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Department of Physics

Newsletter

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THE FUTURE OF INERTIAL FUSION

This March, at a Hooke Discussion Meeting at The Royal Society, Peter Norreys, Professor of Inertial Fusion Science at Oxford University's Department of Physics, brought together nearly 100 leading fusion scientists from around the globe. They met to discuss the future of producing net electrical power from the nuclear reactions that take place inside igniting nuclear fuel at the extremes of compression, heat, and electromagnetic radiation. The goal of this initiative was an internationally endorsed roadmap that could assess the viability of a potentially 'transformative' technology.

Prof Peter Norreys

Prof Gianluca Gregori

Prof Justin Wark

The motivation and objectives for this international collaboration arose from an Enabling Research grant from EUROFusion, part of EURATOM, awarded in January 2019 to Professor Norreys. The funding supports preparations for experiments on the PETAL/LMJ facility in Bordeaux, France, and focuses on advancing inertial fusion energy science and engineering using high-power laser facilities across the European Union. The project's consortium comprises fifteen laboratories in nine nations, including the United Kingdom.

COULD INERTIAL FUSION MAKE AN IMPACT IN EFFORTS TO COMBAT CLIMATE CHANGE?

For many years, fusion energy has been described as the holy grail of the world's energy problems – a limitless and clean energy source that would address the ever-increasing demands, free from carbon emissions. This is an aspiration that has stimulated the minds of great scientists, but the path towards an economically viable fusion power plant is an arduous one.

Inertial fusion energy (IFE) requires the thousand-fold compression of matter to ultra-high densities and temperatures to mimic the compressional effect of gravity in the sun, nature's very effective nuclear fusion reactor. By irradiating and imploding a small spherical shell containing isotopes of hydrogen (deuterium and tritium) in the laboratory (either directly using intense laser beams or by first converting the laser energy into soft X-rays) the fuel's own inertia, eg the tendency of matter to resist sudden acceleration, permits a sufficient fraction of the isotope pairs to fuse into a helium nucleus. This process takes place during compression and stagnation before the fuel eventually expands from the increasingly high pressure. While two hydrogen nuclei are sufficiently close, even for this short duration, the strong but short-range nuclear force dominates over the tendency of 'like charges' to repel, inherent to the hydrogen pair's positive electric charge, that dominates when separation exceeds the nuclear force's range.

During each fusion event, a sudden and intense release of energy occurs because the rest mass of the fusion products (a helium nucleus and a free neutron) is less than the combined masses of the deuterium and tritium ions. (Remember that energy equals mass multiplied by the square of the speed of light, ie $E=mc^2$.) If these fusion reactions occur at a sufficient rate, then more energy is generated than is expended to drive the compression in the first place. This heat, if captured in a surrounding blanket, as in a conventional power plant, can drive a steam turbine that generates electric power.

However, the reality is that controlled thermonuclear fusion has not yet been proven. Indeed, the idea of laser-driven fusion was first put forward by John Nuckolls in 1972, close to half a century ago, and despite enormous progress over that time, getting more energy out of a target from fusion than is put in by the laser to create the reaction in the first place has still not yet been demonstrated. As such, IFE is not, as of today, a realistic replacement solution to the world's greenhouse-gas problems. Nevertheless, significant enthusiasm for the pursuit of IFE remains because the scientific and technological progress in exploratory inertial confinement fusion research has been impressive relative to its modest government-provided research budget, especially in areas related to the assembly and understanding of the high-energy-density conditions in the compressed fuel, as well as in the enabling technologies required for inertial fusion energy applications. These technologies include high-repetition-rate lasers, heavy-ion beam drivers, pulsed-power magnetic-compression generators, and high-reproducibility cryogenic-target 'assembly and qualification'. We believe that the work done by hundreds of scientists in this field has brought us closer to the point where controlled fusion reactions can be attained in a repeatable manner, although still not at the repetition rate and cost that would be necessary for a reactor. For example, the international facility closest to achieving 'breakeven' is the National Ignition Facility (NIF) – a giant laser at Lawrence Livermore Laboratory in California, that holds the record for the largest number of neutrons produced in a single laser-driven fusion event (2×10^{16}). To put this in the context of IFE, this vast number of neutrons has an energy of only a few percent of the close to 2MJ laser pulse that created the reaction that produced them. Furthermore, the NIF can only fire shots to achieve such fusion reactions about twice a day – for a power plant this would need to happen ten times per second. In addition, the fusion targets are exquisite pieces of technical engineering, costing many thousands of dollars apiece: an IFE power plant would require every shot to cost only a few US cents to be commercially viable.

Whilst the NIF has yet to achieve 'ignition', and net energy gain, the results coming from the facility are still hugely impressive. Firstly, it can be shown that to create those 2×10^{16} neutrons, a process known as 'alpha burn' must be taking place – that is to say the alpha particles produced by fusion are themselves starting to heat up surrounding colder deuterium and tritium nuclei, causing them in turn to fuse. It is as though the target is starting to 'fizz', or 'glow', but not yet fully ignite.

> The project's consortium comprises fifteen laboratories in nine nations, including the United Kingdom

> INDUSTRIAL SPIN-OFFS OFTEN ACCOMPANY TECHNOLOGICAL ADVANCES, AND FUSION BREAK-THROUGHS ARE NO DIFFERENT

A further reason for excitement is the sheer neutron flux itself, and the applications that the result brings. These huge numbers of neutrons are produced from a tiny compressed core about 100 microns in diameter, and the fusion reaction is over in about 100 picoseconds. As such, the neutron flux emanating from the core at the time of implosion (neutrons per second per unit area) is not very far off that which exists when a supernova explodes! There are thus already a wealth of ground-breaking scientific discoveries, ranging from stellar astrophysics to quantum electrodynamics, that can be unleashed by studying physics related to the pursuit of IFE, even before (or if) it is realised as an eventual goal. That is to say, we can undertake extremely exciting fundamental research whilst at the same time furthering our understanding of what a potential fusion power plant may look like.

The latter, however, still remains a very challenging task, with many hurdles yet to overcome. In addition, honest assessments are needed to ascertain whether any potential technologies could impact on the timescales relevant to the current pressing climate issues, or whether they might instead form part of a second wave of clean energy technologies. The research we are currently undertaking will soon be able to address this question.

TO RELEASE ENERGY, FUSION *COMBINES* TWO NUCLEI; FISSION *SPLITS* A NUCLEUS

All approaches to nuclear fusion must satisfy a criterion, memorised by fusion scientists, which states that the product of the density, temperature and confinement time of the fusion fuel must exceed a certain threshold value for the energy gain to be positive instead of negative. To maintain the fuel's required ultra-high temperature, all fusion devices must prevent the fusion fuel from coming into thermal contact with the surrounding reactor vessel.

To reach the fuel's required ultra-high density and temperatures, all fusion devices must inject energy into the fuel. Magnetic confinement fusion uses strong confining magnetic fields over ultra-long time-scales at intermediate energy density. This research is now underway at the Culham Centre for Fusion Energy with experiments at the Joint European Torus (JET), the spherical tokamak MAST and StEP programmes at Culham and the International Thermonuclear Experimental Reactor (ITER) in France. Research underway at the Lawrence Livermore National Laboratory in the USA (as mentioned above), and the Laser MegaJoule facility in France (figure 1) uses inertial confinement over ultra-short time-scales at high energy density.

In the inertial fusion approach, the energy is injected by suddenly impacting a fuel capsule with a fusion burn-wave that propagates through the fuel. The burn-wave converts the kinetic energy of the imploding fuel capsule into the fuel's thermal energy by the time the wave reaches stagnation at the capsule centre. Commercialising inertial fusion energy requires repeated injection of fusion pellets and the deployment of high-repetition (5–10 repetitions per second) burn-wave drivers.

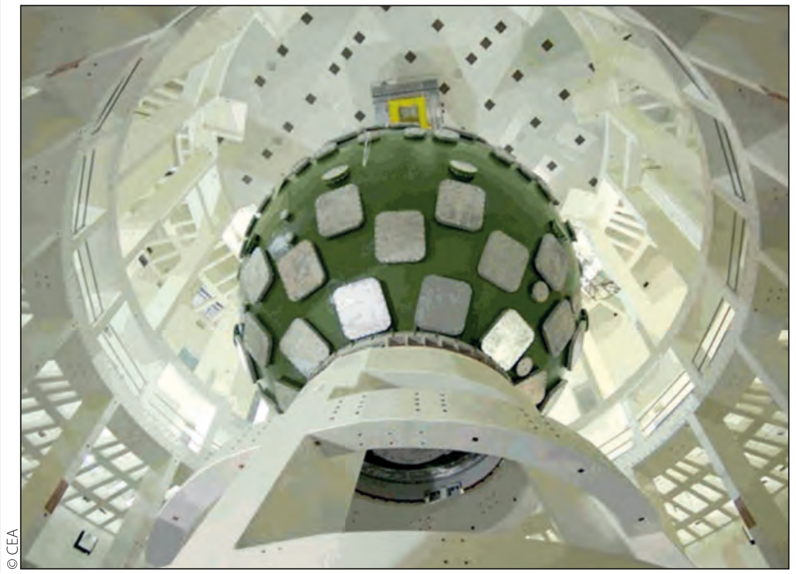

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Figure 1. The 10 m diameter target chamber installed in the laser bay of the Laser MegaJoule facility, Bordeaux, France. The target chamber weighs about 140 tons. It has a 10 cm thick aluminium wall and is covered by a 40 cm thick layer of boronated concrete to ensure the radiological safety of scientists and engineers.

