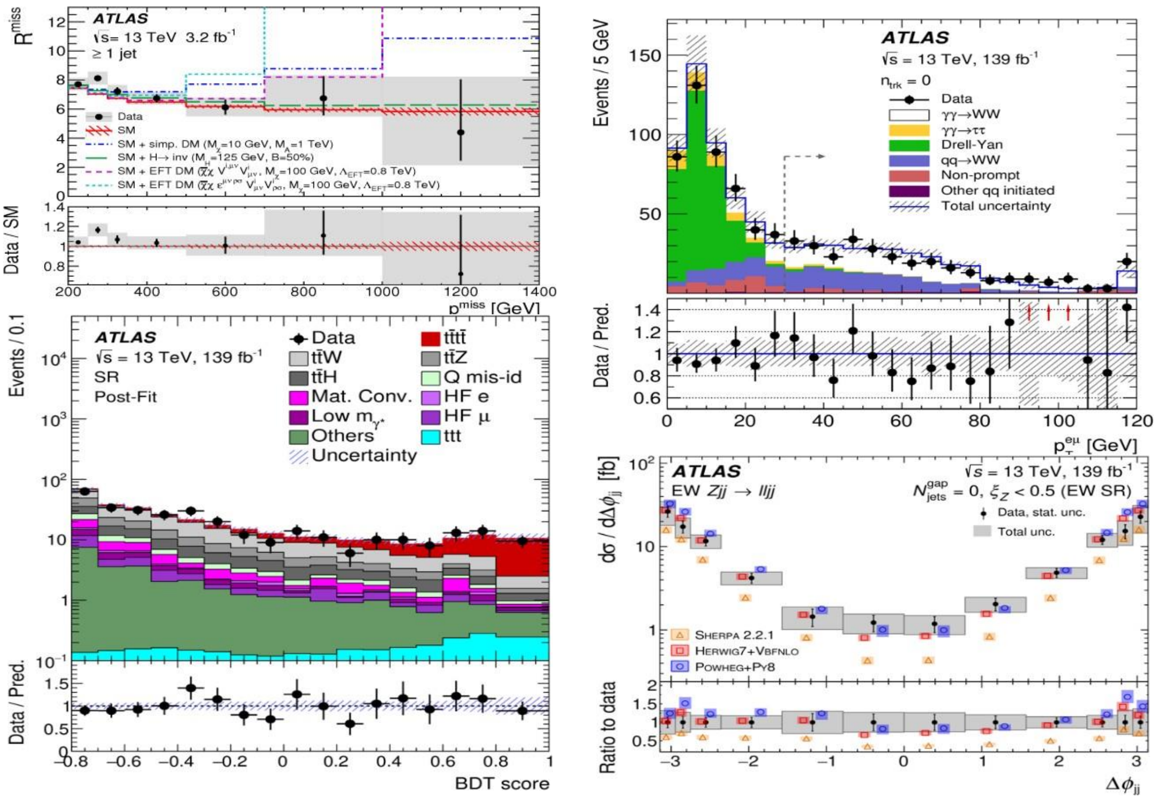

Illustrations of some recent firsts from the ATLAS Manchester group: new methods for searching for dark matter at the LHC (top), observation of the production of W boson pairs in photon-fusion (top right), evidence for four-top production (bottom left), precision measurements of pure electroweak production of Z+2jet systems (bottom right).

ATLAS is a general-purpose particle physics experiment at the Large Hadron Collider (LHC).Manchester has played a major role in the ATLAS experiment for many years, with members taking international leadership across all areas of ATLAS operations, such as data acquisition, physics analysis, detector commissioning and detector upgrade.

ATLAS collected 140 $fb^{-1}$of proton-proton collisions at a centre of mass energy of 13 TeVin the LHC Run-2 (2015-2018). Around 30 fb-1 of data was collected at 13.6 TeV in 2022. This was the first year of LHC Run-3, which will continue until 2025.This provides a dataset that is unprecedented in both size and energy. Our goal is to provide world-leading sensitivity to dark matter, CP-violation, extra dimensions, additional Higgs bosons, heavy Majorana neutrinos, gravitons and leptoquarks. We perform this research from multiple angles. We search directly for these new physics phenomena as predicted by specific theories. We also produce model-independent measurements that test the predictions of the Standard Model, which could provide the first hints of something completely new and unexpected. In 2023, we expect to offer projects in the areas of electroweak physics, Higgs physics, and physics beyond the Standard Model.

