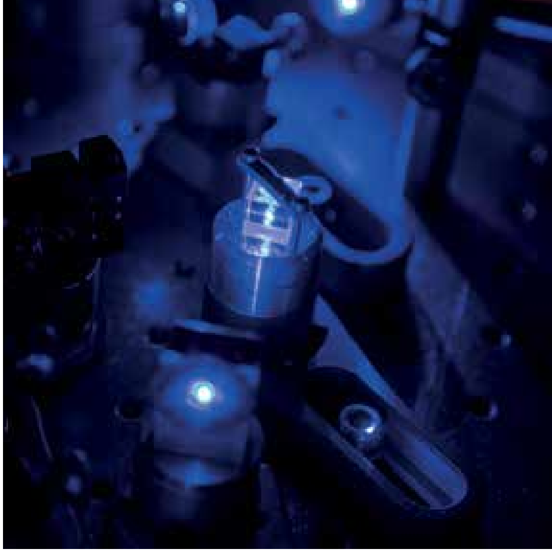
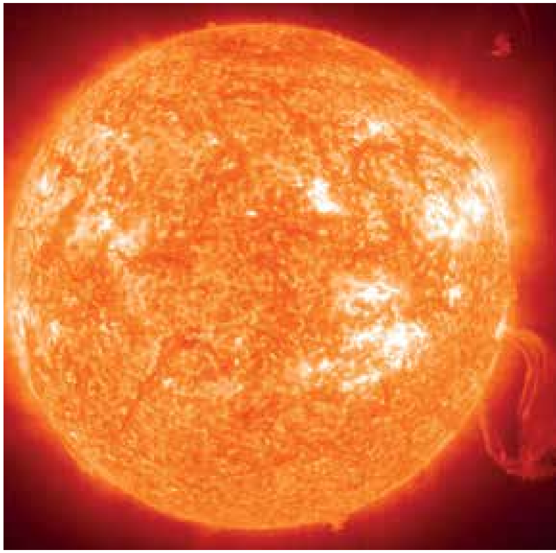
UNIVERSITY OF BIRMINGHAM





RESEARCH IN THE SCHOOL OF PHYSICS AND ASTRONOMY

WWW.BIRMINGHAM.AC.UK/PHYSICS

As a member of the School of Physics and Astronomy at Birmingham, you will be part of a large research-intensive school. You will join a long history of world-leading research starting with our founding Head of School, Professor Poynting, who is known for weighing the Earth and deriving the Poynting vector in the study of electromagnetism. Our accomplishments continued through the 20th century, including the development of the cavity magnetron in the 1940s, work on topological states of matter in the 1970s (which won the Nobel prize in 2016) and measurements of the elementary W and Z particles in the 1980s. In the last decade, we've continued to contribute to new exciting discoveries which have shaped our intrinsic view of the Universe, including the discovery of the Higgs boson and gravitational waves. Read on for a brief taste of our current research and to learn how, as a student at Birmingham, you will learn from these inspirational scientists and will be involved in the research yourself. Working together, we can look forward to the next scientific leaps forward, like the applications of quantum mechanics to new technologies or the search for life outside our solar system.

ASTRONOMY AND EXPERIMENTAL GRAVITY

GRAVITATIONAL WAVE ASTRONOMY AND GALAXIES

Studying black holes and neutron stars, the most violent cosmic collisions and largest structures in the universe using gravitational and electromagnetic waves.

We are using gravitational-wave and multi-messenger observations to transform our understanding of the violent Universe, including the properties of neutron stars and black holes, and the behaviour of gravity in extreme conditions. In the long term, we aim to observe the Universe when it was a fraction of a second old.

We are members of the LIGO team that in 2015 detected gravitational waves for the first time, and has since discovered more binary black holes and observed the first merger of a binary neutron star. Our group brings together expertise in laser interferometry, metrology, quantum systems, data analysis, transient astronomy, theoretical astrophysics and general relativity to lead this revolution in astronomy. We are investigating new technologies for future gravitational wave observatories, and developing the Laser Interferometer Space Antenna, a 2.5 million km arm interferometer in space.