WELL-TIMED TECHNOLOGICAL ASPIRATION

If achievable, the realisation of IFE could be transformative for humankind because it allows us to envisage strategies for minimising the human causes of climate change. There are no long-lived radioactive by-products if the reactor chamber materials are carefully selected. An inertial fusion energy reactor must be compatible with the existing electricity infrastructure distribution and generation grid. The process is inherently safe from nuclear meltdown, each nation can have security of abundant long-lasting fuel supply, and helium-exhaust emission is friendly to the environment.

Industrial spin-offs often accompany technological advances, and fusion breakthroughs are no different. For example, investment in the laser-related photonics industry will generate many new spin-offs and highly skilled jobs. The Institute of Physics (IoP) estimates that the photonics industry in the UK contributes £13B annually to the economy. The IoP has recently pointed out that the industry's status as an enabling technology for multiple uses across numerous sectors means that it still lacks a singular champion of the importance of photonics. The IoP's recent report (https://beta.iop.org/health-photonics) by the photonics community has appeared online. It provides a powerful insight into the forthcoming photonics revolution. In the longer term, the UK government is committed to significantly increased spending on research and development, as outlined in the 11 March 2020 budget. Light-based technologies will be crucial in tackling the challenges laid out in the nation's industrial strategy.

In addition, inertial fusion-related research promises further significant improvements in thermal neutron source brightness, even beyond those expected from the European

SCIENCE NEWS
www.physics.ox.ac.uk/research

Spallation Source (ESS) when it is fully commissioned in 2025 (https://science.sciencemag.org/content/315/5815/1092.full). Thermal neutron scattering has found applications across the natural sciences, from condensed matter physics through to biochemistry and the life sciences. Increased source brightness provides greater signal to noise and therefore more precise diffraction patterns to determine the structure of the new materials under study.

ENVISIONING THIS ACHIEVEMENT

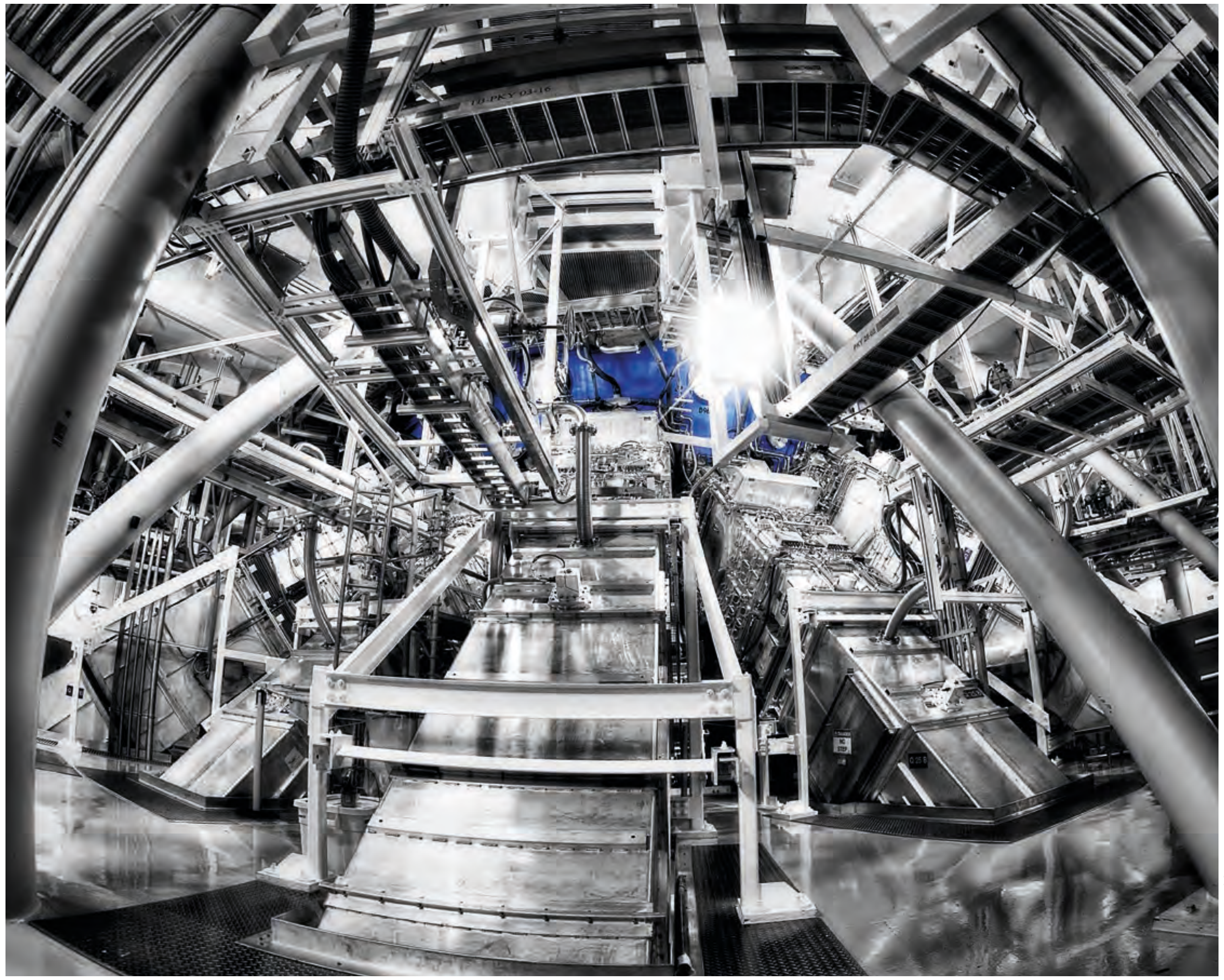
Originally, inertial confinement fusion arose out of the nuclear stockpile stewardship programmes in the US and UK. The concept rests upon the results of classified experiments performed under the limited UK test programme and the US Halite-Centurion programme, as well as the data that has been obtained from the National Ignition Facility (Figure 2).

So while it is true that sustained net-energy gain has not yet been achieved, we would argue that sufficient progress has been made in understanding laser-driven burning plasmas to advance an energy development programme involving a next-generation facility, especially because the fundamental science, in terms of nuclear physics and laboratory astrophysics, that is associated with achieving fusion is a worthy goal in its own right, and such research would be undertaken side by side with that into fusion itself.

As many are aware, the threats facing humankind from climate change are urgent, and specific milestones have been outlined by the UN for countries to achieve within the next 10 to 30 years. It may well be that IFE is not yet well-developed enough to ever be in the first wave of technologies to have an impact on those relative short terms, but however the future pans out, the overall goal of a clean, safe, and abundant source of nuclear energy will remain. We thus believe that such a facility should aim for net energy gain, termed 'proof of principle' or 'physics break-even', or even move towards higher gain, known as 'engineering break-even'.

The Enabling Research grant from the EUROFusion project is enabling increased co-operation and co-ordination of Inertial Fusion Energy development activities. If the UK government were to embark on a concerted international effort and were to form a European Fusion Centre alongside the US and Asia, then we could realise this dream synergistically and expediently. We in Oxford Physics are taking the lead in coordinating the European effort and, in doing so, are doing our bit not only for physics of a fundamental nature, but also for assessing the possibility of fusion-based clean energy.

Below: Figure 2. NIF Target Bay. This dramatic image of NIF beamlines entering the lower hemisphere of the NIF Target Chamber, as seen from the ground floor of the Target Bay, was taken by NIF photographer Damien Jemison. Five exposures were taken to capture the range of light in the dimly lit Target Bay. Jemison used the high dynamic range (HDR) Efex Pro program to process the five images into a single photo of one of the most spectacular views in the facility.



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THE FIRST DEMONSTRATION OF IONISATION COOLING

A small step towards a muon collider and neutrino factory

Prof Emeritus John Cobb

Many discoveries in particle physics have been made with beams of accelerated particles, most recently the Higgs boson at the CERN LHC using colliding beams of high energy protons. Future advances are expected to come from accelerators operating at either 'the intensity frontier' – to search for rare processes – or at the 'energy frontier' – to probe deeply into the structure of matter. The technology for accelerating and storing beams of protons and electrons is mature. There are, however, a number of advantages in being able to accelerate and store high quality beams of *muons*.

WHY ACCELERATE MUONS?

In a circular accelerator particles are bent by magnetic fields and lose energy by synchrotron radiation at a rate proportional to $(E/m)^4$. The power required to replace these losses limits the energy achievable with electron synchrotrons. (Synchrotron radiation is the *object* of machines such as the STFC's Diamond Light Source.) Future electron accelerators would either be linear accelerators or synchrotrons with radii of hundreds of km. Because protons are two thousand times heavier than electrons, proton accelerators do not suffer from synchrotron radiation losses. However, unlike electrons, which are point-like, protons are composite and it is really the interactions between the quarks and gluons which are studied at proton colliders. Each constituent carries only a fraction of the proton's momentum and a significant fraction of the proton energy is wasted.

Muons are two hundred times heavier than electrons and a muon accelerator would not suffer from synchrotron radiation losses. Their point-like nature means that in a muon collider their entire energy would be available for physics. A further advantage is that because of their greater mass, muons couple much more strongly to the Higgs than electrons; muon colliders have been proposed as 'Higgs Factories'.