The Manchester group has played a major role in studying the self-interactions of the weak bosons. Recent highlights include precision differential measurements of vector-boson scattering processes at a hadron collider, the first observation of photon-photon fusion processes, and the search for proton-proton collision events that contain three weak bosons. Each of these processes is sensitive to the self-interactions of electroweak bosons, which is a key prediction of the Standard Model, and deviations from the expected event rates would signify anomalous weak boson self-interactions: a smoking gun for new physics! The processes however are extremely rare and measurements are only becoming possible now, with the large datasets available from the LHC.

In the Higgs sector, we continue to develop new ways of understanding the interactions of the Higgs boson. Our group members made the first measurements of the Higgs boson differential cross sections and used these to search for anomalous Higgs boson interactions. We are also heavily involved in studying the relationship between the Higgs boson and the Top quark, with major contributions to the observation of Higgs bosons produced in association with a top-antitop pair. We currently lead measurements that probe the CP nature of the Higgs-Top interaction, which could provide the missing source of CP violation needed to explain the matter-antimatter asymmetry of the universe.

The Manchester group has been central to the development of new initiatives in the search for new physics phenomena, spearheading new approaches to the search for dark matter through precision measurements and through real-time data-analysis techniques. We lead new efforts to search for heavy Majorana neutrinos and other lepton number violating phenomena at the LHC through weak boson fusion processes, have developed novel observables to test the principle of lepton universality in W boson decays, and are the primary developers of the 'Trigger-Level Analysis' technique that dramatically improves the sensitivity to final states that are limited by the ATLAS data acquisition system. We have a broad direct search programme for new particles through two-boson and three-boson final states (searching for high mass particles like gravitons), di-tau final states (searching for particles preferentially coupling to third-generation particles, or doubly-charged Higgs bosons), bb-tau- tau final states (sensitive to leptoquark and di-Higgs production), and searches for rare low mass particles that would evade standard searches.

Very few particle physics groups in this country or the rest of Europe can boast of a close and long-standing connection between experimental and theoretical particle physicists. This provides plenty of fruitful opportunities for joint experiment-theory collaborations in LHC physics. We have had several 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 physics analysis, PhD students contribute to one of the other areas of ATLAS operations. The Manchester group has long-term involvement and leadership in developing the data acquisition system (the 'trigger'), improving hadronic jet reconstruction and calibration (including heavy-flavour tagging), and determining the properties of hadronic tau decays. We are also strongly involved in upgrading the ATLAS pixel detector for data-taking through to 2035. The PhD projects will combine activities from any of these research areas.

R&D for neutrino detectors

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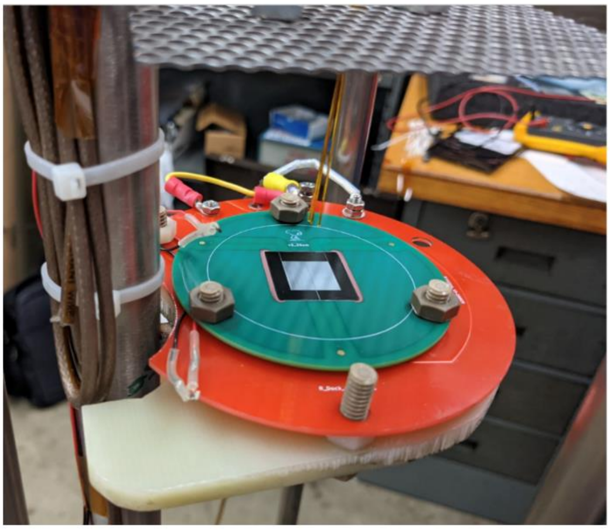
The Manchester group is developing new technologies for future generation of detectors, especially in the context of noble element media: small scale cutting edge R&D today is the first step to unlock the discoveries of tomorrow. Currently, the group is focused on developing new cryogenic photodetector concepts (LILAr [arxiv.org] and Metalenses) and new charge readouts (Q-Pix [arxiv.org]). The Light Imaging in Liquid Argon (LILAr) project aims to develop coatings of amorphous selenium for the detection of VUV light in noble element detectors with high quantum efficiency in wide surface detectors. Metalenses are nanostructures that focus light, allowing for a cost-effective solution to increase the light collection while maintaining a reasonable number of photosensors in noble element detectors. Both projects have potential ties to material science and industry.