We study the evolution of structure through cosmic times, from massive black hole formation at the centre of galaxies, to galaxy evolution and cluster assembly. We use the most powerful telescopes on Earth and in space across the whole electromagnetic spectrum, to investigate the assembly history of the Universe, and shed light on some of its mysterious components, dark energy and dark matter.

SUN, STARS AND EXOPLANETS

Research in solar and stellar physics and finding and characterising planets orbiting other stars.

Did you know that Sun-like stars in the night sky are playing their own stellar symphonies, resonating due to trapped sound waves? Or that we now know that many of these stars host planets?

We use asteroseismology to study stars by observing their natural, resonant oscillations. We focus on stars that host planets, allowing us to characterise these newly discovered stellar systems; and also different populations of stars in our Galaxy, the Milky Way, allowing us to perform Galactic Archaeology to understand its formation and evolution.

We not only use data from the NASA Kepler/K2 and TESS satellites but have international leadership roles in the missions. We are also involved in new missions such as the ESA PLATO project. Additionally, we study the Sun (helioseismology) using our global network of observatories, the Birmingham Solar Oscillations Network (BiSON). Our focus is to understand the origins of the current, unusually low levels of solar activity.

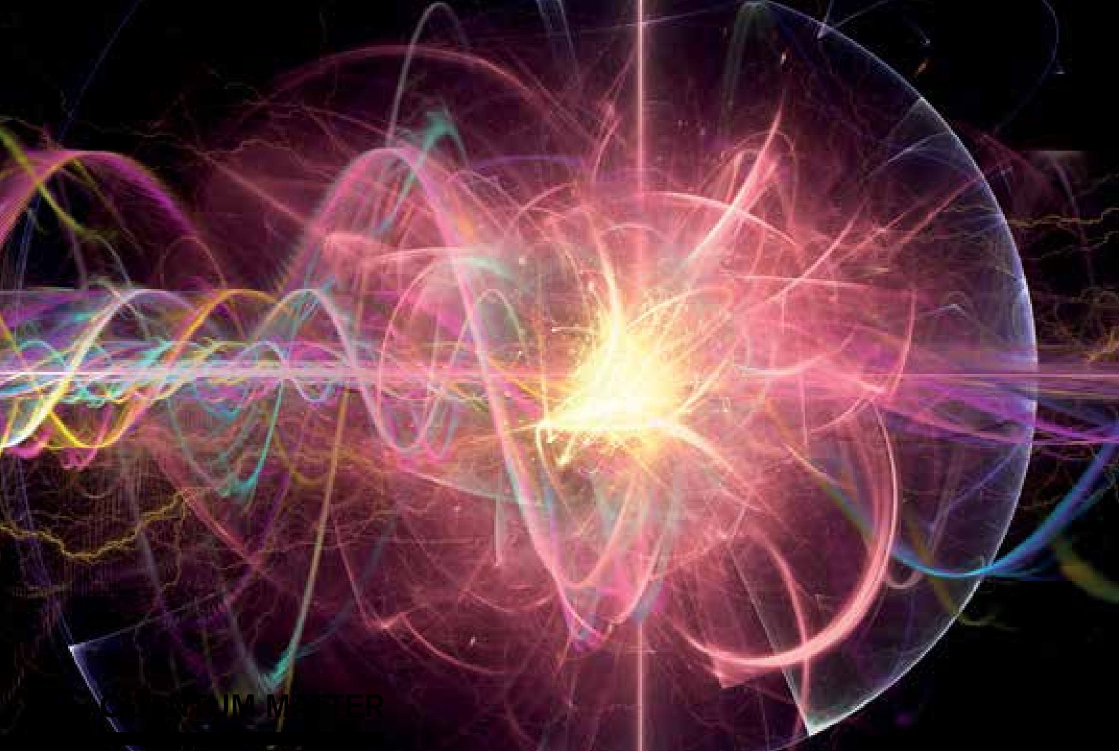
The group has leading involvement in the discovery and characterisation of multiple planetary systems, such as TRAPPIST-1. An important focus is also the discovery of circumbinary planets, which orbit not one but two stars in a binary.