The sensitivity of current and proposed neutrino oscillation experiments (eg DUNE) using conventional muon neutrino beams is limited by the systematic uncertainties of neutrino production. Muons decay to an electron, a muon antineutrino and an electron neutrino. Muons stored in a race-track ring would emit beams of both these flavours of neutrinos. In contrast to conventional neutrino beams, the energy spectra and intensities of these neutrino beams would be very well understood and allow precision studies of neutrino oscillations. Oppositely charged muons would decay to the charge-conjugate neutrinos, allowing precision studies of CP or T violation by neutrinos. The concept of deriving high quality neutrino beams from stored muons has been dubbed a 'Neutrino Factory'.

WHY IS 'COOLING' NECESSARY, AND WHAT IS IT?

In a muon collider (or neutrino factory), muons must be produced, accelerated and stored. Each step is a new technical challenge. The muons would be produced by an intense proton beam striking a target to produce pions, which are then allowed to decay to muons. Because of this tertiary mechanism, the resulting muon beam would be wide and divergent, and could barely be called a beam; it must be conditioned before further acceleration. The essential first step is to 'cool' it.

The particles in any beam moving through a magnetic transport system oscillate in the transverse dimensions. The 'amplitude' of these oscillations is the area of the ellipse that a particle traces in phase-space (position-momentum space). High-amplitude particles have high transverse momenta or are far from the axis. Although the magnetic elements used to transport beams transform position to angle and vice-versa (like optical lenses) amplitude is a conserved quantity.

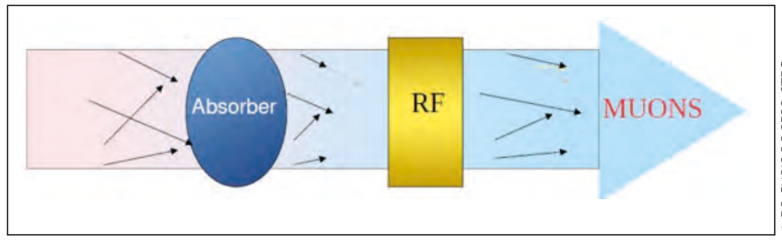
The mean amplitude of the particles in a beam is termed its 'emittance' and is (roughly) the product of the beam's *root mean square* (*rms*) size and its *rms* divergence. Liouville's theorem ('phase-space is incompressible') asserts that emittance is constant if there are no dissipative processes. 'Cooling' a beam means reducing its emittance by reducing the amplitude of the transverse oscillations of the particles; the amplitude distribution will shift to lower amplitudes and the particle density at the core of the beam will increase. Despite Liouville's theorem, beams *can* be cooled.

Stochastic cooling was developed for anti-proton beams at the CERN SPS; electron cooling, where heavy particles transfer energy to a co-moving electron beam, is used to cool beams of ions or antiprotons. These schemes are, however, far too slow to cool beams of muons whose proper lifetime is only two microseconds.

IONISATION COOLING

Ionisation cooling is a way to cool muon beams. It is fast and simple in concept: the beam traverses some material – an 'absorber' – where muons lose longitudinal and transverse momentum by ionisation. The muons are then re-accelerated longitudinally and the net divergence of the beam, and hence its emittance, are reduced (figure 1).

Figure 1. The principle of ionisation cooling: a muon loses longitudinal and transverse momentum in an absorber; the longitudinal momentum is replaced by acceleration in an RF cavity.



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(This would not happen once but in a series of absorbers interleaved with accelerating radio-frequency cavities in a channel perhaps a few hundred metres long.) The physics underlying ionisation cooling is well understood but there are considerable technical challenges to be met.

THE CHALLENGES

A charged particle passing through matter not only loses energy but is also scattered through random angles due to many collisions with nuclei. This multiple Coulomb scattering will increase the emittance of a beam. Energy loss arises from incoherent collisions with atomic electrons at a rate proportional to Z, the atomic number of the material; scattering by the nucleus is coherent and proportional to Z^2. There is therefore competition between cooling by energy loss and heating by multiple scattering. The implication is that only low Z materials, primarily liquid hydrogen or lithium hydride, are useful as absorbers. Even so, the beam must be focused tightly onto the absorber so that it has a large divergence and the heating by scattering is minimised.

Conventional quadrupole magnets are too weak to focus a beam tightly enough. Instead, cooling channel designs use periodic lattices of superconducting solenoids with axial magnetic fields of a few Tesla. Because the muon beam is initially large, the solenoids must have a large bore, and there are potentially large forces between coils. This places unusual constraints on the construction of the cryostats and cold-mass suspensions of the coils. The absorbers must be embedded inside the magnets to achieve a tight focus, presenting challenges of mechanical integration. If liquid hydrogen is used as an absorber, the windows of its container must be as thin as possible to reduce reheating the beam. There are also obvious safety concerns with liquid hydrogen or lithium hydride.

THE MICE COOLING DEMONSTRATION

The Muon Ionisation Cooling Experiment (MICE) experiment was conceived both to address these technical challenges and to demonstrate that ionisation cooling works as expected. It was carried out at the Rutherford Appleton Laboratory by the MICE international collaboration of over a hundred physicists and engineers (rather small by current particle standards). A new beam from the ISIS proton synchrotron delivered muons with momenta between 135 and 240 MeV/c, typical of a muon collider front-end, to the apparatus.

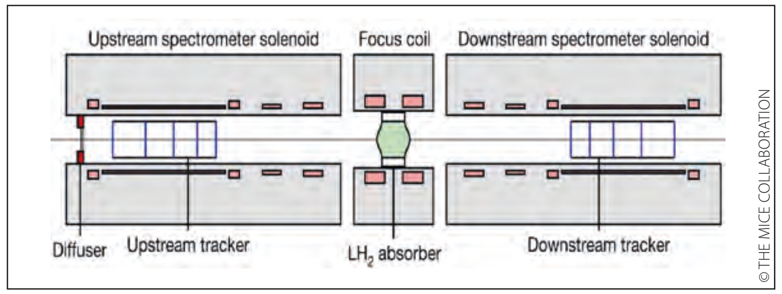


Figure 2. The layout of the MICE experiment. Muons enter from the left and their phase-space coordinates are measured by the upstream spectrometer. They are then focused onto a liquid hydrogen (or lithium hydride) absorber and their new phase-space coordinates measured by the downstream spectrometer.

The layout of MICE is shown in figure 2. The business part consisted of a module (figure 3) containing a pair of superconducting ('focus') coils to focus the beam onto an absorber. For the strongest focus the coils were operated with opposite polarities; the peak field in each was about 3.5 Tesla but zero at the centre of the absorber. The repulsive force between the two coils was approximately 250 tonnes. Two absorbers, a 65 mm disc of lithium hydride or a 35 cm long aluminium vessel containing 22 litres of liquid hydrogen, were used; the aluminium entrance and exit windows of the hydrogen vessel were machined from 50 mm thick discs and were only 160 microns thick at the centre.

Normally emittance is estimated by measuring the size and divergence of a beam as a whole. By contrast, MICE used particle physics instrumentation to measure the position and momentum of *each* muon. Crucially, this allowed the amplitude distributions of muons to be reconstructed.

The phase-space coordinates (x, p) of muons before and after the absorber were measured with magnetic spectrometers. Each spectrometer module contained three superconducting coils to give a uniform field for momentum measurement, and two to match the beam to the focus coils. Scintillating fibre trackers inside the uniform field region recorded the spatial coordinates of each muon. Ancillary instrumentation up- and downstream provided particle identification. A variable thickness brass and tungsten diffuser was used to scatter muons and vary the emittance of the incoming beam. The three modules were partially enclosed with 15 cm of iron for magnetic shielding. Data were recorded with beams of several momenta, a range of magnet settings, the two different absorbers, and – vitally – without any absorber.

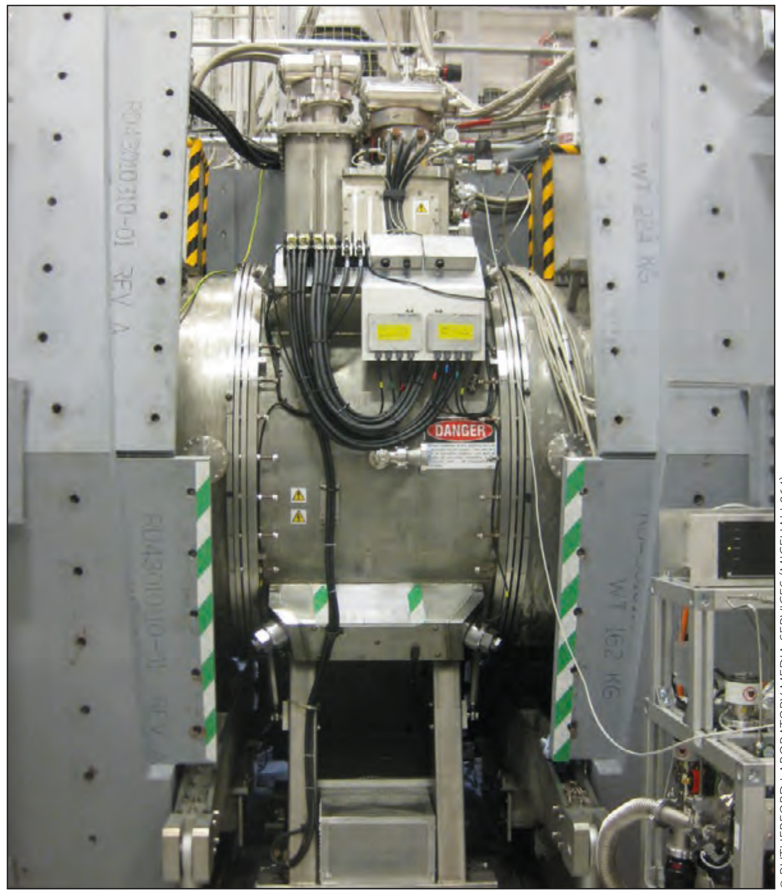


Figure 3. The focus coil module which contains a pair of split-field superconducting coils and the absorber. A section of the iron magnetic shielding has been removed.