QPix is a novel ionisation readout and waveform digitisation scheme to pixelate kiloton-scale LArTPC detectors. With the SoLAr project, the group is also developing a new fully pixelated light-charge readout concept for the detection of low-energy solar or supernova neutrinos. As part of the QPix consortium, the group is in the process of building the "Pixel Lab": a University of Manchester space for the development of pixelated TPC technology. Table top experiments are extremely rare in particle physics: the Pixel Lab will give unprecedented opportunities to our students for hands-on work on detector R&D.


LILAr first prototype

3D Diamond Detectors

Project: Development of a beam conditions monitor with 3D diamond for the ATLAS experiment

Main Contacts:

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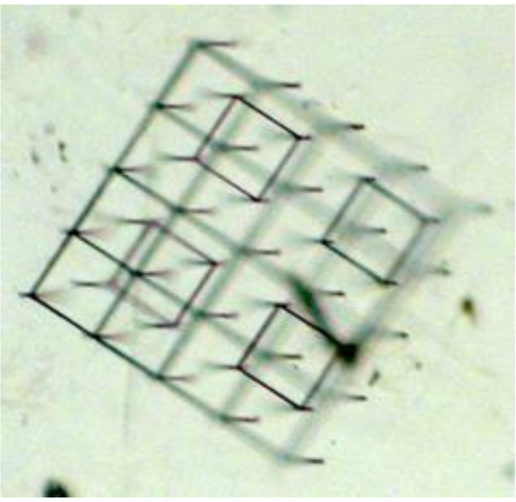
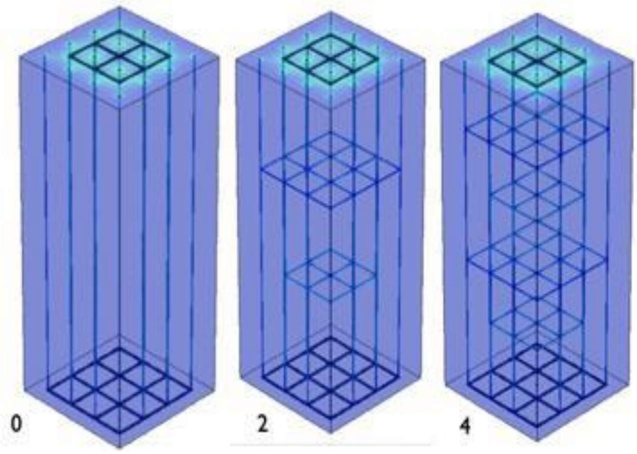




A photograph of a 3D diamond detector with graphitic wires inside the buld diamond (left) and a simulation of the device with different wire geometries (right).

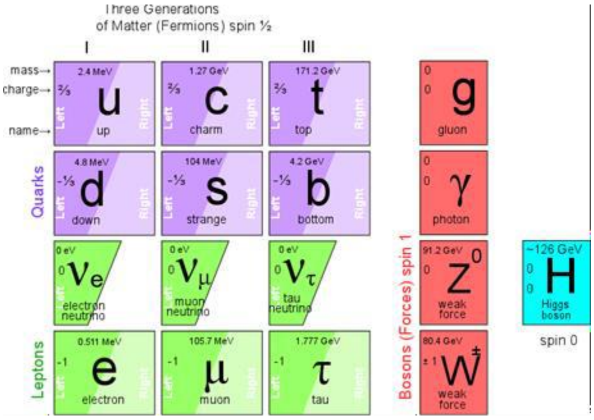
3D diamond detectors have evolved from an idea to an actual proven concept. The key point is to combine radiation hard detector material with in-bulk electrodes (called 3D). The Manchester group is leading the development of this novel technology, being the first to successfully produce the first ever 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.

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. Here a so-called Beam Conditions Monitor (BCM) will be safeguarding the inner silicon tracker against any abnormal beam conditions of the LHC. The BCM' project is developing and will commission a diamond-based detector to be installed during the long shutdown 3 of the LHC in 2024.