ASTROPHYSICS FOR UNDERGRADUATES

Our astrophysics research features throughout all four years of undergraduate teaching and the specialised degree, Physics and Astrophysics, allows students to focus in this area. These students will take the Astrolab' module in the first year, and work with data from NASA missions and the LIGO detections of gravitational waves. Many modules related to our research are open to students across all the Physics courses, from introductory astronomy and cosmology courses to advanced astronomy and astrophysics modules, such as Relativistic Astrophysics or Asteroseismology and Exoplanets. In the third year, students work in teams on a major project, such as planning for an upcoming European Space Agency Mission to discover exoplanets and study stars or reconstructing the properties and formation channels of populations of black holes and neutron stars throughout the Universe using LIGO data. Students in the MSci programme can carry out a final year project on a cutting edge research theme supervised by one of our experts. They could be working on, for example, reconstructing the assembly history of our Galaxy or planning the first space based gravitational wave detector currently developed by the European Space Agency.

ASTROPHYSICS FOR POSTGRADUATES

In the Astrophysics and Space Research group, we are looking for PhD students to support the breadth of our research activities. We currently have over 20 PhD students focused on projects covering new instrumentation for the next generation gravitational-wave detectors, such as LIGO upgrades and the Einstein Telescope, observational astronomy and data-intensive astrostatistics – both with gravitational-wave observatories (such as LIGO and the future ESA mission LISA) and with new optical telescopes such as LSST – and theoretical astrophysics and general relativity. Students have the opportunity to work within our diverse group of experts in Birmingham and to join large international teams pursuing groundbreaking projects at the forefront of astronomy and new explorations of the Universe. In Solar and Stellar Physics, we offer PhD positions covering our range of expertise, from seismic studies of the Sun and other stars to exoplanets, and studies of the history and evolution of stellar populations within the Galaxy. Students benefit from working in a team with complementary expertise (observation, data analysis, astrostatistics, stellar modelling) to analyse and exploit large quantities and variety of space- and ground-based data, including using data from our own telescopes (the Birmingham Solar-Oscillations Network and one of the SPECULOOS telescopes searching for planets around low-mass stars) and work on future programmes like the ESA PLATO Mission.



COLD ATOMS

Understanding and controlling quantum light and matter.

When cooled to temperatures near absolute zero, atoms unveil their wave-like nature and quantum mechanical laws replace those of classical mechanics. By using finely controlled lasers and magnetic fields, we can cool small ensembles of atoms down to the lowest temperatures in the Universe – just a few billionths of a degree above absolute zero – and thus access the realm of fully quantum mechanical motion.

All the essential parameters of the atomic samples, including the density, the motion of atoms and the forces between them, can be precisely controlled, making these ideal systems for discovering new quantum behaviour and new states of matter. In the Cold Atoms group, we exploit these exceptional systems to study several quantum phenomena including superfluidity, cavity quantum electrodynamics, quantum thermodynamics and the creation of light with exotic properties not found in nature.

In addition to these fundamental physics explorations, there is an emerging demand for new quantum-enhanced technologies. We lead the national Quantum Technology Hub for Sensors and Metrology, which has the aim of utilising the exceptional properties of quantum matter to realise novel devices for real-world applications. These include ultra-precise atomic clocks and interferometers, and 'gravity cameras', which can unveil the underworld – from modern urban infrastructure to the buried secrets of Stonehenge.

EXPERIMENTAL CONDENSED MATTER

Understanding and manipulating quantum physics of materials from magnetism to superconductivity.

We are investigating a variety of new quantum states, or phases, of materials. Among them are the long-sought Quantum Spin Liquids where the electrons, acting as tiny magnets, remain strongly fluctuating, in a correlated manner, even at absolute zero temperature. This exotic quantum phase not only challenges our fundamental understanding of quantum matter on a macroscopic scale but also may be useful for building a quantum computer.