COOLING OBSERVED

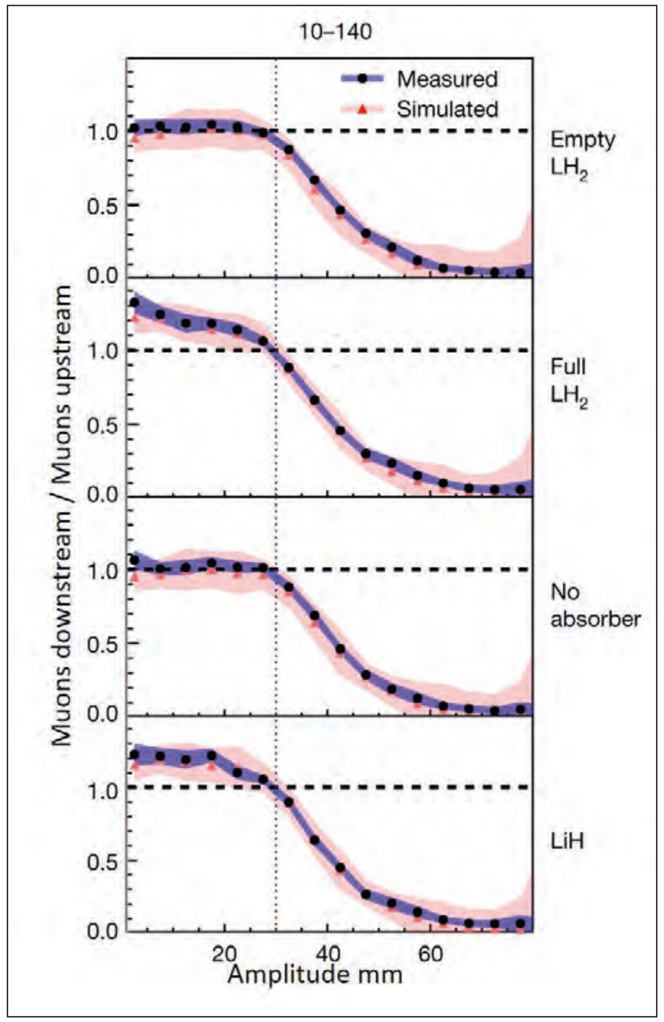
The distributions of single-muon amplitudes before and after the absorber were reconstructed off-line. Figure 4 shows the ratio of the downstream to upstream amplitude distributions for one beam setting with and without the two different absorbers. It is clear from a comparison of the 'with' and 'without absorber' distributions that the core (low amplitude) density of the beam had increased after it passed through an absorber. As discussed above, the increase in muon density at low amplitudes is demonstrative of cooling. The results agree well with the predictions of simulations, which are also shown in figure 4. (The decrease of the ratio at amplitudes above 30 mm is due to scraping of the beam tails and does not alter the conclusion.)

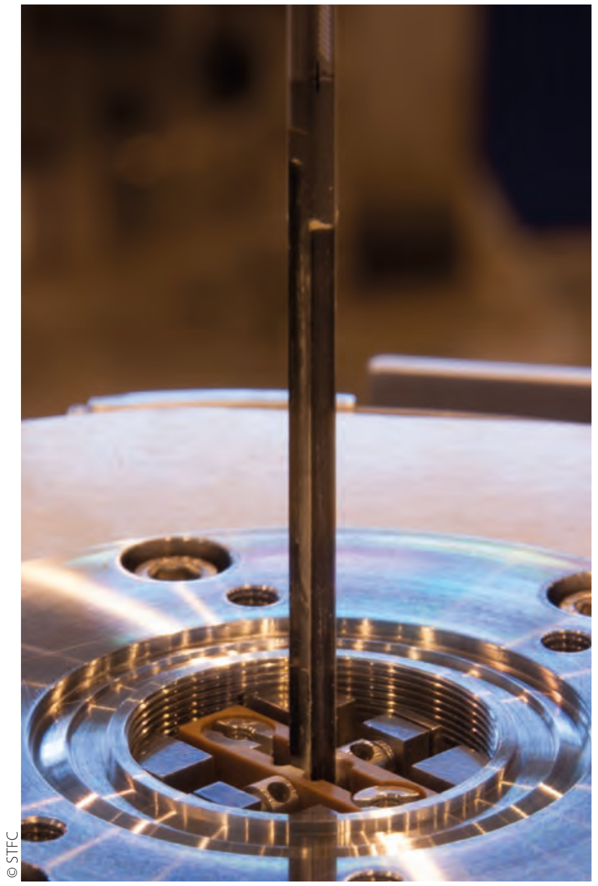
The reader will have noticed that MICE did not include an RF cavity. Re-acceleration is not essential for a demonstration of cooling because the quantities of interest are amplitude and emittance normalised to beam momentum. Suitable RF cavities have been developed at Fermilab.

The MICE results are not only an unambiguous demonstration that ionisation cooling works, but also that a large system of coupled solenoids with an embedded liquid hydrogen absorber can be operated – and are a first small step towards the development of a muon collider.

Space does not permit a full description of the Oxford group's role but this covered many aspects of the experiment, from the design of the focus coils and aluminium absorber windows, to new physics models of energy loss and multiple scattering. The latter neatly completed a nearly fifty year circle for the author whose DPhil thesis was (partly) on ionisation energy loss!

Reference: https://www.nature.com/articles/s41586-020-1958-9





Above: Figure 4. Ratios of the downstream to upstream amplitude (normalised to $p/mc = 1$) distributions for the same beam with and without the liquid hydrogen or lithium hydride absorbers. The enhancement at low amplitudes when an absorber is present is a clear demonstration of cooling.

Far left: MICE target during development testing.

Left: The target used to generate MUONS.

COVID-19:
PHYSICS IN THE REAL WORLD

'Without physics and physicists there could be no modern technological society, from microelectronics and telecommunications, to LCD displays and PET scanners in hospitals; it is therefore not surprising that physics has much to offer in the battle against CoV-2. Along with my colleagues, I am incredibly proud of the combined efforts of our department and our alumni as we contribute to overcoming the global challenges we face from COVID-19.'
— Professor Ian Shipsey, Head of Department

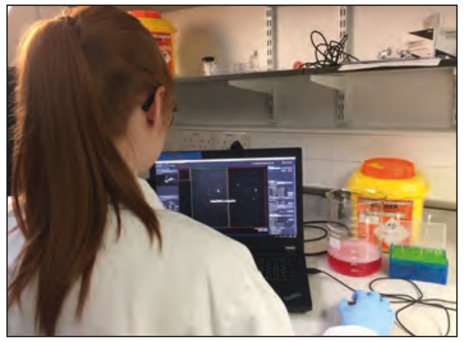
Oxford's Department of Physics is part of the global effort to defeat the COVID-19-causing virus. Scientists around the world are racing to understand more about the virus – and physicists at Oxford are no exception. Here are just some of the ways the Department of Physics is contributing to the global effort to control and tackle the coronavirus outbreak.

Specialist expertise

Our specialist mechanical engineering and electronic engineering workshops have offered their services – from supporting production to collaborating with the Nuffield Department of Surgical Sciences to develop and build medical instruments to help with the treatment of COVID-19.

Nurturing partnerships

Thanks to the Department of Physics' collaboration with ShanghaiTech University, the Chinese institution has donated 13,000 surgical masks, 700 medical full body suits and 800 N95 masks primarily to Oxford University hospitals but also for use in university departments and colleges. The gift comes at a critical time when supplies are limited.



Essential research

A group of researchers led by the Department of Physics is working on a new method that would allow extremely rapid detection of the virus that causes COVID-19 – in as little as one minute. Led by Dr Nicole Robb and Professor Achillefs Kapanidis, the group's work to detect infectious diseases caused by viruses was already underway and efforts have intensified to apply the research to the current pandemic. Using influenza as a model virus, the Oxford group showed that virus particles in clinical samples can be labelled and detected in as little as one minute, substantially faster than existing diagnostic tests. The method is general and is currently being further developed for use on SARS-CoV-2, the virus that causes COVID-19.

www.physics.ox.ac.uk/news/2020/03/26/measure-and-control-covid-19-rapid-detection

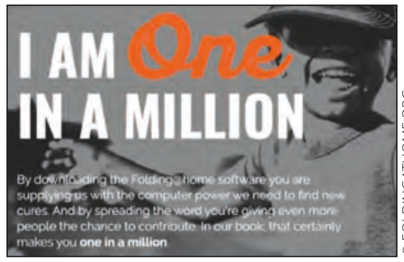
Eminent alumni

Neil Ferguson, the epidemiologist from Imperial College London whose advice we are all relying on at the moment is an Oxford undergraduate and postgraduate alumnus. He studied physics at Oxford and went on to start his research career by doing his DPhil in quantum theory of gravity before specialising in mathematical biology.

Alumnus Alfonso Castrejon-Pita studied for his DPhil within the Atmospheric, Oceanic and Planetary Physics sub-department at Oxford before taking up a research post with us. Today, as a professor in engineering science, he is part of an initiative between the University of Oxford and King's College London to develop a simple and rapidly deployable ventilator that can be manufactured easily and quickly by industry.

