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News from the Cavendish Laboratory

THE WINTON PROGRAMME FOR THE
Physics of Sustainability

Ten Years of the Winton Programme

Special Winton Symposium 2022: 10 Years of the Winton Programme

2022 marks formally the final tenth year of the Winton Programme for the Physics of Sustainability. Unlike previous Winton Symposia, this event focussed on past and present achievements of members of the Winton community and the dramatic results of their programmes.

FIG. 1. David Harding, Richard Friend and Siân Dutton welcoming the participants.

COVER IMAGE: David Harding with past and present Winton Scholars who attended the Winton 10th Anniversary meeting.

It scarcely seems possible to believe that the Winton Programme for the Physics of Sustainability is ten years old, its success made possible by David Harding's generosity and Richard Friend's inspired leadership in converting a dream into a reality.

In his opening remarks, Richard was delighted that the programme had expanded significantly through interactions with other departments and generated many new collaborations. This came about through the three central pillars of the programme: the scholarship programme for graduate students, the appointment of outstanding post-doctoral fellows and the provision of start-up funds to enable initiatives to get off to a quick start. He noted the very high quality of the scholars and post-docs, many of whom have now obtained faculty positions in Cambridge and elsewhere. Examples are given below.

Richard has now passed the directorship over to **Siân Dutton**, one of the first beneficiaries of the programme. She joined the new Winton community as a Winton Advanced Research Fellow in early 2012, focussing on controlling functional materials through synthesis and characterisation of a wide range of materials systems, from complex metal oxide insulators to hybrid inorganic-organic semiconductors for energy applications. Siân was appointed to a lectureship in the Cavendish Laboratory in 2015 and is now Professor of Physics and Solid State Chemistry in the Laboratory. She says:

"My Directorship of the Winton Programme began in 2020, following on from Richard Friend's tireless work in establishing the Programme and championing its grand objective of supporting new science to address the practical barriers to achieving a sustainable future. The Winton Programme will continue to support researchers for the next few years across diverse research themes, some with well-established connections to sustainability, and others seeding exciting new research areas, the impact of which will be revealed in their future applications."

This special symposium was held in a splendid marquee at David Harding's home. The keynote lecturers were former holders of Winton research fellowships and beneficiaries of the programme who have gone on to highly successful academic careers.

Giuliana di Martino, Assistant Professor Department of Materials Science and Metallurgy (Winton Advanced Research Fellow, 2018). In 2020 Giuliana was appointed to a Lectureship in Device Materials in the Department of Materials Science and Metallurgy. Her research group links the fields of low-energy nanoscale device engineering and plasmon-enhanced light-matter interactions by implementing optically-accessible memristive devices. This new generation of ultra-low energy memory nano-devices has potential to open up new routes to sustainable future IT.

Alex Chin, Assistant Professor CNRS and Sorbonne Université (Winton Advanced Research Fellow, 2012). Alex investigates the role of non-classical properties of quantum mechanics in the remarkably high efficiency and sensitivity of key biological processes, such as avian navigation, olfaction and photosynthetic light-harvesting. His research concerns theoretical aspects of the new field of Quantum Effects in Biological Systems (QUEBS), combining techniques from condensed matter theory, quantum optics and physical chemistry to study the novel physics of biomolecular processes at the boundary of quantum and classical descriptions.

Rosana Collepardo Guevara, **Professor of Molecular and Computational Biophysics, Department of Chemistry and Department of Genetics** (Winton Advanced Research Fellow 2016). Rosana's group develops multiscale modelling approaches to investigate the physicochemical driving forces that govern DNA packaging inside cells. She also investigates membraneless compartamentalisation via liquid-liquid phase behaviour of biomolecules, chromatin structure, epigenetic phenomena, and the relationship between the structure of the genome and gene expression regulation.

Akshay Rao, Harding Lecturer, Department of Physics (Winton Advanced Research Fellow 2014) Akshay completed his PhD at the Laboratory in 2011 and was appointed to a Harding Lectureship in 2019. His research concerns the study of energy materials to elucidate their fundamental electronic, structural and transport dynamics and to help guide the design of novel materials and devices for applications in photovoltaics, LEDs and batteries. He is co-founder of Cambridge Photon Technology and Illumion.

Chiara Ciccarelli, Harding Lecturer, Department of Physics (Winton Advanced Research Fellow 2016). In 2017 Chiara became a Royal Society University Research Fellow, before being appointed to a Harding Lectureship in the Laboratory. Her research focuses on the spin-dynamics of magnetically-ordered materials, from ferromagnets to anti-ferromagnets to chiral magnets. She studies spin-charge interconversion for electrically reading and writing spin-states. In 2016 she set up a time-resolved Terahertz spectroscopy laboratory in the Maxwell Centre, which enables monitoring of spin dynamics on picosecond timescales.

Helena Knowles, University Lecturer, Department of Physics (Recipient of Winton Start-up Funding 2020). Helena is a University Lecturer and a Royal Society Research Fellow at the Cavendish Laboratory. Her group focusses on quantum control and quantum imaging at the nanometre-scale. She uses quantum optics tools and defects in diamond to perform nanoscale NMR experiments in biological and solid-state systems. At Harvard in 2017 she investigated single-atom thin materials using defects in diamond.

Bartomeu Monserrat, **Gianna Angelopoulos Lecturer in Computational Materials Science, Department of Materials Science and Metallurgy** (Winton Advanced Research Fellowship 2018) In 2020 Bartomeu was appointed Gianna Angelopoulos Lecturer in Computational Materials Science in the Department of Materials Science and Metallurgy. He develops quantum mechanical methods to study material properties theoretically. Areas of current interest include the optoelectronic properties of solar cells and transparent conductors, topological materials, superconducting materials, and the physics of matter under extreme conditions of pressure and temperature.

These excellent talks were followed by an equally excellent series of 12 three-minute talks by current Winton students. The cover picture shows David Harding with past and present Winton Scholars who attended the event.

This was a wonderful, happy celebration of the success of the Winton programme. What struck me was the sheer diversity of the science and its originality. We could not have predicted these outcomes when the programme was formally opened on 24th March 2011 (see CavMag6).

We also need to recognise the central importance of David Harding's gift in the redevelopment of the Laboratory. This unambiguous endorsement of the importance of the science had a leveraging effect upon our ability to raise the funds needed for the rebuilding of the Laboratory into which we will be moving in just over a year's time. The legacy of the Winton programme will be the new science which it enabled and which will be centrepieces of the new laboratory's programme.

MALCOLM LONGAIR

FIG. 2, OPPOSITE. The marquee in which the 2022 Special Winton Symposium took place. The audience were members of the Winton community and those involved in supporting the Winton programme.

All photographs of the meeting, including the cover image, taken by Chris Brock.

Neutrinos continue to rock the boat

MELISSA UCHIDA, Head of the Cavendish Neutrino Group, gives an enthusiastic and enlightening description of the latest twists and turns in the neutrino physics story.