Matter usually changes its state or phase as the temperature is changed. However, the phase change can also take place at absolute zero temperature by changing other external parameters such as an electric or magnetic field, pressure or chemical substitution. Such a phase change is not driven by the thermal fluctuations but the quantum fluctuations of the Uncertainty Principle, and thus is called a Quantum Phase Transition. We are developing methodologies and carrying out experiments to understand these challenging phenomena, which will then allow us to design materials with novel properties and functionalities.

Superconductivity, a total suppression of electrical resistivity, is a representative macroscopic quantum phenomenon, which, after more than a hundred years since its discovery, continues to attract much theoretical and experimental research. Our group has made several important contributions to the field, especially since the 1987 discovery of high-temperature superconductivity, whose origin remains one of the biggest challenges in modern physics. Our research is strongly supported by international large-scale facilities in the UK, France, Germany and others. We perform x-ray and neutron scattering and muon spin relaxation measurements through these international collaborations.

METAMATERIALS

Manipulating light with artificial photonic structures and advancing the understanding of light-matter interaction on the nanoscale.

Our research focuses on the development of metamaterials whose electromagnetic or acoustic properties cannot be found in natural materials. Examples of such properties include a negative index of refraction, gigantic optical activities and topological photonics. These ‘unnatural’ properties enable us to turn into science fact technologies that were once the domain of science fiction: invisibility cloaks and super imaging lenses. The University of Birmingham was the first to make a macroscopic object – a paper clip – invisible.

We are also interested in nano-plasmonics, a subject focused on the interaction of light with metallic structures in the nanoscale, leading to strong optical field enhancement. This phenomenon is challenging to create naturally, but with the development of this new research area along with metamaterials, scientists have been able to realise this through the assembly of artificial atoms.

The construction of metamaterials and nanoplasmonic structures often involves the latest nanofabrication techniques. To this end, the group hosts the world’s highest-resolution commercial 3D printer – the Nanoscribe Photonic Professional – and collaborates with colleagues using top-down and bottom-up nanofabrication techniques such as electron beam lithography and molecular self-assembly, respectively.

NANOSCALE PHYSICS

Nanoscale physics investigates the physical properties of objects (nanoparticles) which are only slightly larger than the size of a few atoms. When objects are that small their physical characteristics, such as electrical and thermal conductivity, light emission, forces between nanoparticles, structural resistance, chemical activity and appearance of quantum behaviour, can be very different from those of bulk materials. We use a variety of the most advanced techniques to fabricate nanoscale materials and investigate their properties.

Our lab facilities include a broad range of microscopes which allow us to see individual atoms and their arrangements. Using scanning tunnelling and force microscopes we can see nanoscale objects and assess their electric and mechanical properties. While with Transmission Electron Microscopy we can investigate the arrangement of atoms with sub-atomic sensitivity. To access optical properties, our lab employs a wide range of the most advanced techniques, including ultra-fast optical measurements and thermal imaging.

To fabricate metallic nanoparticles, we use unique equipment that fuses together individual atoms ejected by bombardment from a metal target by energetic inert gas atoms. Alternatively, to produce semiconducting nanostructures, etching techniques are used to remove material from bulk with the precision of a few nanometres.

Nanoscale materials have a very wide use in medicine, the food industry, electronic and electro-optics. They can assist in promoting or inhibiting chemical reactions. Nanoparticles are helpful to enhance harvesting of light in solar cells and used for detection of extremely weak optical signals. The group has leading contribution in the fields of nano-tomography, development of applications using nano-porous silicon, investigations of nanoparticles catalytic properties and research of nanometre-sized structures on surfaces.

CONDENSED MATTER AND OPTICS THEORY

Developing our understanding of the behaviour of matter and light, underpinned by mathematical complexity and physical insight, from four-dimensional quantum systems to time crystals.