Alumnus Mike Fischer CBE has launched the COVID-19 Volunteer Testing Network and is working to recruit laboratories across the country to get behind the initiative. Using equipment commonly found in laboratories like the polymerase chain reaction (PCR) machine, he is confident that the UK's testing capacity can be greatly increased and has donated £1 million of his own money to the project. Mike Fischer is Director of Systems Biology Laboratory, a not-for-profit medical research laboratory in Oxfordshire.

Computing power



The Department of Physics is volunteering its computer power to help fight the COVID-19 virus through the Folding@home project. We have allocated a significant proportion of our GridPP computing cluster – the resources used to analyse data from the Large Hadron Collider at CERN – to run Folding@home's enormous simulations to model the COVID-19-causing virus. We are also running Folding@home on the personal computers in the department as colleagues work from home. The more computers it has to help, the more simulations can be run – which increases our chances of finding ways to successfully tackle the virus.

https://foldingathome.org/covid19/

INNOVATION – THE NEXT GENERATION

Dr Phillip Tait, Innovation and Enterprise Manager

Oxford Physics is increasing its support for undergraduate and postgraduate students who wish to explore how they can use their physics learning and problem solving skills to tackle challenges that lie beyond the university. Whilst our students are studying physics they do so in a world struggling to find solutions to issues that face us all, from climate change to internet security or affordable healthcare. A growing number of our current and recently graduated students are now looking to see how they can make a difference, often by teaming up with fellow students from other sciences, as well as the humanities and seeking out opportunities to develop the knowledge and skills needed to turn ideas into inventions and eventually into real world impact. This article highlights just a few of those people and how the university and department is now recognising and responding to the growing ambition amongst our students to bring physics and enterprise together.

BUILDING FOR THE FUTURE

Two years ago, the university opened the Oxford Foundry for the benefit of all students and alumni, a new facility with a mission to build a new generation of ventures that better society and to nurture more ethical leaders who put people and the planet first. Situated in a refurbished building on Hythe Bridge Street, near the train station, it was developed by the Saïd Business School with the aim of inspiring and supporting Oxford's 24,000 students as well as alumni and includes co-working spaces, event and workshop areas and a café.

To support startups (newly created companies that don't use university-owned Intellectual Property (IP), ie most student and alumni ventures), the Foundry created OXFO L.E.V8 (Elevate), which provides select startups with working space and support to accelerate their growth and with no charge or handover of IP. So far, 33 ventures have been supported, raising £11m of investment. Amongst these are startups led by former physics DPhil students. Dr Irwin Zaid (Theoretical Physics) and Dr Oliver Harriman (Condensed Matter Physics) are now co-founders of See Through Scientific, which is working on a new method for sampling tumours of cancer patients to aid genomic analyses for personalised medicine. Dr Ian Preston and Dr Christopher Boddy (both Particle Physics), are co-founders of Peergos, a privacy-focused online platform for people and companies to store, share and communicate data and content. The Foundry is also supporting former MPhys students on their entrepreneurial journeys, including Dr Claire Timlin, co-founder of Ufonia, a company which is applying artificial intelligence technologies for autonomous speech-based monitoring of health and Dr Jack Weston, co-founder of Novoic, a digital biotech company analysing speech to detect early signs of brain disease.

We are excited to see our former students tackling such important and varied challenges and wish their new companies the best of luck.

AWARD-WINNING STUDENTS

One of our current DPhil students has made the most of the co-creation opportunities provided by the Foundry. Anna Jungbluth (Condensed Matter Physics) is researching organic solar cells under the supervision of Prof Moritz Riede and has also worked on a number of award winning innovation projects through the Foundry's annual Artificial Intelligence (AI) Impact competitions. These involve students forming inter-disciplinary teams and learning how to build innovative, financially viable and ethically responsible AI-based solutions to address that year's theme. In 2018, Anna's team took home the top prize for using AI to teach children to identify and understand fake news. In 2019, students looked for AI solutions to enable fairer recruitment processes, with Anna and fellow physics students Sophia Sosnina and Miha Zgubic winning prizes for their team's solutions. This year the theme was tackling climate change and once again teams containing Anna and also fellow physics student Siobhan Tobin were amongst the winners.

> As a generation, millennials desire to be more socially responsible, innovative and to make an impact. Whether starting their own ventures or aspiring to lead in organisations, the Oxford Foundry will develop students' entrepreneurial skills, understanding and self-efficacy.
>
> *— Ana Bakshi, Director of the Oxford Foundry*

© RICHARD CAVE

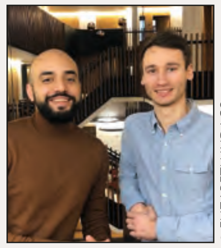
Left: The Foundry is open from 8am until 10pm Monday to Sunday for the benefit of all students and alumni of the university. Located on Hythe Bridge Street, in a building that was once the Oxford Ice Factory, the Foundry is spacious, easily accessible and has facilities for co-working, workshops, events and more.

PHYSICIST OR ENTREPRENEUR – WHY NOT BOTH?

Last summer, students from across the University were invited to join a new entrepreneurship programme: the Student Entrepreneurs Programme (StEP). Run by Oxford University Innovation (OUI) in partnership with Oxford Science Innovation (OSI), an early-stage investment firm that has raised more than £600m to invest in Oxford University spin-outs, and the Oxford Foundry, the programme admitted students from any department and taught them the skills required to turn an idea into a business. DPhil students in Atomic and Laser Physics, Marko Mayr and Dr Ramy Aboushelbaya (now a postdoc here) took up the challenge after reading about the initiative. 'Neither of us had done anything like it before, however it seemed like a great opportunity – to learn really useful and transferrable skills for future endeavours,' comments Marko. 'The programme runs for four weeks over the summer and we were given intensive training as well as access to a mentor. One thing that really helped was the fact that our DPhil supervisor, Prof Peter Norreys, encouraged us in the initiative and was supportive throughout.' Marko and Ramy formed a six-strong team with students from the departments of Materials, Chemistry and Mathematical Sciences and were able to choose from a range of real university intellectual property proposed by OUI. They chose a technology invented right here in the Department of Physics a few years earlier – a quantum random number generator. The challenge? To turn the IP into an investable business case – to bring it to life and try to create a spinout company. 'Our challenge was to think about what application this quantum random number generator might have beyond academic research,' continues Marko. 'We thought about what problems it could solve and who might want to use it. In doing so, we formed a business plan that considered possible interest in the cybersecurity industry. We had to pitch our plan, Dragon's Den-style to a panel of investors from OSI – and we won.' The team was awarded financial and entrepreneurship support to turn their plan into a real spin-out company. Thus, Quantum Dice entered the university's incubator at OUI with Marko and Ramy taking up senior roles that are shaping the future company – while continuing their research in the department. 'It was a really enriching experience – I think particularly for people from our discipline. It was such an interesting process to work out a viable application for the research, learn to translate that into a business plan and then articulate it in the right way to "sell" it to others. The skills we gained would prove useful to someone continuing to pursue research as much as to those wanting to pursue a career in industry.'

The OUI incubator has also supported physics alumna Dr Cici Muldoon (Atomic and Laser Physics) with her startup company VeriVin, which is developing and producing a unique through-barrier Raman spectrometer for the identification and classification of complex liquids in sealed containers. The company is growing quickly and won the Institute of Physics' Business Start-up Award last year.

www.physics.ox.ac.uk/enterprise



© ELIZABETH INDACO

Ramy Aboushelbaya and Marko Mayr

50 THE NUMBER OF DPHIL STUDENTS SIGNED UP TO THE INAUGURAL PHYSICS INNOVATION COURSE, A SELL-OUT

Image right: A team of students from across the university (including Anna Jungbluth, centre) who developed a map app that helps users find the safest way home after a night out. It was amongst the winners in the All-Innovate 2019 competition.

LEARNING FROM THE EXPERTS

To build on the success of these pioneers, we are now offering students the chance to take the department's first innovation and entrepreneurship course. The department has carefully designed the seven-week course in collaboration with the Oxford Foundry and Saïd Business School to equip students with the knowledge and skills to transform physics ideas and inventions into scalable businesses. During the programme, students learn from expert start-up coaches, physicists-turned-entrepreneurs, industry experts, and senior faculty from the Saïd Business School. Topics range from intellectual property (IP) and licensing, to market segmentation, knowing your customer, and designing a business model. This first term will be something of a pilot, but plans are already in place to open it to undergraduates in the next academic year. By collaborating with the Oxford Foundry and Saïd Business School, we are maximising the wealth of expertise that we have here at Oxford and as a result, students will gain valuable transferrable skills that will serve them well – and potentially open doors to a whole new future.

Where are physicists needed?

We are incredibly excited to see the breadth of challenges our students are wanting to take on, and the progress they can make in such a short time. We hope that by providing more opportunities to learn new skills and share ideas with others, we can support our students' entrepreneurial ambitions within or beyond academia. We will highlight more of our student innovators and entrepreneurs in the next Newsletter, but we'd also love to hear from you, our alumni. How have *you* used your physics knowledge or problem solving training? Do you work on new technology development or run a business? We'd love to hear your story. Write to: alumni@physics.ox.ac.uk.

NOTES FROM THE HEAD OF PHYSICS

Prof Ian Shipsey, Head of Department

I hope you and your loved ones are safe and well. The COVID-19 global pandemic has changed the lives of all of us. You will not be surprised to learn, however, that we have been able to carry on most of our normal activity since we began working from home on 13 March, eleven days before the national lockdown commenced.

LIFE UNDER COVID-19

Since that time the only research continuing in our buildings has been that of the Kapanidis/Robb group on the rapid detection of COVID-19 (see pages 8–9), I am very proud of their work. Theirs is one of the many research projects taking place as part of the university's response to the COVID-19 outbreak including vaccine development, treatment, and testing.