I remember very well first learning about neutrinos in the 3rd year of my undergraduate degree. We had been looking at the Standard Model of particle physics that describes all of the fundamental particles, those which we believe cannot be broken down into anything smaller, and their interactions. It is a beautiful model into which everything fits perfectly, even the Higgs boson, which at that time was just a theoretical particle. Yet, it could not explain how the Universe came to exist – how matter and antimatter didn't annihilate each other, but left us instead in the matter-dominated Universe we know and love. Then we learnt about neutrinos. There are three types of neutrino: electron, muon and tau, which are each considered massless in the Standard Model, yet they can change into one another, or oscillate, as they travel which tells us that they have mass and provides the first direct evidence of Physics Beyond the Standard Model. Not theoretical but physical, experimentally proven evidence of new physics that could perhaps be the key to understanding our matter dominated Universe – I was hooked!

That's the funny thing about neutrinos. Most of our exciting discoveries involving them have come from experimental anomalies – we went in looking for one thing and neutrinos threw us a 'curve ball' and we ended up discovering something quite unexpected. The very idea of their existence came as an explanation to the missing energy problem in beta decay, in which beta rays seemingly defied the laws of energy conservation. The Homestake experiment in the 1960s, designed to collect and count neutrinos emitted by nuclear fusion in the Sun, was the first to observe neutrino oscillations. Unexpectedly, the experiment detected only 1/3 of the predicted number of electron neutrinos. The missing neutrinos had oscillated into one of the other two types – but it took new experiments to explore and prove this beyond any doubt.

So when a new anomaly is observed in a neutrino experiment it is prudent to investigate. This was the motivation for MicroBooNE. Two previous experiments, namely the LSND (Fig 1) and MiniBooNE experiments observed that, at low energies, there appeared to be an excess of electron neutrinos over and above what would be expected from the three known types of neutrino oscillating together. This became known as the *Low Energy Excess*. What is going on? New particles? New more complex physics? Or perhaps there were some background processes that those experiments could not see such as photons misidentified as electrons from electron neutrinos? We needed MicroBooNE to test the results and describe the anomaly.

MicroBooNE uses a novel detector technology which enables us to observe the aftermath of neutrino interactions with unprecedented clarity and, importantly, to distinguish easily photons from electrons. A real life event in MicroBooNE is shown in Fig 2. It also uses the same source of neutrinos as MiniBooNE and sits at the same distance from that source, thereby improving its ability to test MiniBooNE's result. The Low Energy Excess gave rise to many theoretical explanations – sterile neutrinos which could explain how neutrinos have mass and could likewise help explain the matter domination of our Universe, new even more complex physics processes and particles, and indeed explanations of potential background processes, several of which also involve new physics. Many of these theories have similar experimental signatures and so rather than test one theory at a time it is more robust to look for the experimental signatures of the most likely, that is, the simplest, explanations first. This 'theory-agnostic' approach enables MicroBooNE to use its fantastic imaging capabilities to understand precisely what is going on, and not just to test a few theories.

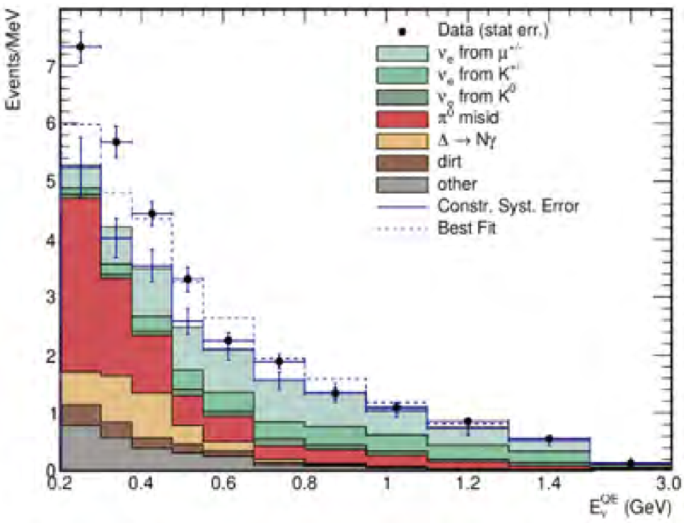


FIG 1: LSND Results showing the expected electron neutrino events for 3 types of oscillating neutrinos in the coloured bands and the measured data as black crosses. At energies below ~0.6GeV the excess of events is clearly seen. Ref: Phys. Rev. Lett. 121, 221801 (2018)

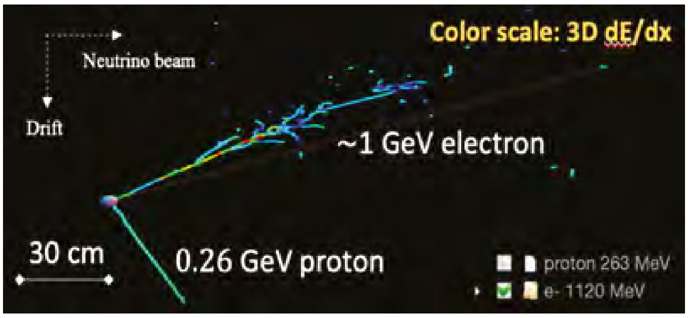


FIG 2: A MicroBoNE neutrino event showing an electron neutrino interaction creating a 0.26GeV proton and a 1GeV electron. Ref: PRD arXiv:2110.13978

While as physicists we may enjoy the really novel complex ideas as explanations for such anomalies, these very rarely, in my experience, prove to be the correct ones. In physics, the simplest explanation is usually right. Yet in the case of MicroBooNE, and for the first time in my career, the answer wasn't what we expected. Specifically, MicroBooNE has taken five years of data and the first set of results use half of these data. The most likely signatures of a real electron neutrino excess and the most likely signature of photons that could have masqueraded as electrons in the previous experiments were explored. ALL WERE RULED OUT! Crucially, MicroBooNE has ruled out the most likely explanation of the anomaly which does not require new physics.

The next place to look is for some type of as yet undiscovered types of neutrino. One in particular, the light Sterile neutrino, is considered to be a front runner. No evidence of a light sterile neutrino has been found and a lot of the available parameter space for such a particle was excluded, the next set of results

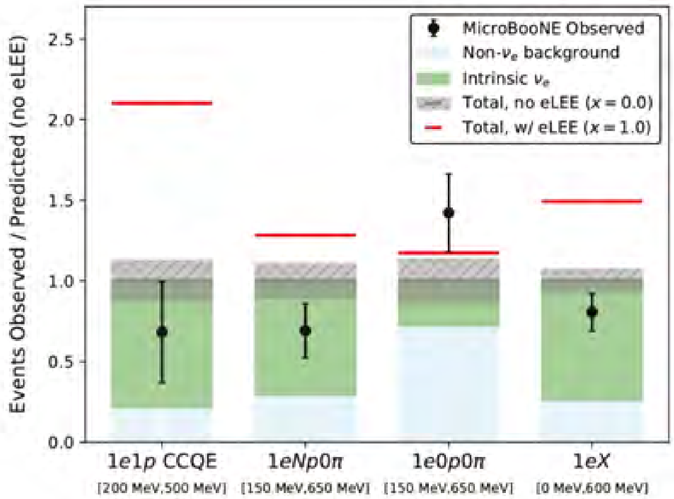


Fig 3: All MicroBooNE analyses observe electron neutrino event rates at below the predicted rates from 3 types of neutrino oscillating, over full analysis energy range and in the signal-enhanced low-energy region, with the exception of the 1e0p0π, which is background dominated. Ref: https://arxiv.org/abs/2110.14054

allowing us to cover the remaining possibilities. It doesn't mean that Sterile neutrinos don't exist, but it means that if they do they are far more complex than we thought.