Electrons are quantum mechanical and repel each other. In a solid, they exhibit many different types of behaviour and transitions between different states. For example, when they become superconducting, they may experience a quantum ‘traffic jam’, or they may become magnetic. But there are also more exotic possibilities, such as phases where the electric current carries a charge in units of less than one electron charge. An understanding of such strange phenomena is essential to interpret the often confusing results emerging from experiments, enabling us to predict new kinds of behaviour or applications of them. Further, such insight helps us make connections with other areas of mathematics and physics, such as our work in quantum physics in four-dimensional space, realised in cold gases of atoms in three-dimensional space.

As recognised by the 2016 Physics Nobel Prize awarded for research carried out in Birmingham, the mathematics of topology is reshaping our understanding of physics. Over the past several years, this has led to fresh insights into how electrons move in crystals, sound in fluids, and polarised light in optical fibres. As theorists, our research spans different branches of physics, leading to new ways to create and explore exotic states of matter and light, such as our recent research in 'time crystals'.

QUANTUM MATTER FOR UNDERGRADUATES

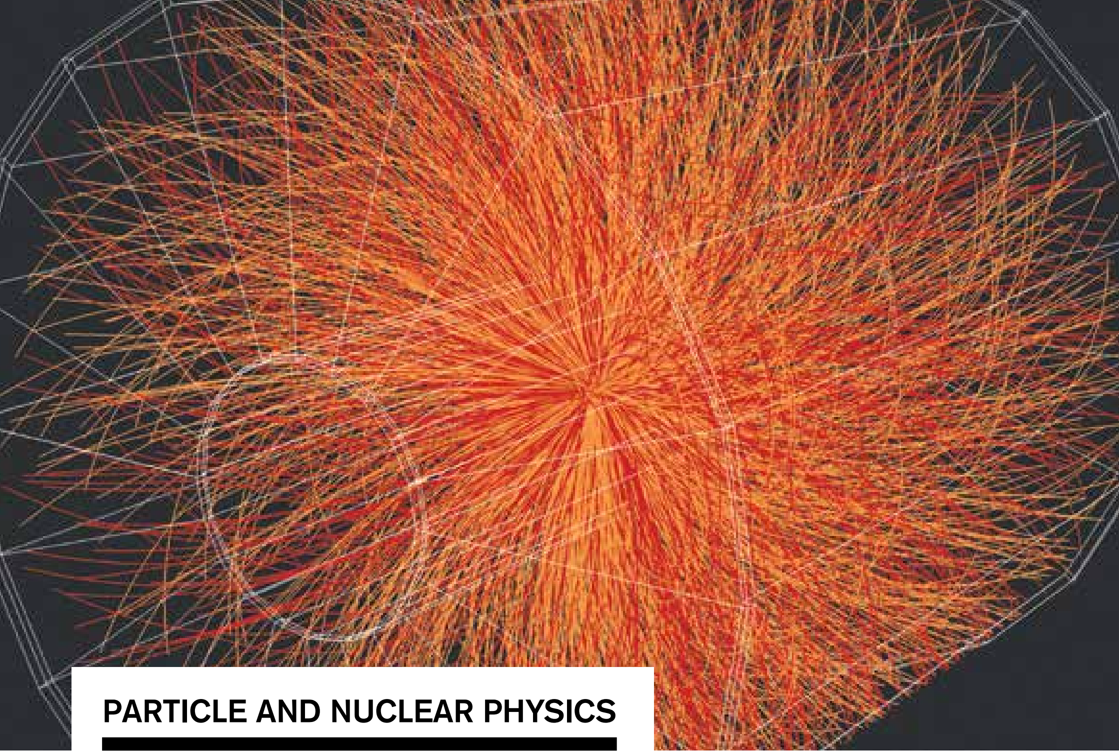
Researchers in Quantum Matter and Nanoscale groups teach modules throughout the undergraduate course and offer many modules related to our research. Importantly, the new knowledge that we create through research is integrated into our teaching. Additionally, members of the Theoretical Physics research group teach our specialised Mathematics for Physicists modules. Quantum mechanics is taught through all years and advanced topics are optional in later years. These include Ultracold Atoms and Quantum Gases, Quantum Optics, Many Particle and Quantum Field Theory, and Advanced Condensed Matter Physics.