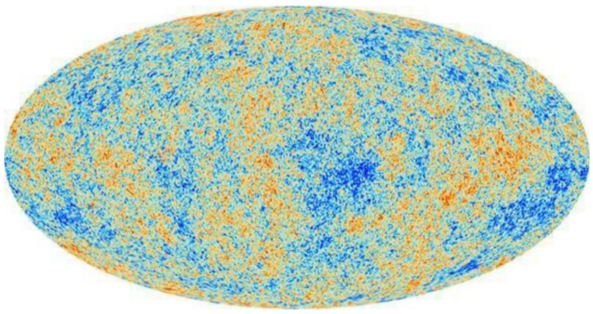
We also collaborate with The Christie Hospital to apply this technology to challenges in radiology. The objective is to use 3D diamond dosimeters for in vivo dosimetry applications for photon and proton beam therapy. More info our activities can be found here: http://alexanderoh.ch/

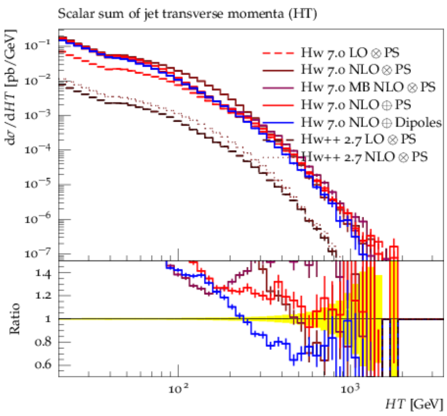
PARTICLE PHYSICS - THEORY

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.

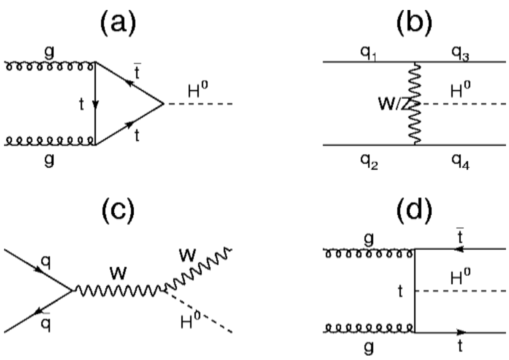


Standard Model.


PLANCK CMB image.



HERWIG 7.0 Higgs production.



Higgs production channel.

Beyond the Standard Model and Particle Cosmology
Prof. Apostolos Pilaftsis
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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.

Using QCD to explore the TeV scale at the Large Hadron Collider
Dr Mrinal Dasgupta
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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
Prof. Jeff Forshaw
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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
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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.

Quantum field theory and its applications in fundamental physics

Dr Peter Millington
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One of the most powerful mathematical frameworks that we have for describing the subatomic building blocks of nature (the elementary particles) and the forces that act between them is called quantum field theory. Given the many successes of the Standard Model of particle physics, it might come as a surprise that there remain many important and outstanding questions in quantum field theory itself, with implications for a wide range of areas, from high energy physics, cosmology, astroparticle physics and gravitation, to condensed matter and solid state physics.

We are working on various aspects of quantum field theory and its applications across fundamental physics, and examples include:

- Revisiting basic principles in quantum theory, such as the condition of Hermiticity of the Hamiltonian, which can be relaxed in favour of other discrete anti-linear symmetries in the framework of pseudo-Hermitian quantum theory, whose extension from quantum mechanics to quantum field theory we are pioneering.

- Constructing frameworks within quantum field theory that can describe the relativistic quantum dynamics of open systems, those at finite temperature, or those evolving out-of-thermodynamic equilibrium.
- Building techniques that go beyond perturbation theory, based, e.g., on the quantum effective action or the functional renormalization group, which allows us to study how physics changes with energy scale.
- Understanding the behaviour of the ground states of quantum field theories, and quantum field theories in curved spacetime, with potential implications for the famous cosmological constant problem and the infra-red divergences that arise in massless gauge theories, such as QED and QCD.