So whatever the cause of the Low Energy Excess anomaly, we have (1) ruled out the boring, (2) ruled out the vanilla explanations and (3) ruled out the expected. MicroBooNE's journey continues and it's going to be quite a ride!

LEFT IMAGES: Inside the MicroBooNE detector.

TOP RIGHT: MicroBooNE being lowered into the detector building.

BOTTOM RIGHT: The author standing below MicroBooNE. The white bottom of the detector is visible and the cosmic ray tagger can be seen in silver on the right.

The in-plane photoelectric effect – a new quantum phenomemon



Cavendish Laboratory scientists, DAVID RITCHIE, HARVEY BEERE and WLADISLAW MICHAILOW have discovered a new phenomenon in two-dimensional electron systems that enables highly efficient detection of terahertz radiation.

Why is terahertz (10^{12} Hz) radiation interesting? 'It is the electromagnetic radiation that lies between the microwave range, which we use in mobile phone communications, and the infrared radiation, used in heat and night vision cameras,' explains David Ritchie, Head of the Semiconductor Physics (SP) Group at the Cavendish Laboratory. 'Terahertz waves can be used in communications, materials science, security, and medicine. But at the moment, there is a lack of cheap, efficient, and easy-to-use sources and detectors of these waves, which hinders the widespread use of terahertz technology.'

Terahertz waves could have many applications. For example, they can unlock the potential for novel, convenient walk-through airport scanners that can distinguish medicines from illegal drugs and explosives. Cancerous tissue, that is not visible with the naked eye, could be imaged using these waves, and they could also enable even faster wireless communications, beyond the state-of-the-art.

In 2002, the SP group, together with researchers from Pisa and Torino in Italy, demonstrated the first semiconductor laser operating at terahertz frequencies – a *terahertz quantum cascade laser*. The semiconductor materials for these devices were grown by molecular beam epitaxy (MBE). 'This technique allows us to grow complex ultrapure heterostructure wafers using conventional semiconductors, with compositional control at the level of a single layer of atoms' says Harvey Beere, who leads the terahertz subgroup. 'Starting with a plain wafer, we use our fabrication cleanroom to process it into ready-to-use semiconductor chips.' Over the past few years, within the EPSRC programme grant *HyperTerahertz*, the group has developed a terahertz microscope, functional metamaterials devices and new detector types for the terahertz range.

Recently, researchers from the Cavendish Laboratory together with colleagues from Germany and the University of Lancaster have discovered a new physical effect when two-dimensional electron systems are exposed to terahertz waves. 'We have developed a new design of terahertz detector,' (Fig.1) says Wladislaw Michailow, Junior Research Fellow at Trinity College Cambridge. 'Its photoresponse turned out to be much stronger than expected from known mechanisms, and as a result it became clear that we were faced with an unknown effect.'

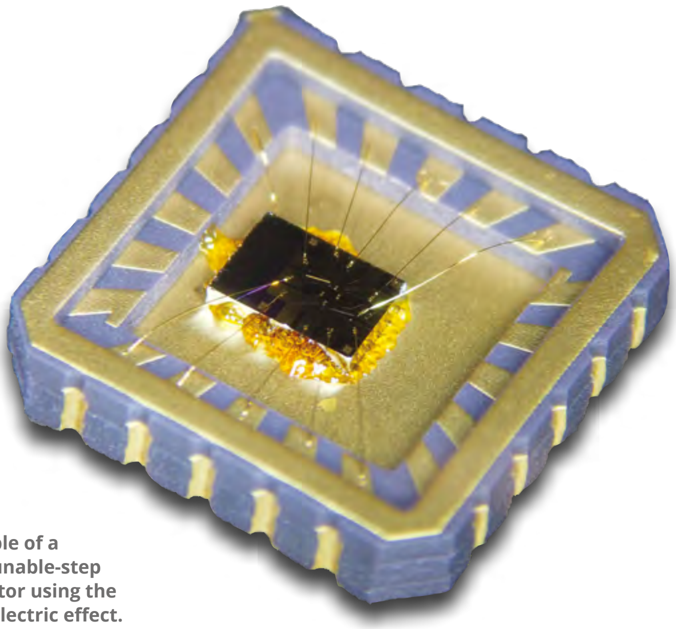


FIG.1. An example of a photoelectric tunable-step terahertz detector using the in-plane photoelectric effect.

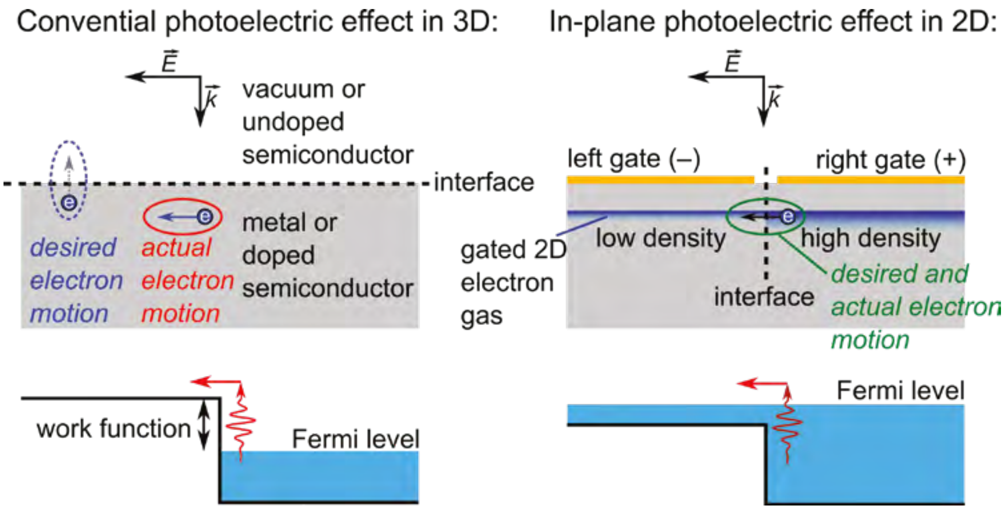


FIG. 2 Schematic representation of the difference between (left) the conventional photoelectric effect and (right) the in-plane photoelectric effect.

The team came up with a new explanation, which at its core lies in the way light interacts with matter. At high frequencies, matter absorbs light in the form of single particles – photons. This interpretation, first proposed by Einstein, formed the foundation of quantum mechanics and accounts for the photoelectric effect.

The photoelectric effect involves the release of electrons from a conductive material – a metal or a semiconductor – by incident photons. In the three-dimensional case, electrons can be expelled into the vacuum by photons in the ultraviolet or x-ray region of the electromagnetic spectrum, or released into a dielectric in the mid-infrared to visible region. But in the terahertz range, the photon energy is too small to exploit even this internal photoelectric effect. The scientists have, however, now discovered a quantum photoexcitation process, that exists within highly conductive, two-dimensional electron gases at much lower, terahertz frequencies.