In Year 3, students undertake a group project, allowing them to tackle a large Physics problem. We currently run projects related to atom interferometry and laser cooling. Year 4 projects allow those taking the MSci course to work with us on our current research. Recent topics have included: superfluid quantum gases, quantum imaging with nonclassical light, novel lasers and light-matter interactions, atom interferometry, topological metamaterials and the exploitation of THz radiation for spectroscopy and bioimaging applications.

We offer two undergraduate degrees focused on theoretical physics. Both the Single Honours and the Joint Honours with Applied Mathematics are challenging courses with a strong emphasis on mathematical content and training. The degrees are composed of three parts: mathematics, a physics core and illustrations of those ideas in physical applications such as quantum mechanics in nuclear or particle physics. Students on these courses take Current Topics in Theoretical Physics, in which they will delve into current research areas. These include quantum computing, Bose-Einstein condensates (macroscopic quantum states describing cold atoms and lasers) and anyons (topological ‘particles’, which only exist in 2D systems). Final-year theoretical physics research projects often follow on from these themes. Projects can involve collaborations with experimentalists or mathematicians. Recent examples include working on understanding new forms of superconductor, the mathematics of Clifford algebras and quantum chaos.

QUANTUM MATTER FOR POSTGRADUATES

There are currently over 30 PhD students working across a wide range of research topics within Quantum Matter at Birmingham, students often work in collaboration with other disciplines at Birmingham and with other universities worldwide. Some example research topics include theoretical physics students working on topological physics and strongly correlated condensed matter systems. Cold Atoms topics include fundamental physics with quantum gases and entangled beams of light, quantum sensors breaking new ground in medical physics, climate change, navigation, and communications. Metamaterials research covers theoretical quantum plasmonics, THz imaging for biological applications and understanding the structure and dynamics of a ternary liquid mixture. Research students from across all our Quantum Matter research groups contribute to the leading edge of research in quantum science, and former PhD students have found careers in academia, industry, government, education and consulting.



PARTICLE AND NUCLEAR PHYSICS

NUCLEAR PHYSICS

From physics research and techniques to industrial and medical imaging and nuclear power technology.

The research of the Nuclear Physics group explores the properties of the strong interaction that is responsible for binding quarks and gluons inside protons and neutrons, and for binding protons and neutrons into atomic nuclei. At the heart of every atom, the atomic nucleus is an incredibly dense, strongly interacting system with unusual properties. For example, we have discovered that some nuclei like to form clusters. Nuclear clustering is important for understanding how elements are formed inside stars. Remarkably, we would not be here at all if an excited carbon nucleus didn't sometimes condense into a clustered arrangement of three alpha particles. Other nuclei form even more exotic molecular-like cluster structures that share one or more valence nucleons.

The Nuclear Physics group also explores the quark and gluon structure of strongly interacting matter. The quark-gluon plasma is the high-temperature and high-density phase of nuclear matter, which would have existed until around ten microseconds after the Big Bang. We are leading members of the ALICE collaboration at CERN, which uses the Large Hadron Collider to study how protons and neutrons were formed from this primordial cosmic soup. We designed and built the electronic trigger system that determines when a nuclear collision has taken place and controls the readout of the detector. Each collision is a microcosm of the Universe and we create millions of them each year to study what matter was like before atomic nuclei first formed.

PARTICLE PHYSICS

Studying collisions in particle accelerators to determine the ultimate structure of matter and the forces of nature.