Although our buildings are almost empty, seminars continue online; committee, faculty and research group meetings and DPhil vivas continue online; and we have instituted online coffee chats. Grant proposals are being written and submitted to funding bodies online. Data continues to be analysed, and papers continue to be written, reviewed and published. Attendance at conferences has become virtual and recruitment of new faculty members and staff has continued.

Our departmental closing coincided with the end of Hilary Term, and as I write this, Trinity Term is well underway. I am thrilled to share with you that our first week of remote teaching has been a success. It is so very important to be able to deliver on our promise to our student body and provide them with the world class education they deserve and expect.

All of this activity has been accomplished with a minimum amount of fuss. I am very proud of, and grateful to, all the academic and administrative staff and our students who have adapted so well and so quickly.

OXFORD PHYSICS ON THE INTERNATIONAL STAGE

Our goal is to be the number one physics department in the world. We don't mean by this being assessed number one by The Times Higher Education or QS World University Ranking. We mean that when there is a conversation between scientists in the hallways at MIT or Stanford about the latest physics result or idea, that result or idea has often come from Oxford. At the moment the answer is 'sometimes'; we would like to increase that frequency of occurrence. Accordingly, over the last 18 months we have been developing a decadal strategic plan for research to help guide us there. In November I appointed an External Advisory Board for Research made up of 11 eminent international physicists with expertise spanning the broad range of physics at Oxford. The principal purpose of the Board is to advise the department on our research programme.

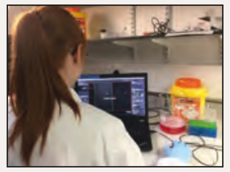
The inaugural two-day meeting was held on 17–18 February 2020 in Oxford. The Board found a vibrant community of scientists and one of the leading physics departments in the world, pursuing state-of-the-art research programmes across a broad front, educating the next generation of physicists to the highest standard, and enhancing the public's understanding of physics and science more broadly.

FROM NANOPARTICLES TO EXOPLANETS AND BEYOND

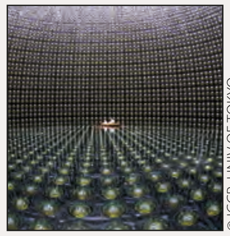
The Board were impressed by: (a) our view that the research role of a modern physics department is to address those foremost scientific problems of our age where the experience, skills and intuition of a physicist can make a difference; (b) our scale and our breadth: 120 permanent faculty members, 180 post doctoral researchers, 150 technical and administrative support staff, 400 DPhil students, and 760 undergraduate students working across 11 major themes: accelerator science, astrophysics, biophysics, physical climate science, fundamental particles, (exo-) planetary science, high energy density science, plasma physics, quantum materials, quantum information, and semiconductor devices and photovoltaics; (c) our close collaboration with many other departments in Oxford, and in other institutions both nationally (including Culham and Harwell) and internationally; (d) our collaborations with high-tech industry and the spin-out companies that have been created to commercialise in-house developed technology; (e) our very substantial technical facilities, including mechanical and electronic workshops, nanofabrication, and materials preparation and characterisation; and (f) our international character: 50% of our faculty, researchers, and students are from outside the UK.

The Board identified areas particularly ripe for further development, including: quantum physics; machine learning in physics; extreme plasmas; and exoplanetary science. The Board marvelled at the Beecroft Building and highlighted the need for a significant increase in the quality of our other existing space and the need for significant additional high quality space to conduct our research. The Board stressed the crucial importance of graduate students to research; while the leading US physics programmes have a faculty to student ratio of 1:4, Oxford is at 1:3. If Oxford physics is to be number one it will be necessary to significantly increase the number of DPhil students (by about 25 per year for a total increase in cohort size of 100). With this in mind we are particularly pleased to be able to announce in this issue of the Newsletter the first OXPEG students (see page 13).

We are looking forward to a phased return to work in the department over the next months, starting with work that cannot be done from home, while those who can work from home will continue to do so. We hope the natural cadence of the academic year will have returned by Michaelmas term and that we can welcome many of you back to Oxford for alumni events then.



A group of researchers led by the Department of Physics is working on a new method that would allow extremely rapid detection of the virus that causes COVID-19 – in as little as one minute.



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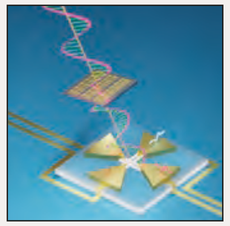
Oxford physicists have played a key role in the T2K experiment as part of a collaboration to understand the difference between matter and antimatter.



Scientists from Oxford's Condensed Matter Physics group have managed to record the full polarisation state of terahertz pulses by developing a nanowire-based sensor.

THE OXFORD PHYSICS ENDOWMENT FOR GRADUATES (OXPEG)

One of the strengths of the Department of Physics is its leadership in research and teaching.

The generous donations of many individuals and families enable us to go further. We identified the Oxford Physics Endowment for Graduates (OXPEG) initiative as a funding priority and set an ambitious target to provide funding for a number of graduate scholarships, matched by the department. The fund is continuing to grow and we are delighted to be seeing the benefits of this flexible funding in action.

The Department of Physics has awarded OXPEG funding to four students to enable their studies at Oxford in the academic year 2019–20. OXPEG funding has enabled us to recruit high-calibre candidates with immense potential. These students span the areas of astrophysics, particle physics and theoretical physics, working on a wide range of topics, from the spiral structure in galaxies, to searching for the neutrinoless double beta decay, and understanding the DNA's response to proteins. Ultimately, OXPEG will support all areas of research in the department.

Dominic Dootson's research focuses on understanding the spiral structure of galaxies. Using observations taken with Gaia, one of the European Space Agency's space observatories, he will investigate how models of axisymmetric discs respond to internal and external perturbations. For his work, Dominic will use the Vlasov-Poisson equations, which describe the evolution of the disc, an approach that is so far underexplored in this area of research. Prior to starting his DPhil, Dominic completed an undergraduate degree in physics at Keble College, Oxford and a Master's degree in Mathematical and Theoretical Physics.

Wilber Lim will work on furthering our understanding of the DNA's response to proteins. Traditionally, DNA has been viewed as a passive digital repository of information, where proteins are considered to be the primary active agents. However, recent findings indicate that rather than being a static elastic medium, DNA's response to proteins can vary dramatically depending on inhomogeneous properties along its chain. An emerging hypothesis is that, in addition to its digital genetic code, DNA carries a subtle elastic code that controls how and when it is read. To understand this new code, scientists must work out the basic physics of inhomogeneous DNA under twist and tension. Wilber is currently studying the role of a DNA defect called the thymine dimer. Learning how DNA alters its response to torque and tension when damaged could help explain how repair proteins can quickly identify a damaged site, and reveal the physical circumstances under which defects may remain undetected by these repair mechanisms.

The University of Oxford would like to express sincere thanks to our donors for their generous support of OXPEG and its enabling role in our research. For information on how you can support OXPEG, please see page 14.

MAIN IMAGE: © ESA / M REBISZ; SMALL SPIRAL GALAXY: © DATA: ESA/GAIA/DPAC, A. KHALATYAN(AIP) & STARHORSE TEAM; GALAXY MAP: NASA/JPL-CALTECH/R. HURT (SSC/CALTECH)

INTRODUCING...

Lisa Willmot, Senior Development Executive

The University of Oxford has a well-established history and culture of philanthropic support for its teaching and research, so I was delighted to take up a new role in March, raising funds for the Department of Physics.

Despite joining at a challenging time for the department – as experiments were paused and laboratories temporarily shut down in response to the COVID-19 outbreak – I have been struck by the warmth and commitment of our donor and alumni communities. I have had the pleasure of speaking with several of you already, and look forward to when we can meet in person.

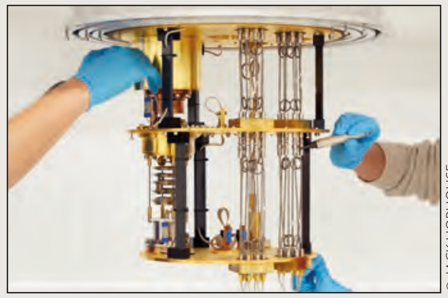
CGI ARTIST WIGWAM VISUAL © HAWKINS\BROWN

Our donors make remarkable things possible. The wonderful Beecroft Building benefited from support from many of you, whilst the Oxford Physics Endowment for Graduates (page 13), funded by our donors, helps ensure that the very best graduate students can undertake their research at Oxford. As we navigate the impact of external events such as Brexit and Coronavirus on the department, this is more important now than ever.

Could you consider a gift to support physics at Oxford? Your generosity will help ensure that we attract the best academics and students to the department, whose work will maintain its reputation as a world-leader in teaching and research.

To find out more and to make a donation online, please visit www.development.ox.ac.uk/physics.

Although as I write this I am working remotely, I am still very much available for anyone who wishes to discuss support for the Department of Physics.



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Perhaps you have been considering a more substantial gift to the department, or would like to learn more about the specific programmes and projects you can help fund. Please feel free to contact me on +44 (0)7717 695534 or email lisa.willmot@physics.ox.ac.uk – I'd love to hear from you.