How did the researchers obtain a large signal from low-energy terahertz photons? 'The issue with using the conventional photoelectric effect for detection is the transverse nature of electromagnetic waves: after being excited by photons, electrons move perpendicular to the propagation direction of the incident wave. Hence under normal incidence, photoexcited electrons move parallel to the material interface,' explains Wladislaw, first author of the study. But to extract electrons from a material, their momenta need to be perpendicular to the interface to overcome the potential barrier, the work function.

How can this problem be solved? 'In our case, we create an artificial potential step for electrons moving within the plane of the 2D electron gas, by applying different voltages to two gates that we placed on top of the 2D electron gas. As a result, photoexcited electrons then move naturally in the desired direction: onto the step,' says Wladislaw. This exploits the photon energy in an ideal way, leading to a strong signal. In this case the potential step height, the analogue of the surface work function in the 3D case, is dynamically tunable by changing the voltages applied to the gates, which are also used to focus the radiation onto the 2D electron gas. The researchers called the phenomenon accordingly, an *in-plane photoelectric effect* (Fig.2). The theory of the effect was developed by a colleague from the University of Augsburg, Germany, and the international team of researchers published their findings in *Science Advances* (DOI: 10.1126/sciadv.abi8398).

The SP group now aims to take this discovery further. Together with partners from the University of Leeds and University College London, the SP group has been awarded a £7M EPSRC programme grant, *TeraCom*. 'The goal of this project is to develop future high speed communication systems in the terahertz range – for inter-satellite communication in space and for ultrafast wireless links in data centres and in consumer mobile networks,' says Giles Davies, who leads *TeraCom* at Leeds, working with other Cavendish alumni Edmund Linfield, John Cunningham and Joshua Freeman. In this new project, the Cambridge group will develop high-speed terahertz modulators and explore the physics of the in-plane photoelectric effect in detail to functionalise it for the fabrication of high-performance, ultrafast terahertz detectors. Both are key components required for next-generation communication systems.

Characterizing the physics of the first luminous structures in the Universe

We are delighted to welcome SANDRO TACCHELLA who recently joined the Laboratory as an University Assistant Professor. His research focuses on understanding the physics of the formation and evolution of galaxies and black holes across cosmic time. He investigates the physical mechanisms that govern the formation of the first galaxies, the build-up of the bulge and disc components in galaxies, and the cessation of star formation in massive galaxies. With the advent of the James Webb Space Telescope (JWST), he is leading the exploration of the internal workings of galaxies shortly after the Big Bang. Here he describes how he plans to achieve these goals.

Galaxies are luminous structures that host stars, planets, black holes, interstellar gas, dust and dark matter. Tremendous progress has been made in understanding how galaxies assemble by peering further and further into the past with the most advanced telescopes on Earth and in space. Many key questions however remain unanswered: when and how did the first galaxies and black holes form? How was the Universe reionized? Why do galaxies stop forming stars?

The 10B$ James Webb Space Telecscope (JWST) will revolutionize our understanding of the most distant and obscured objects in the sky, helping with the search for exoplanets and exploring the earliest days of the universe. Thanks to its operation in space, its large mirror and its sensitive infrared instruments, the JWST allows us to make a giant leap in sensitivity from current instruments, comparable to going from Galileo Galilei's telescope to the Very Large Telescopes in Chile. The JWST has four science instruments, the prime imager being NIRCam and the principal spectrograph NIRSpec, both having spectral coverage ranging from the edge of the visible through to near infrared wavelengths, from 0.6 to 5 micron.

As a member of the NIRCam science team, I am heavily involved in the JWST's Guaranteed Time Observer (GTO) programme as well as other General Observer (GO) programmes. The NIRCam-NIRSpec joint GTO programme, called the JWST Advanced Deep Extragalactic Survey (JADES), will survey deep extragalactic fields in both the northern and southern hemisphere with a wide range of NIRCam and NIRSpec observations. With over 800 hours of observations, JADES is the largest JWST programme for the next few years. These imaging and spectroscopic data will be deeper, extend further into the infrared, and cover a wider area of sky than current observations with the Hubble Space Telescope.

By combining my imaging with NIRCam with spectroscopy from NIRSpec, led by Roberto Maiolino, JADES will allow us to build unique synergies here in the Cavendish. For example, NIRCam images allow us to discover the earliest and most interesting objects in the universe, while the follow-up with NIRSpec will help us to characterize their physical properties in great detail. My scientific focus will be on establishing a complete census of galaxy formation at the current redshift frontier of z = 8-10, only a few hundred million years after the Big Bang. I will also study the stellar and chemical enrichment of galaxies, learn about the ionizing photon production efficiency and thereby find the sources that drive 'cosmic reionization', when the primordial fog of neutral hydrogen from the early Universe was ionised. Spatially resolving the structure of these early galaxies will shed new light on the physical mechanisms that are responsible for creating today's diversity of galaxies.

FIG. 1. Zoomed region of a simulation of the JADES southern deep imaging region. This false-colour image was created from synthetic data produced with the Guitarra image simulator (Willmer et al. 2020) and processed with the JADES mosaicing and analysis pipeline.

Sandro received his PhD from ETH Zurich, Switzerland in 2017. His PhD thesis has been awarded several prizes, including an ETH medal for an outstanding doctoral thesis and the Edith Alice Müller Award for the best PhD thesis from the Swiss Society for Astrophysics and Astronomy. From 2017 till 2021, he held the prestigious CfA Fellowship at the Harvard-Smithsonian Center for Astrophysics. In 2021, Sandro was appointed assistant professor in physics at the Ulsan National Institute of Science and Technology (UNIST) in South Korea.

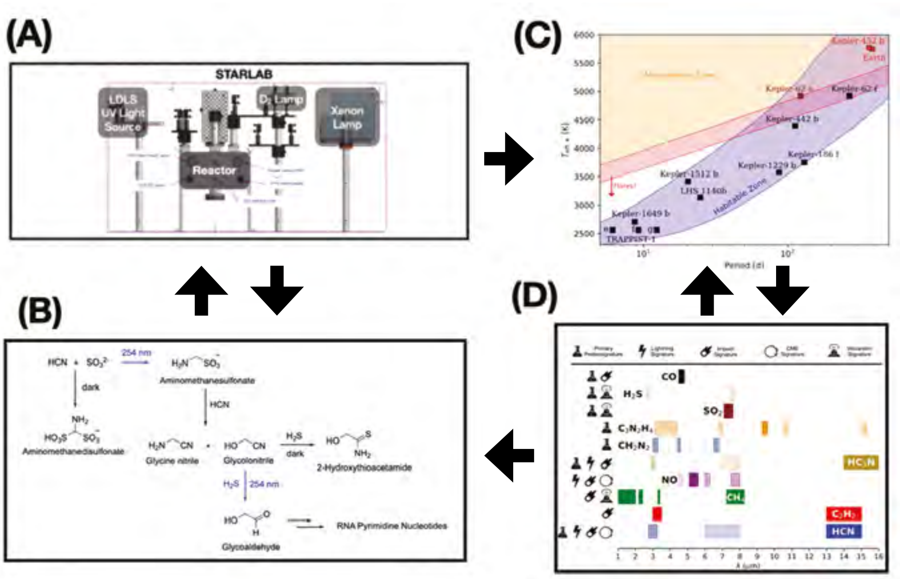
Simulating Planetary Surface Environments in the Laboratory - Testing Theories of the Origins of Life

We are delighted to welcome PAUL RIMMER as an University Associate Professor in the Laboratory and a member of the Leverhulme Centre for Life in the Universe. Here he describes the new scientific directions he brings with him in this extremely multi-disciplinary area of science.