We are using particle accelerators at CERN to understand the most basic structure of matter and the forces of nature with the highest resolution ever achieved. Our recent activities have ranged from the discovery and characterisation of the mysterious Higgs boson that gives mass to all of the other fundamental particles to a world-leading programme of engagement with the general public and with schools. Our specialised laboratories build some of the charged particle detectors that sit at the very centre of the huge experiments at the LHC, as well as the specialised electronics that ensure the most interesting collisions are permanently recorded for analysis from among the full 1 billion that take place. Our distributed computing site performs LHC data analysis for physicists all over the world.

We have a central involvement in the ATLAS experiment at the Large Hadron Collider, where we are studying the Higgs and searching for other signs of new physics at the energy frontier. We are investigating the matter-antimatter asymmetry in the Universe using beauty quarks at the LHCb experiment. Our NA62 group is studying ultra-rare decays of particles containing strange quarks to search for new physics. We have fast-developing interests in studying the very weakly interacting neutrino particles using the DUNE experiment in the USA and in direct attempts to detect elusive Dark Matter particles that are known from astronomy to make up most of the matter in the Universe. We are also busy investigating future possibilities for electron-positron, electron-proton and proton-proton colliders.

PARTICLE AND NUCLEAR PHYSICS FOR UNDERGRADUATES

Group members teach particle physics and nuclear physics from introductory courses in Years 1 and 2 to advanced courses in Years 3 and 4. These include a theoretical module on Current Topics in Particle Physics and a more experimental course on Techniques used in Particle Physics experiments, as well as modules in medical imaging, nuclear physics, and fission and fusion.

Third-year students can take our nuclear group study project focused on medical imaging – based around imaging with a Compton camera – or a particle-oriented study on designing your own Large Hadron Collider. Fourth-year nuclear research projects give students the opportunity to perform cutting-edge research, including running experiments on the School's own particle accelerator, joining our researchers studying data on the quark-gluon plasma collected using the ALICE detector at CERN, studying the Higgs boson using ATLAS data or developing silicon tracking detectors for use in new collider experiments.

We offer a dedicated particle-focused degree course, Physics with Particle Physics and Cosmology. Students taking this course have priority access to all particle physics modules and projects, including the extended final-year project that makes up almost half of the year. They also receive personal tutorials from academics in the Particle Physics group and have the opportunity to visit CERN. Undergraduates that wish to specialise in Nuclear Science and Engineering exclusively can apply for our courses run jointly with the School of Metallurgy and Materials, Nuclear Science BSc or Nuclear Engineering MEng.

PARTICLE AND NUCLEAR PHYSICS FOR POSTGRADUATES

We run Masters courses on the Physics and Technology of Nuclear Reactors and Nuclear Decommissioning and Waste Management, which are highly respected by the civil nuclear industry and combine a summer research project placement together with lectures from industry leaders throughout the course. Both nuclear MSc programmes are often in part or fully sponsored by the industry in order to attract future talented individuals to the field.

The Nuclear Physics group has a vibrant and growing team, 16 current PhD students split over the topics of nuclear clustering, quark-gluon plasma, detectors for a future electron-ion collider, medical and industry applications and reactor research. Experiments are conducted at international laboratories around the world but also close to home, as members of the group lead the Birmingham Cyclotron Facility, the Positron Imaging Centre and the Birmingham Energy Institute. At the cyclotron, beams of ions are accelerated and used for both medical isotope production and research – including postgraduate and undergraduate projects – with research projects spanning from fundamental nuclear research with astrophysical importance to industrial applications in conjunction with leading industrial partners (eg, the National Physical Laboratory, and National Nuclear Laboratory).

Around half of the 50-strong Particle Physics group are PhD students. They play a full role in all of our activities, in particular being the driving force behind the data analysis that leads to publications by all of our experiments. We are always looking to recruit strong new students to work on ATLAS, LHCb and NA62 and also to work on basic R&D into new silicon detector concepts, both for use in particle physics detectors and for spin-offs into medical applications. With new activities building up in Dark Matter and neutrino physics, there are enormous current opportunities to spearhead our work as it evolves in new directions. Around half of our PhD students go on to work in jobs in particle physics, whilst the remainder go into a wide range of employment areas, ranging from teaching to computing to finance.

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