Because of the pandemic, all paper donation forms are currently suspended.
If you would like to make a donation please follow the link:
www.physics.ox.ac.uk/about-us/supporting-physics

EVENTS & SOCIAL MEDIA

The arrival of the COVID-19 pandemic coincided with the start of our alumni events calendar. Since the lockdown, we have been working on ways to restructure and reorganise our offer to the alumni and wider physics friends community. We encourage all of you to find us on social media and engage in the conversation. We are on Twitter, Instagram, Facebook, LinkedIn and now our YouTube channel, where we hope to add more videos in time. Not only can you share our work, but also follow a lot of members of the department who are very active and produce their own content. Feel free to invite family members and friends to join us, too. Our Outreach team produces a lot of materials that can help with home schooling or just to keep learning from home.

Likewise, if YOU have any physics-related content you'd like to share, feel free to email alumni@physics.ox.ac.uk or simply tag us on social media.

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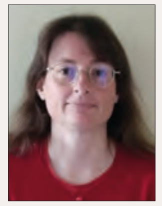
AN UPDATE FROM THE PHYSICS TEACHING LABORATORIES



Dr Jenny Barnes

A staple of any undergraduate physics degree is experimental work, and the teaching laboratories in the Department of Physics continue to be a core part of every physicist's training. The teaching laboratories are currently located in the basement of the Denys Wilkinson Building (DWB), in space which previously housed the control room for the Van de Graaff accelerator, the original purpose of the building (see a very interesting film about the building at www.youtube.com/watch?v=yZkbJ_OwQ2Q).

The first year syllabus offers a range of practicals, from monochromators and diffraction in the Optics lab, to measuring electromagnetic forces in the Electrostatics and Magnetism lab, or studying moments of inertia and the electron as a particle and a wave in the General Physics lab.

The installation of large LED panels (see image below left) has added some welcome colour to the General Physics lab. In addition, new experiments on normal modes and driven simple harmonic motion, topics which students study in their lectures, have been introduced to the suite of practicals offered in this lab.

In the Electronics lab, we recently introduced new equipment (see image below right) so that every student now performs experiments on their own. This ensures that all students learn how to use essential electronics equipment such as oscilloscopes and function generators, which they might encounter later in a research career.

Second and third year experiments continue to be varied and offer a wider choice, for example digitisation and sampling in second year Electronics lab or 'fun with a wave tank' in third year Atmospheric Physics lab. Other labs include Biophysics, Astrophysics, Nuclear Physics, Optics, Electromagnetism, Condensed Matter and Thermal Physics. This wide range of subject areas, which links to research themes in the wider department, enables students to tailor the practicals to their own personal physics interests or long term career goals.

Our third year syllabus has recently changed to offer more choice for the keen experimental physicist, with the introduction of Computational and Experimental projects. These projects offer students an option to replace a written paper with a 60-hour-plus project, and examination is via a write-up and *viva*. Projects offered this year include: Rutherford scattering to demonstrate the point-like nature of the nucleus of an atom; studies into the breakdown in the Quantum Hall effect; and single photon counting experiments to show optical quantum effects. In addition, a project was offered to build a spectrometer for the Philip Wetton telescope, which sits on top of the DWB and has had recent upgrades, funded by alumni of the physics department. These new projects were oversubscribed and show that the desire for developing experimental skills during their degree is very much alive in our students.

Third year students taking the BA degree are given the option to do a group project with an industrial partner during the Michaelmas and Hilary terms. Recent partner companies have included: Adaptix; Airbus; AWE; MeVitae; Serralux; Oxford Instruments; and Biral, covering projects from mobile 3D X-ray imaging; using reflectometry to measure the detonation velocity of a projectile; simulation and measurement of daylighting window filters; to developing cryogen-free environments for nanoscience experiments. These projects are very rewarding for both the students and companies – the students learn to work as a group, scheduling tasks to fit within allocated weeks, and the companies gain enthusiastic students to work on speculative topics which they may not have capacity to work on in-house.

Further information about the teaching laboratories can be found at: www.physics.ox.ac.uk/study-here/undergraduates/teaching-labs

WE ARE ALWAYS LOOKING FOR NEW PARTNER COMPANIES: IF YOU ARE INTERESTED IN WORKING WITH US ON THESE PROJECTS, PLEASE CONTACT ENQUIRIES@PHYSICS.OX.AC.UK

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MAKING PHYSICS ACCESSIBLE FOR ALL

For more information: www.physics.ox.ac.uk/outreachnews

The Department of Physics engages in a series of highly active outreach programmes, which have reached more than 200,000 people over the last five years. Our outreach work is focused in four main areas:

INCREASING ACCESS TO OXORD

Supporting disadvantaged students who have the potential to benefit from study in the department

ENGAGING LOCAL COMMUNITIES

Building partnerships with local communities to enrich the life of the city

INCREASING DIVERSITY IN STEM

Working with children from under-represented backgrounds to raise aspirations

PUBLIC ENGAGEMENT

Supporting our researchers in engaging the public with their research

MARIE CURIOUS

On 15 February 2020, the Department of Physics opened its doors to 100 girls aged 11–14 for its annual 'Marie Curious' event. This was a day of free, hands-on science fun, with events designed to challenge girls to get stuck into science, technology, engineering and maths (STEM).

The event included hands-on workshops run by scientists from across the university and beyond, on topics ranging from quantum computing to the human body, via the mysteries of levitating superconductors and the peculiar properties of goo. In the afternoon, there was a visit to St John's College, where the girls had the opportunity to quiz a panel of scientists about their work and life, as well as explore the college.

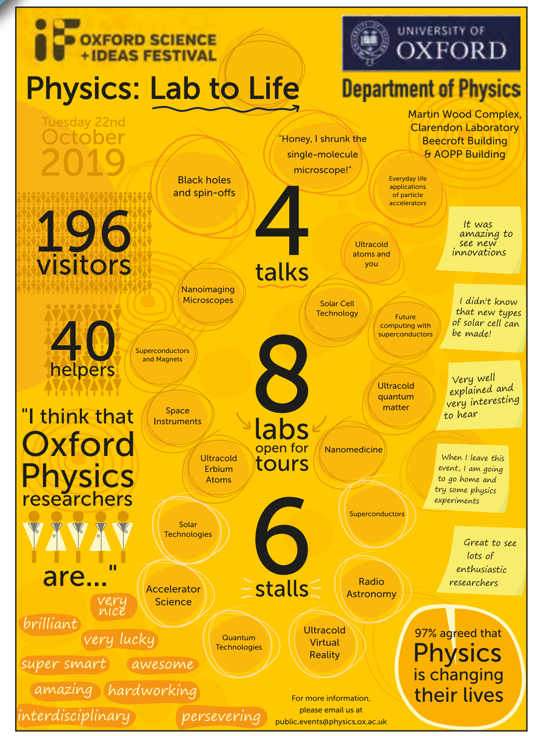
IT WAS AMAZING TO SEE NEW INNOVATIONS

I DIDN'T KNOW THAT NEW TYPES OF SOLAR CELL CAN BE MADE!

LAB TO LIFE

How do we transform our research from something hidden in our labs into a technology people can use? In October, we shared some of our secrets through our 'Physics: Lab to Life' initiative as part of the IF Oxford science festival. We opened our doors to some 200 curious teenagers and adults so they could find out more about physics and how it impacts daily life. Visitors were able to listen to lectures as well as take tours of our laboratories and speak to the physicists themselves about their work.

During the event, visitors were offered a choice between three lectures covering diverse topics: Professor Katherine Blundell OBE, shared her research on black holes and the 'Global Jet Watch' project, through which she engages young people in developing countries in science; Professor Achillefs Kapanidis, the BBRSC's Innovator of the Year, showcased his work on single-molecule microscopes, which allow us to peer into the deepest secrets of biological cells; and two postdoctoral researchers shared the applications of their research: Dr Elliot Bentine spoke on ultracold atoms and devices that could harness them, and Dr Hector Garcia Morales explored the everyday applications of particle accelerators.



STARGAZING

Ever wondered how you can measure the speed of light with marshmallows or wanted to find out more about the largest telescope on Earth? The Department of Physics opened its doors for its annual Stargazing event on 25 January and welcomed 1,209 keen and curious visitors of all ages.

'STARGAZING IS OUR LARGEST EVENT, AND ONE OF THE YEAR'S HIGHLIGHTS. IT'S GREAT TO WELCOME FAMILIES AND OUR LOCAL COMMUNITY INTO OUR BUILDING, AND OUR RESEARCHERS ARE DELIGHTED TO BE ABLE TO SHARE THE EXCITEMENT OF THE UNIVERSE. EVERYTHING IS HANDS-ON, SO PEOPLE GET A UNIQUE INSIGHT INTO THE LATEST RESEARCH, OUR PROJECTS – AND HOPEFULLY THEY HAVE SOME FUN ALONG THE WAY.'
— PROF CHRIS LINTOTT

WE HAD SO MUCH FUN. A TERRIFIC OPPORTUNITY TO DO SOMETHING AS A FAMILY. BETWEEN US WE LEARNT SO MUCH.

HAD A GREAT TIME LEARNING ABOUT SPACE ALONGSIDE MY KIDS. GREAT TOPIC OF CONVERSATION WHEN WE GOT HOME, THANK YOU.