Multiple Parton Interactions at the Large Hadron Collider and Beyond

Dr. Jonathan R. Gaunt jonathan.gaunt@manchester.ac.uk

The proton-proton collisions that occur at the Large Hadron Collider (LHC) are highly complex environments. Protons are not elementary particles, but are composed of many quarks and gluons (collectively, 'partons') bound together via the strong nuclear force. In each proton-proton collision there are typically many parton-parton collisions, and the products of these collisions can further interact with each other and with the non-colliding 'spectator' partons via the strong force. Most research work conducted so far has been focussed on the dynamics of the 'primary' highest-energy collision in the absence of other interactions. For a small set of measurements, it has been shown that the effect of the multiple additional interactions can be ignored, but in many other cases it has been assumed to be the case, or the additional interactions have been modelled in a very approximate way. However, we are entering a phase of precision physics at the LHC where we are searching for signs of new physics in small deviations between experimental measurements and precise theoretical predictions. Thus, theoretical control over the additional interaction effects is now needed. This project involves developing novel first-principles theoretical descriptions of the additional interactions, and developing numerical tools based on these descriptions to make predictions at the LHC. The project will not only be of significant utility to the LHC precision physics programme, but will also lead to new understanding of proton structure and the interactions of the proton constituents.

Effective Field for New Physics at the LHC:

Dr. Eleni Vryonidou <eleni.vryonidou@manchester.ac.uk>

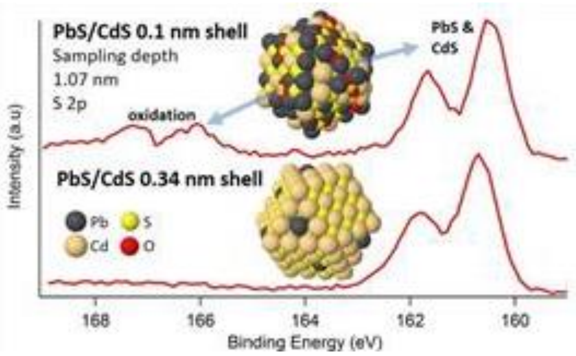
The Large Hadron Collider (LHC) is colliding protons at unprecedented energies in an exciting effort to learn more about the fundamental particles of Nature. After the Higgs discovery at the LHC, the particle physics community is pursuing a gigantic effort of determining the properties of the Higgs boson and hunting for signs of new phenomena beyond our current theoretical understanding of particle physics, the so-called Standard Model (SM). The LHC is searching for undiscovered particles and measuring the interactions of all known particles. If new particles are too heavy to be directly produced in the collisions, their effects can be detected by small modifications of the interactions of the particles that we already know exist. These small modifications can be studied within a theoretical framework that particle physicists call the SM Effective Field Theory (SMEFT). A precise determination of the interactions of the Higgs and all fundamental particles constitutes a challenge, and requires collaboration between experimental and theoretical particle physicists. My work aims at providing accurate theoretical predictions and the necessary computer codes to compute the probabilities of scattering processes occurring at the LHC within the SMEFT. Combining the predictions and data, I will then extract information on the interactions of the elementary particles such as the Higgs boson to other particles and itself. Any modification of interactions found will point to the mass scale of new particles and can provide hints to the answers of the most fundamental questions of Nature.

PHOTON PHYSICS

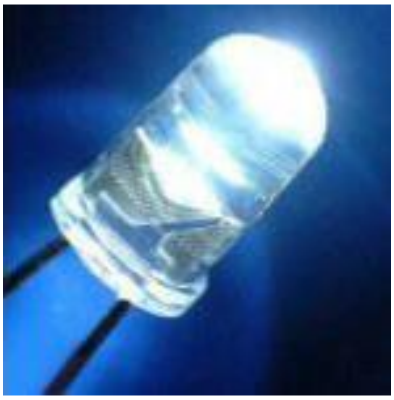
The Photon Physics group studies the interactions between light and matter and uses light to investigate a range of novel and important systems. The scope of our work ranges from improving our theoretical understanding of the quantum nature of these interactions to developing new spectroscopic and microscopic 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, and as such we work with a wide range of industrial and research partners.

Students working with the lasers at the Photon Science Institute.



Synchrotron-excited nm-scale depth profiling used to understand passivation of the surfaces of quantum dot light harvesters.



An LED incorporating InGaN quantum wells.

Carrier dynamics in GaN films and InGaN/GaN Quantum Wells
Dr. David Binks
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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 in collaboration with the Department of Materials and Metallurgy at the University of Cambridge. We use a suite of spectroscopic techniques on cryogenically cooled samples in well-equipped, established laboratories. 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.