There is a rich variety of chemical environments that exist on the surfaces and in the clouds of rocky planets. Perhaps some of these environments are conducive for the chemistry that could lead to the emergence of life. Given the immense timescales and uncertainty surrounding origins of life, it is a challenge to provide empirical tests for these assertions.

I and my colleagues explore the connections between fundamental physical processes, boundary conditions and prebiotic chemistry for environments on rocky planets, where prebiotically-relevant chemical reactions can take place. Our goal is pragmatic: first to search for those parameters that can be most readily explored in the laboratory and are most accurately constrained by observations. We start with the light of the star, which is almost always the best known component of any exoplanet system, and can be simulated in a relatively straightforward way in the laboratory (see Box 1).

The specific physical and chemical conditions present in a local environment can correlate with its global atmospheric chemistry, which can be a trace of these physical and chemical conditions on young rocky planets, such as those discovered with TESS and other surveys for exoplanets. Atmospheric characterization of these planets with JWST (see pp.10-11) and future observatories can provide insight into what local chemical environments are most likely to be present on these planets. Eventually, the observations of evolved systems can be connected with young systems to give insight into the evolution of planetary environments through remote detection of their atmospheres. If signs of life are found in exoplanet atmospheres, this would provide the first, and possibly one of the only ways, of empirically testing origins of life scenarios.



BOX 1. An experimental apparatus (A) that simulates the ultraviolet emission of any main sequence star, with a reactor chamber that can mimic the conditions on the surface of a rocky planet (B), the results of which may expand and modify these networks and (C) identify planets and exoplanets where this chemistry is most likely to take place, resulting in the identification of atmospheric chemical signatures (D) that can link physical conditions needed for prebiotic chemistry to the chemistry of the planet's atmosphere.

Chemistry is universal. The chemistry we focus on can be studied in greatest detail in the laboratory, next in local environments on Earth, then on planets within our solar system and finally on exoplanets. Exoplanets have the advantage of very large numbers, allowing statistical investigations across the broadest possible ranges of stellar environments and planet formation histories. We start with laboratory investigations into the rates at which chemical reactions occur, and apply our results to models and observations of rocky solar system objects, especially Earth, Mars and Venus. Then, we can we apply this understanding to provide the necessary context for the study of exoplanets. Yet it will be on exoplanets where many of the ideas about life's origins, presently confined to the laboratory, will someday be put to the test in the nature of other worlds.

Brief Curriculum vitae

Paul is an astrophysicist and astrochemist. He completed his PhD in Physics at Ohio State University under Eric Herbst, and undertook postdoctoral research on exoplanet atmospheres at St Andrews with Christiane Helling, and at Cambridge with Didier Queloz and John Sutherland, working on the connection between prebiotic chemistry and the search for life on exoplanets. He is now building up a Planetary Astrochemistry group in the Laboratory.

James Webb Space Telescope (JWST) delivers the first Early Release Data

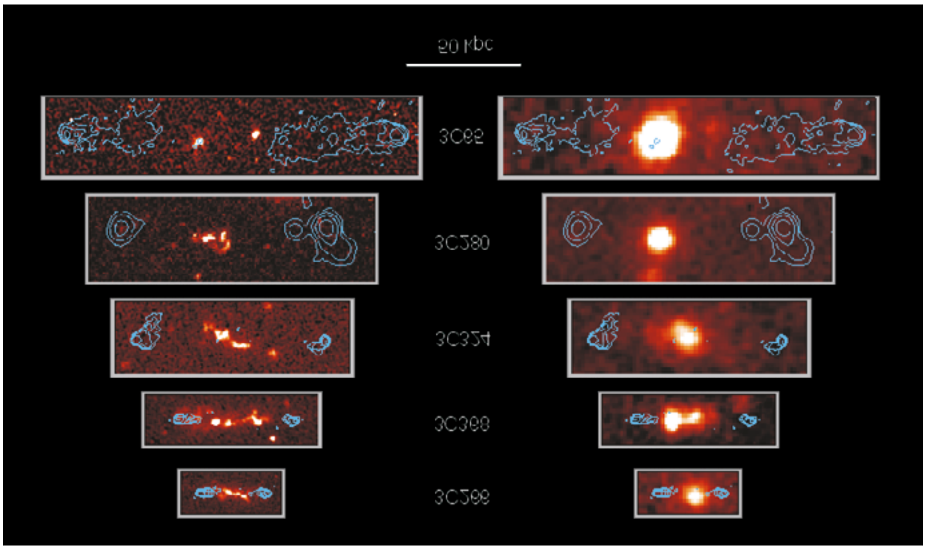
The successful release of the first images taken by the James Webb Space Telescope (JWST) is an incredible achievement by all the agencies, scientists and engineers involved in this very large $10B space project.

FIG. 1. The galaxy cluster SMACS 0723 observed in the near infrared waveband by the JWST. This deep field image, taken with the Near-Infrared Camera (NIRCam), is a composite of images at different wavelengths in an 12.5 hour observation. The cluster acts as a gravitational lens, magnifying much more distant galaxies and creating the 'arcs' centred on the cluster. Image Credit: courtesy of NASA, ESA, CSA, and STScI.

Space astronomy is an expensive business but, when the requirement is to launch and operate diffraction-limited telescopes for the optical/infrared regions of the spectrum, the costs are literally 'astronomical'. I was fortunate enough to serve on senior advisory committees for both the Hubble Space Telescope (HST) and the James Webb Space Telescope (JWST). It is a humbling story, this essay reflecting not only on the science but also on the technical and political challenges which had to be overcome. In another article in this edition of CavMag, Sandro Tacchella (p.8) describes how he will be tackling the problems of the origins of galaxies and black holes as a Guaranteed Time Observer on the JWST – if I were a young astrophysicist again, I would do exactly what he will be doing!

Concepts for a large optical telescope in space had their origins in Lyman Spitzer's review for the RAND corporation of 1946 entitled 'Astronomical Advantages of an Extraterrestrial Observatory.' Concepts for a large optical telescope in space began in the early 1960s and in 1971 NASA began detailed studies of a 3-metre telescope, the Large Space Telescope. In 1977, the US Congress approved the project for a 2.4 metre Space Telescope, which would comfortably fit in the cargo bay of the Space Shuttle. This made the project much more feasible, but what many of us did not know was that NASA had already launched a diffraction-limited 2.4 m telescope for surveillance purposes (see Wikipedia article on the KH-11 Kennen high-resolution surveillance satellite project).

The approval process was touch and go, the project being secured by involvement of the European Space Agency at a level of 15% of the total cost. I was fortunate enough to be selected as an interdisciplinary scientist of the Science Working Group (SWG) for the project. Indelibly ingrained on my memory are the words of the Project Manager of the first meeting of the SWG in October 1977: 'This is a low-cost success-oriented programme which will cost $700M.' The killer words were 'success-oriented' – nothing had to go wrong. The rest of the story is well-known: the underfunding of the project, the tragedy of the 1986 *Challenger* disaster, the launch in 1990 and the discovery of the spherical aberration problem with the optics and the final success with the first refurbishment mission of 1994. I



obtained my spectacular images of large redshift radio galaxies within a year of the refurbishment of the telescope (Fig. 2). The HST turned out to be a terrific success, despite its turbulent history, Almost every branch of astronomy has benefitted from the superb imaging and spectroscopic capabilities of the HST.