A DREAM COME TRUE FOR MY SON WHO WATCHES SO MANY SPACE CLIPS ON YOUTUBE

IMAGES © JOHN CAIRNS PHOTOGRAPHY

NOBEL PHYSICS LAUREATE VISITS OXFORD

Prof Donna Strickland was awarded the 2018 Nobel Prize in physics, together with Prof Gerard Mourou (her PhD supervisor), for the discovery of Chirped Pulse Amplification (CPA). They shared the prize with Prof Arthur Ashkin (who won his share for work on optical trapping). CPA is a technique that has revolutionised laser technology and brought it from the laboratory tables into common usage. It enables scientists to take very short laser pulses (of order picoseconds or shorter) and amplify them to very high energies, and hence intensities. Back in the 1980s, when Prof Strickland invented this technique at the University of Rochester, amplifying short pulses was not possible because the intensity that would build up in the laser amplifier would destroy the laser itself. Prof Strickland and Prof Mourou circumvented this problem by taking a weak short pulse, stretching it in time, and then amplifying it (so the intensity within the laser was not so great, as it was a longer pulse): only after it had been amplified was it then recompressed in time back to the original duration. Since this invention, new forms of eye laser surgery have become available, as well as the ability to precision-cut glass to make cell phones. CPA has also enabled the development of very high-intensity laser systems, opening up the possibility of using such lasers to create exotic states of matter, including the production in the laboratory of charged particles and electron-positron beams; plasma wakefields; and intense burst of X-rays. These have been used for studies in laboratory astrophysics, 4th generation light sources and inertial confinement fusion experiments. Some of this work has been led by faculty members in Atomic and Laser Physics, Theory, Particle Physics and the John Adams Institute for Accelerator Science.

In February we felt exceptionally honoured to welcome Prof Strickland to the Department of Physics – a visit organised by Prof Gianluca Gregori from Lady Margaret Hall (LMH). She gave a well attended public lecture outlining the research that led to the Nobel prize. The lecture was introduced by Prof Justin Wark from the Atomic and Laser Physics sub-department, who in 1985 (when the paper on CPA by Prof Strickland and Prof Mourou was published) happened to be working in the same laboratory at the University of Rochester. Prof Strickland gave a wonderful account of CPA, readily accessible to the general public, and her lecture finished with a personal account of what went on behind the Nobel ceremony, with many photographs and amusing anecdotes.

After the lecture, Prof Strickland also met with Dame Jocelyn Bell Burnell, Prof Karl Krushelnick (Mourou's successor at the Center for Ultrafast Optical Science at the University of Michigan), and Prof Bob Bingham, who hosted her at the Rutherford Appleton Laboratory. Prof Strickland's visit to Oxford ended with a banquet at Lady Margaret Hall (one of the first two colleges in Oxford to admit women since 1879). At LMH, Prof Strickland engaged in many discussions with current physics students and postdocs of the Women in Physics Society, and her experience, thoughts and encouragement were inspirational.

Prof Gianluca Gregori

Far left: Prof Donna Strickland (centre) at Lady Margaret Hall surrounded by students and postdocs of the Women in Physics Society.

Left: Prof Donna Strickland (first on the right) with Prof Peter Norreys (behind) and Prof Stephen Blundell (in the foreground) talking with students in Atomic and Laser Physics.

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FIVE MINUTES WITH... **HELENA COTTERILL**

Quantum Materials Outreach Officer

© CHLOE FAIRBANKS

@HelenaCotterill and @QM_Oxford

I REMEMBER WATCHING SOMEONE LEAPING AROUND ON THAT STAGE, USING THIS GIANT MACHINE TO CREATE BOLTS OF LIGHTNING AND EVEN CREATING MUSIC FROM ELECTRICITY BY MAKING TESLA COILS 'SING'

Tell us a little bit about your background

I'm originally from Nottingham, but spent most of my school years in a small town in Lincolnshire called Grantham. From there, I began my undergraduate degree in physics here at Oxford and never left! I started a DPhil in Atmospheric, Oceanic, and Planetary Physics immediately after my undergraduate studies and it was during this time as a graduate student that I discovered the wonderful world of physics outreach and I got hooked. About half way through my DPhil I decided academia wasn't for me, switched to a Masters, and joined Dr Kathryn Boast as a second Quantum Materials Outreach Officer.

Can you explain the work you do?

As Quantum Materials Outreach Officer, I'm continuing the excellent work that Kathryn has done in the role, working with the Quantum Materials group in developing interesting and fun ways to communicate their research to a range of audiences. In addition to running our existing programme of science shows, workshops and stalls, I am involved in some new initiatives, including running a magnetism-themed day at Barton Community Centre as part of their school holiday club and helping about 50 local Year 5 students gain their CREST Superstar award by creating some experiments with magnets for them to investigate. In addition to this role, I will soon start work on an exciting new outreach project linked with the Zooniverse citizen science platform, bringing cutting-edge research into schools and allowing primary school children to be scientists and contribute to this research themselves.

When did you know you wanted to become a physicist?

I think I first realised that I wanted to study physics when I visited the Museum of Science in Boston, USA, at age 15. There, they have a 'Theater of Electricity' which houses the world's largest air-insulated Van de Graaff generator, originally built by Dr Robert Van de Graaff in 1932 and standing at an impressive 40ft (~12m) in height. I remember watching someone leaping around on that stage, using this giant machine to create bolts of lightning and even creating music from electricity by making Tesla coils 'sing'. They put on this spectacular show for museum-goers, all whilst explaining fundamental physics concepts. I thought 'I want to do that!' and came away truly inspired. This also sparked my passion for outreach, although I didn't realise it at the time.

What other interests do you have besides physics?

The two other passions in my life are music and theatre. I've been playing violin since I was eight, and singing pretty much since I was able to form sounds! Honestly, if I hadn't studied physics, I probably would have been a musician. Currently, I am the principal violinist of a few orchestras in Oxford, including the Oxford Millennium Orchestra, and I have also performed with the Oxford University Gilbert & Sullivan Society.

What advice would you give people who want to study physics?

Make sure that physics is something you enjoy. There are a wide range of topics that make up physics as a whole, but as long as there is something in this field that you love, this will give you the motivation to keep learning and making new discoveries. Read around the topics that interest you and do some research of your own. And just know that if you have a passion for the subject, then there is nothing to stop you from reaching your goals – I come from a single parent family, have a state school background, and am the first generation in my family to go to university, and now I work for the Department of Physics at the University of Oxford! Not only that, but I get to do things like explode hydrogen balloons and make liquid nitrogen ice cream in front of more than 200 people!

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Image top right: Playing violin for the Oxford University Gilbert & Sullivan Society Hilary Term 2019 production of *Iolanthe.*

Left: Getting ready to pop a hydrogen balloon as part of the 'Dancing Atoms' show for primary school children.

HONOURS AND AWARDS...

Oxford physicists carry out ground-breaking research in a diverse range of topics from nanoparticles to exoplanets, galaxies and beyond. Their world-leading expertise is recognised annually through prizes and awards.

Prof Stephen Blundell was awarded the prestigious Yamazaki Prize by the International Society for Muon Spectroscopy. The prize recognises his outstanding, sustained work in the field; he has been using muons to study the behaviour of advanced materials for more than 25 years.

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Dr Adam Nahum was awarded the Physik-Preis of the Max Planck Institute for the Physics of Complex Systems (MPI-PKS) and Technische Universität Dresden.

Prof Rob Fender received the Royal Astronomical Society's Herschel Medal, which is awarded for an outstanding contribution to observational astrophysics. It recognises Prof Fender's key contribution to understanding the connection between accretion and jet formation around accreting relativistic objects, such as black holes.

Prof Steven Balbus was awarded the Royal Astronomical Society Eddington medal, for investigations of outstanding merit in theoretical astrophysics. Prof Balbus has revolutionised the theory of accreting systems and made fundamental contributions to the theory of stability, turbulence and transport in astrophysical fluids.

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Noah Waterfield Price, a joint DPhil student between the University of Oxford and the Diamond Light Source, was awarded the PANalytical Thesis Prize in Physical Crystallography. Noah's winning dissertation, entitled 'Domains and functionality in multiferroic $BiFeO_3$ films', was co-supervised by Dr Sarnjeet Dhesi at Diamond and Prof Paolo Radaelli at the Clarendon Laboratory, University of Oxford.

Prof Donal Bradley, Visiting Professor of Physics and former head of the Mathematical Physical and Life Sciences division at the University of Oxford, was awarded the European Material Research Society's Jan Czochralski Gold Medal. The award recognises Prof Bradley's outstanding achievements in the field of advanced materials science and, in particular, his work on soluble semiconductor materials for the display and lighting, electronics, solar energy and photonic device sectors.

Prof Artur Ekert was awarded the Micius Quantum Prize 2019 for his inventions of quantum cryptography (the award was shared with C Bennett, G Bassard and S Wiesner). Selected as one of the 2019 Citation Laureates, 'a list of candidates considered likely to win the Nobel Prize in their respective fields'.

Prof Tim Palmer, Royal Society Research Professor in Climate Physics, has been elected as an International Member of the National Academy of Sciences (NAS) in recognition of his distinguished and continuing achievement in original research.

Prof Raymond Pierrehumbert, the Halley Professor of Physics at Oxford, has been elected as Fellow of the Royal Society in recognition of his outstanding contribution to scientific understanding. Prof Pierrehumbert works on the physics of the climate of planets, including the Earth.

Prof Séamus Davis is one of six world-class scientists to have been awarded a prestigious Royal Society Research Professorship. The appointment recognises scientists who have made – and continue to make – exceptional contributions to science. Prof Davis studies exotic new quantum mechanical states of matter and this appointment specifically supports his work in quantum spin liquids.

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We hope you enjoyed reading this issue of the Department of Physics' Newsletter. To contact the Newsletter editor, Prof Dimitra Rigopoulou, please email **newsletter@physics.ox.ac.uk**. For latest news on developments at the Department of Physics, see **www.physics.ox.ac.uk**. To contact the alumni office, email **alumni@physics.ox.ac.uk**. For events and lectures, see **www.physics.ox.ac.uk/events**.