Research projects include:

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

Optical techniques as medical diagnosis tools

Prof. Mark Dickinson in collaboration with Dr. Andrea Murray
(mark.dickinson@manchester.ac.uk and 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.

Research projects include:

- 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.

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, efficiency 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 experiments conducted using custom-built spectrometers together with the laser facilities in the Photon Science Institute. We operate 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).

Research projects include:

- Electron impact ionization and excitation of atoms and molecules
- Study of quantum interference from two-colour photoionization pathways using a toroidal spectrometer (a 'double-slit' experiment with a single atom – see Physics World, Feb 2020) (fully funded EPSRC project)
- Production of a quantum diffraction grating using single photo-electrons emitted from a cold atom array (fully funded EPSRC project)
- Producing & ionizing highly excited Rydberg atoms following stepwise electron impact and laser excitation (fully funded EPSRC project)

High-throughput and automated measurement for photonic quantum technologies
Dr. Patrick Parkinson
(patrick.parkinson@manchester.ac.uk)

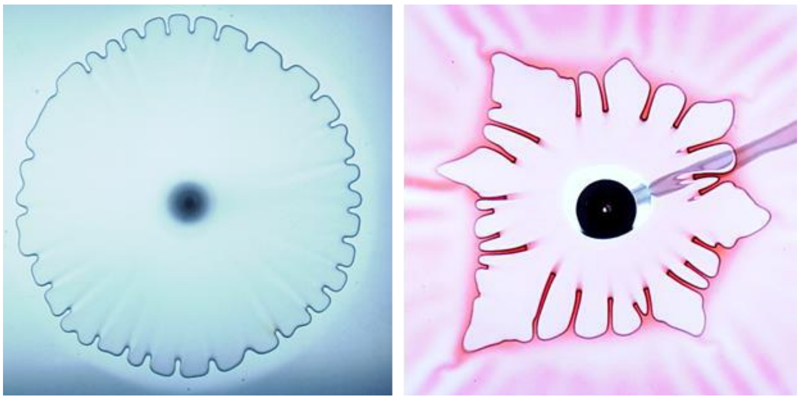
It is over 60 years since Richard Feynman claimed, "There's plenty of room at the bottom", establishing the field of functional nanotechnology. In this field, performance depends on both the geometry and quality of a material. Optical nanotechnology is rapidly emerging as an enabling technology for the new field of on-chip photonic integrated circuitry, which provides a novel alternative for fast, low cost and energy efficiency computation. Key elements include light emitters, lasers, and sensor which must be designed and produced at the sub-wavelength scale; by exploiting advances in bottom-up fabrication, billions of single element devices can be produced in a single growth run. However, understanding the complex behaviour of material, electronics, and light within sub-micron and heterogeneous materials presents a huge challenge. This is particularly the case for photonic quantum technologies, where single photon emitters and detectors must be produced at scale and at high yield.

As part of a multi-million-pound, multi-year UKRI Future Leaders Fellowship "Big-Data for Nano-Electronics", our group develop an experimental and data-science framework for high-throughput functional characterisation of single-element nanotechnology. The aim of this project is to make use of existing high-throughput imaging and spectroscopy tools to measure geometrical and material properties of large ensembles (~10^6) of single devices which make use of a newly installed cutting-edge laser system. Statistical approaches including Bayesian optimization and machine-learning will be used to identify routes to control and harness disorder, to produce a framework for analysis of large, correlated datasets.

Research projects include:

- Ultra-high-throughput spectroscopy and imaging to the million-endpoint regime
- Bayesian optimization for model development in nanoelectronics
- Single-photons and large-scale analysis; joining big-data to quantum measurements

PHYSICS OF FLUIDS AND SOFT MATTER



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 12 members including three permanent members of academic staff (Dr Draga Pihler-Puzović, Dr Finn Box and Prof Anne Juel) and a laboratory technician (Martin Quinn). 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 where PhD projects are available include:

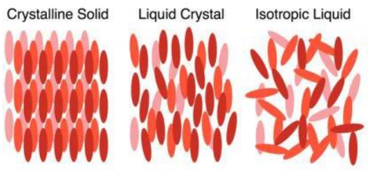
- Instabilities in two phase flows and fluid-structure interaction (AJ, DPP, FB).
- Biomimetic flows and microfluidics (AJ, DPP, FB).
- Instabilities of soft solids and metamaterials (DPP, FB).
- Wetting and drying (AJ).
- Yield phenomena and viscoelasticity (AJ, DPP).