In due course, I was invited to become a member of the JWST Science Working Group, reporting to the Director of the Space Telescope Science Institute. If the HST was a major challenge, the JWST was a truly staggering challenge. The mirror was to be 6.5 m in diameter, consisting of 18 hexagonal segments which had to be unfolded in space to form a perfect mirror; the telescope was to be located at the second Lagangian point very far from the Earth and so everything had to work successfully remotely; the telescope was designed for infrared wavelengths and so the mirror had to be passively cooled while the scientific instruments had to be cryogenically cooled; perhaps most challenging of all, there had to be a sun/heat shield to prevent overheating of the whole telescope structure and instruments. This last was a very scary part of the project – it consists of five separated sheets of Kapton E with aluminum and doped-silicon coatings, the outer sheet being 0.05 mm thick while the other four layers are 0.025 mm thick, each the size of a tennis court.

The project had numerous ups and downs. With the termination of the Space Shuttle programme, NASA had no launcher capable of placing the telescope in a trajectory to reach the second Lagrangian point. Instead, collaboration with the European Space Agency resulted in agreement to launch the telescope with an ESA Arianne 5 rocket. Getting agreement to this decision took time with consequent increases to the cost of the programme. The project was over-budget. To my surprise, I was asked by NASA to chair a 'Tiger team' to recommend savings of $2B for the project. We could do nothing about the delay in the project, but found very significant savings by relaxing some of the extreme performance specifications of a number of key elements of the project. Eventually, these were adopted and a new realistic budget for the project allocated, 8B$. From that point on, the project progressed well, despite a number of challenges along the way.

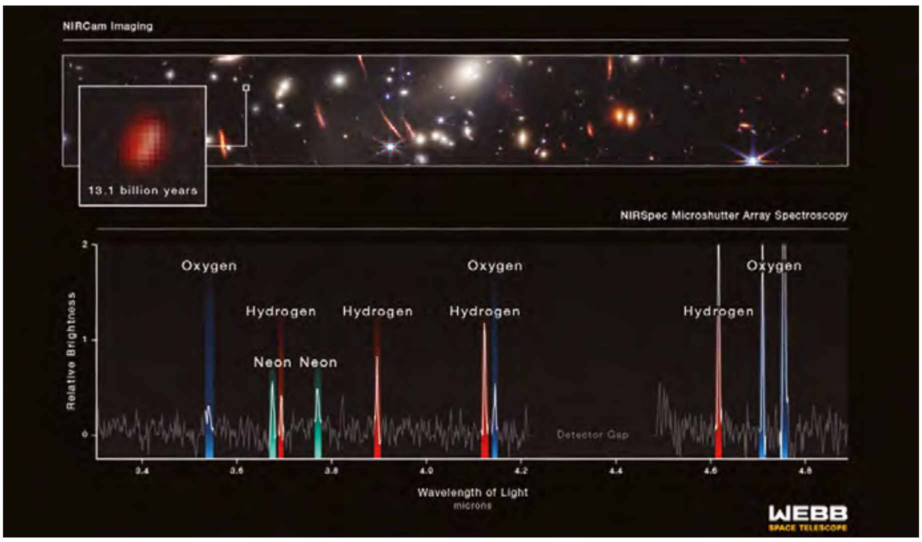
To my amazement, although there were some delays, everything went according to plan, including the deployment of the sun/heat shield. Equally, all the instruments seem to have been successfully deployed. Fig.1 shows a spectacular very deep image of a region of sky taken in the infrared waveband. The image is in 'false colour', being a composite of a number of images at different wavelengths in the 1 to 5 micron waveband. This was intended to enable the most distant and highly redshifted objects to be observed. The near-infrared spectrometer (NIRSpec), provided by ESA, enabled the spectra of very distant galaxies to be observed in the 1 to 5 micron waveband (Fig. 3) The combination of infrared imaging and spectroscopy will undoubtedly open up entirely new windows for astrophysical cosmology, as described by Sandro.

We live in exciting times, perhaps especially for the new generation of young astrophysicists who have the opportunity to create the new astrophysics and cosmology of the 21st century.

MALCOLM LONGAIR

FIG. 2 (ABOVE). HST (optical, left) and UKIRT (2.2 µm, right) images of the radio galaxies 3C 266, 368, 324, 280 and 65 with the VLA radio contours superimposed. The images are drawn on the same physical scale. The resolution of the HST images is 0.1 arcsec while the ground-based infrared images is about 1 arcsec (Longair, M., 1997. A&G, 38, 10–15).

FIG. 3 (BELOW). The spectrum of a very distant galaxy, observed in the near infrared waveband. It emitted its light at a redshift z ~ 8.2, about 13.1 billion years ago. Image Credit: courtesy of NASA, ESA, CSA, and STScI.



Swords into Ploughshares


DAVID WILLIAMSON and PAUL SAGOO describe the powerful facilities at the AWE which can now be used by the University community. New collaborative initiatives are welcomed.

Throughout history, innovations in the understanding of physics have resulted in applications to state security and enhanced military capability. Examples include Galileo's enhancement of the capabilities of the telescope as a means of observing distant naval aggressors and Cockcroft and Walton's 1932 demonstration of lithium disintegration by accelerated protons. In the same year, the discovery of the neutron immediately led to the potential for nuclear fission as a source of extremely high energy releases. During times of national emergency, physicists have carried out research of central importance for national security, for example, the prediction during the second world war of the existence of plutonium carried out by Norman Feather and Egon Bretscher in the Cavendish Laboratory. The UK participated in the Manhattan Project, the British contingent being led by Cavendish Physicist James Chadwick and his colleague G.I. Taylor.

In the 1950s, what was to become the Physics and Chemistry of Solids Group was transferred from Physical Chemistry to the Cavendish under the leadership of Philip Bowden. Abe Yoffe and John Field joined this effort, disentangling the sensitivity of explosives to 'hot-spots' in unstable materials. The group developed important collaborations in the physics of materials under high stresses, which were of interest for military vehicles and in the strength properties of car windscreens.

AWE'S MISSION

AWE has responsibility for the warheads for the UK's deterrent and provides specialist expertise to support national security. It is the technical authority for the UK Government's defence against the illicit trafficking of nuclear and radiological materials. It collaborates with the international community to develop new detection systems with greater sensitivity that will ensure the UK border remains safe. In the event of a nuclear or radiological incident, AWE has the expertise to advise Government on its response and subsequent activities.

When the Comprehensive Test Ban Treaty was signed in 1996 and ratified in 1998, all nuclear testing was prohibited. In order to fulfil AWE's mission, testing now takes place inside incredibly powerful supercomputers. One of their latest supercomputers,

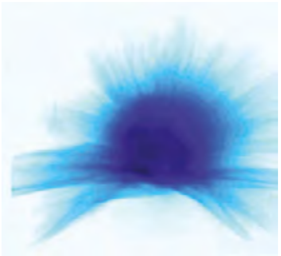

LEFT: The 1932 Cockcroft-Walton machine with Walton in the observation 'tent' and Cockcroft in the background (©Cavendish Laboratory).