For more information, please visit our research page: http://www.mcnd.manchester.ac.uk/
or 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.

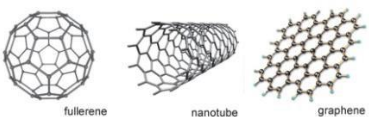
SOFT MATTER AND LIQUID CRYSTALS

Dr.Ingo Dierking (ingo.dierking@manchester.ac.uk)

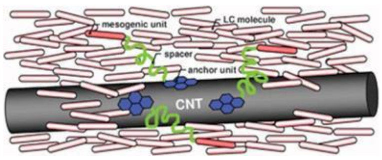
Our group primarily performs experimental research in different areas of soft condensed matter, liquid crystals, polymer modified liquid crystal composites, nanoparticle dispersions in anisotropic fluids and liquid crystal phases formed by colloidal materials, especially graphene oxide. Investigations range from fundamental physical questions to studies which are of relevance to the applications.



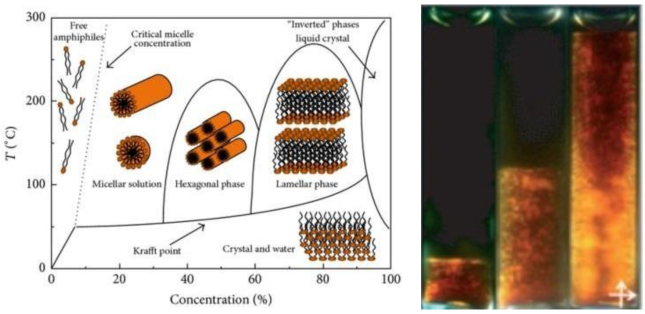
Thermotropic liquid crystal



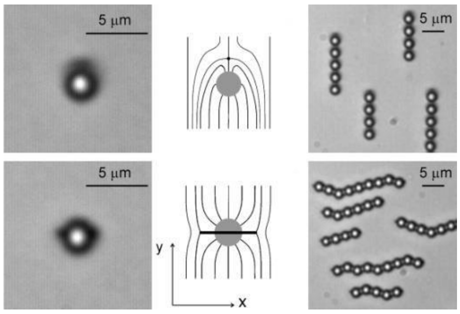
Carbon nanoparticle dopants



Novel functional materials

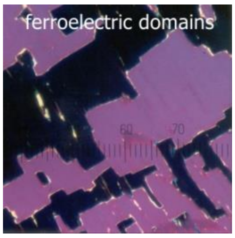


Lyotropic liquid crystals of graphene oxide and colloids

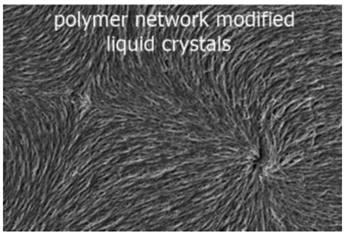


Electrophoresis and colloid chaining

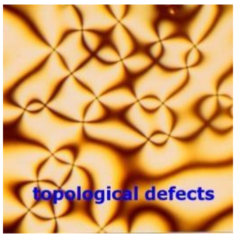
We use a range of in house experimental optic, electric and electro-optic techniques. For some specialized techniques and material synthesis, we collaborate with different groups world-wide.



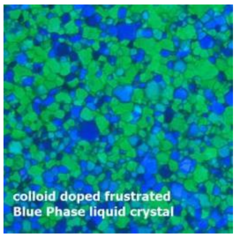
Ferroelectric LC



Polymer modification



Defect annihilation



Frustrated phases

Possible projects

- Defect annihilation in lyotropic chromonic liquid crystals via machine learning
- Pattern formation in hydrogen-bonded liquid crystals
- Cellulose nanocrystal and nanofibre liquid crystals
- Lyotropic liquid crystals from 2D materials
- Solitons in liquid crystals
- Functional nanoparticle dispersed liquid crystals