RIGHT: Philip Dee's 1933 cloud chamber photograph of the disintegration of lithium by fast protons, the reaction observed by Cockcroft and Walton a year earlier (©Cavendish Laboratory).

Vulcan, features 5000 processors based upon 32-core with a theoretical peak performance of 7.42 PetaFLOPs – that is 7.42 million billion calculations per second!

The models and simulations require a deep understanding of nuclear physics, atomic physics, plasma physics, quantum chemistry and hydrodynamics. The physics understanding is informed and validated by experiments using the AWE's Orion laser, the biggest experimental facility for high-energy density physics in the UK.

Orion creates matter many times denser than solids and similar to that found at the centre of giant planets such as Jupiter. At temperatures more than 10 million degrees, Orion can replicate the conditions found at the centre of the Sun and simulate supernovae in the laboratory. These extreme physical conditions provide support to research into inertial fusion energy, planetary and solar physics, high-energy particle acceleration and black holes. AWE allocates up to 15% of Orion's system time each year for cutting-edge collaborative experiments with their academic partners.



LEFT: AWE scientist inspects a target in the Orion laser facility.

RIGHT: Radiochromic film is used to diagnose the protons and ions produced in ultra-high intensity laser-plasma interactions. Major uses are in medical applications such as measuring dose in radiotherapy. (Courtesy of AWE)

COLLABORATIONS – A CAMBRIDGE EXAMPLE

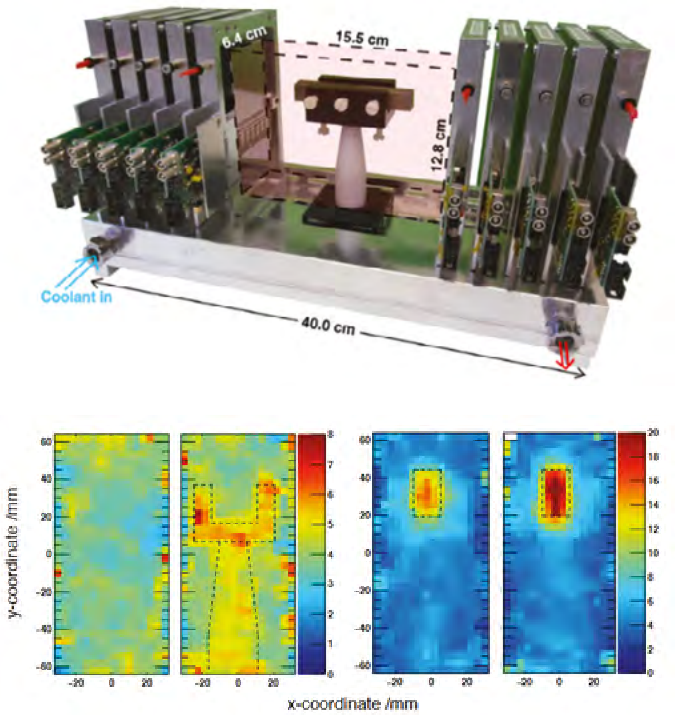
Much of AWE's research and expertise relies on working with academic partners through significant Outreach activities. In collaboration with the UK's Research Councils, AWE provides funding for Centres of Doctoral Training (CDTs) and also benefits from part-funded postgraduate studentships. Current plans recognise the need for greater engagement with business and industry, as well as academe.

AWE has regularly funded a number of PhD studentships at the Cavendish Laboratory and the wider University of Cambridge. A recent example of societal benefit was the AWE-supported PhD project of Cavendish student Floris Keizer. He demonstrated how muon detectors designed for the ATLAS experiment at CERN could be used to detect cosmic-ray muons being scattered by nuclear materials (see right). Such technology links in with AWE's mission to support national security.

One of us, David Williamson, joined the Physics and Chemistry of Solids Group as a graduate student in 2002, jointly funded by AWE and EPRSC through the Industrial CASE scheme. Since 2018, he has been leading a Group of about a dozen PhD students and postdoctoral researchers, almost all of them having either industrial or governmental involvement. David's personal research interests are the dynamic behaviour of materials, the instrumentation to characterise them and the development of the necessary theorical framework. He was recently appointed Director of Research in the Laboratory, a major responsibility being acting as point of contact between the AWE and the Cavendish Laboratory. New areas of particular interest are quantum computing and algorithms, novel sensor technologies and advanced modelling capabilities.

There are many exciting and unique opportunities in science and physics in collaboration with AWE. The expert teams research the physics of extreme temperatures and pressures found in the heart of nuclear events and in the cosmos such as stellar interiors. These enable us to understand the performance, safety and reliability of the deterrent and to safeguard national security, as well as offering innovative applications in STEM.

If you would like to find out more or collaborate with AWE and the other partners and the programmes listed above, please contact David Williamson dmw28@cam.ac.uk. If you would like to know more about AWE's university partnerships, please email outreach@awe.co.uk. See also www.awe.co.uk and Twitter @AWE_plc.



Demonstrating the use of cosmic-ray muons to detect smuggled nuclear materials. TOP: two banks of five ATLAS Semiconductor Tracker modules detect the trajectories of incoming cosmic-ray muons and the angle of scattering by objects placed between them. BOTTOM: tomographic reconstruction of the scattering object. LEFT TO RIGHT: air, plastic holder, iron and lead samples (Courtesy of Floris Keizer, PhD Thesis 2019)

Vibration enhanced transport for fast and long-range electronic charge, ion and energy transport

HENNING SIRRINGHAUS **describes remarkable new insights into the processes which limit efficient energy transport in organic and similar semiconductors and how the traditional limits can be overcome. These innovations have major implications for the sustainability agenda.**

The world faces large and urgent challenges in transitioning to a zero-carbon, sustainable energy economy and in addressing global health needs of ageing and highly connected populations. While many of the required technological solutions already exist, new energy and bioelectronic materials offer great opportunities for improving the performance, reliability, cost, and sustainability of these technologies and new solutions to problems that remain difficult to address. However, these new materials often operate in very different and less well understood physical regimes than those present in conventional inorganic materials, such as silicon.

In silicon and other inorganic semiconductors, the interaction of electronic excitations with lattice vibrations is an undesirable perturbation; it limits charge carrier mobilities and mediates non-radiative recombination. In low-dimensional functional materials with non-covalent bonding the structural dynamics is not a mere perturbation - it moves centre-stage. Some vibrational modes are very soft and strongly anharmonic so that electronic processes occur in a strongly fluctuating structural landscape. The traditional view is that the resulting strong electron-vibrational coupling is also detrimental. In organic semiconductors (OSCs), for example, electronic charges and neutral electron-hole pairs (excitons) are localized by a 'cloud' of lattice deformations, which causes charge mobilities and exciton diffusion lengths to be undesirably small, thus limiting the performance of optoelectronic devices.

We have recently discovered systems in which this traditional paradigm does not hold, but in which the structural dynamics is highly beneficial and mediates surprisingly fast, long-range excitation transport. This runs completely against models developed for traditional semiconductors such as silicon, for which phonons limit electronic transport. The new mechanism involves vibrational modes coupling localized states near the band edges to highly delocalised states within the bands that can then transport charges and energy over unprecedentedly long length scales. This unique vibration-enhanced transport regime, in which excitations are effectively able to "surf on the waves" of structural lattice distortions, is not found in silicon and was first discovered in OSCs.

We have been awarded a new 5-year, £6.7 million Programme Grant by the Engineering and Physical Sciences Research Council (EPSRC) to explore this unique vibration enhanced transport regime as a general paradigm for achieving fast and long-range electronic charge, ion and energy transport in a broad class of organic and inorganic, functional materials with soft structural dynamics. The scope is not limited to OSCs, but also includes hybrid organic-inorganic perovskite (HOIP) semiconductors, 2D conjugated covalent/metal organic frameworks (COFs/MOFs) and inorganic ceramics and ion conductors. The project could lead to new and better materials and device architectures for a range of applications in photodetection and photovoltaics, photocatalysis, thermal energy harvesting, energy storage and bioelectronics. Our team involves a collaboration between researchers in the Cavendish Laboratory (Friend, Greenham, Rao, Sirringhaus (PI)), the Department of Chemistry (Grey, Bronstein), Materials Science (Monserrat) and Electrical Engineering (Malliaras), as well as two researchers at the Department of Chemistry of the University of Oxford (McCulloch, Goodwin).

To better understand this vibration-enhanced transport framework, more technically also referred to as the transient delocalisation framework [1], it is helpful to think of charge carriers and other electronic excitations, such as excitons, as highly dynamic species, that are strongly coupled to the structural dynamics and are constantly changing their shape and size because of their coupling to vibrational modes. As an example, Fig. 1(B) shows the simulated time evolution of the wavefunction of an electron in a single crystal of an organic semiconductor. The coloured regions

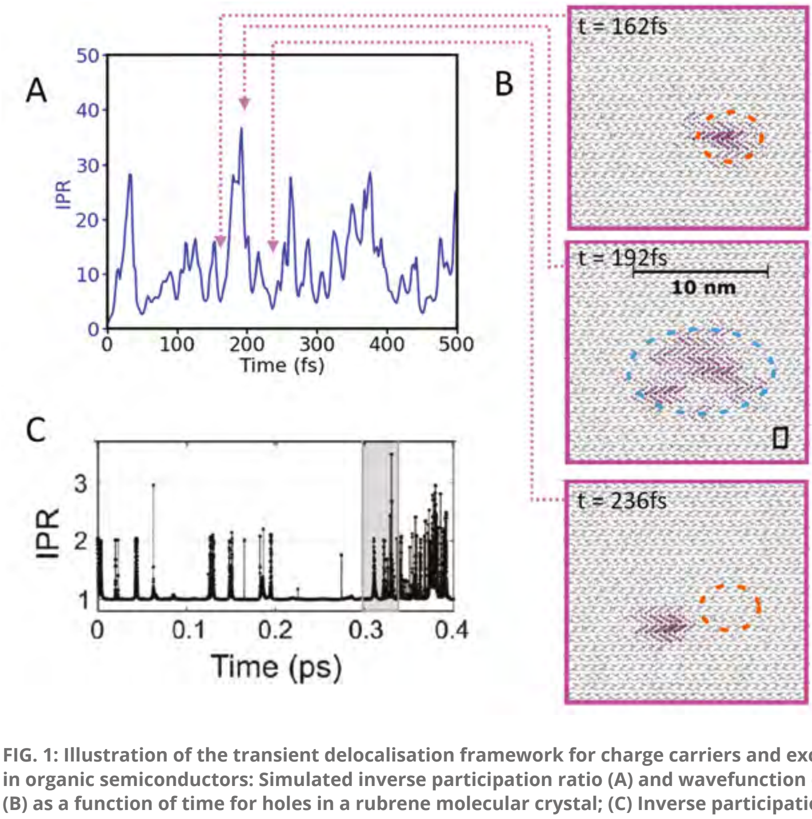


FIG. 1: Illustration of the transient delocalisation framework for charge carriers and excitons in organic semiconductors: Simulated inverse participation ratio (A) and wavefunction extent (B) as a function of time for holes in a rubrene molecular crystal; (C) Inverse participation ratio for excitons in nanofibers of a polythiophene conjugated polymer. Adapted with permission from Ref. [2][3]

indicate where the charge is located at particular points in time and the grey objects are the individual molecules [2]. For most of the time the wavefunction is highly localized on small clusters of molecules, but on a timescale of typically 10's of femtoseconds (fs) the coupling to vibrations allows these excitations to access states that are up to several k_BT away from the band edges and are more delocalized. This is reflected in short, 10s of fs bursts of the inverse participation ratio (IPR), which is a measure of the number of molecules over which the wavefunction is delocalised (A). Occasionally, on a typical timescale of a few 100 fs, these bursts reach states that are very highly delocalised over up to 30-40 molecules. A very similar mechanism also applies to excitons (C). In nanofibres of P3HT excitons can access states in this way that are delocalized over up to 4 polymer chains [3]. After every such delocalisation burst, there is a finite probability that the excitation settles back into a localized state not at the original site, but at a site far away from the original one. It is such long-distance, vibration-mediated charge/energy transfer processes that are responsible for the exceptionally high carrier mobilities [1] and exciton diffusion coefficients recently observed in OSCs [4].

We are grateful for the support from EPSRC that will allow us to explore how general this intriguing vibration-enhanced transport mechanism may be and how it might be utilised for the development of new classes of energy and bioelectronic materials with much enhanced transport properties.

1. Fratini, S. et al. Nat. Mater. 2020, 19, 491–502, doi:10.1038/nmat4970
2. Giannini, S. et al. Nat. Commun. 2019, 10, 3843, doi:10.1038/s41467-019-11775-9.
3. Sneyd, A.J. et al. Sci. Adv. 2021, 7 : eabh4232, doi:10.1126/sciadv.abh4232
4. Jin, X.-H. et al. Science 2018, 360, 897, doi:10.1126/science.aar8104

Amy Ogle – Maxwell's first female undergraduate student

ISOBEL FALCONER **describes the remarkable story of Amy Ogle, a truly pioneering women student who died tragically young.**

'My best man is Ogle,' declared an examiner for Cambridge's Natural Sciences Tripos, in 1876. He was unaware that 'Ogle' was a woman.[1]

Amy Ogle (1848–1878) came top in the Natural Sciences Tripos (NST) 14 years before Philippa Fawcett achieved a similar distinction in Cambridge's Mathematical Tripos. Fawcett is famous, while Ogle is unknown, reflecting the much greater prestige of mathematics over natural sciences at the time, and how the position of women had changed in those 14 years.

When Amy took the NST, women required special permission to take Tripos exams and their results were not published as the men's were. Evidence of her achievement has remained hidden in the NST mark books, apart from a brief mention in an obscure government report two years later. Her college, Newnham, *did* know that she had gained a First, from the customary informal report sent to them by the examiners; this was leaked to the press causing a brief stir. The *Athenaeum* reported,

During the recent Natural Science Tripos examination at Cambridge, a lady, Miss Ogle, who is a student at Newnham Hall, the Cambridge college for women, was, by the permission of the examiners, subjected to precisely the same examination, as that which the members of the University underwent. She acquitted herself in such a manner, as would have entitled her, had she been an undergraduate, to a place in the first-class.[2]

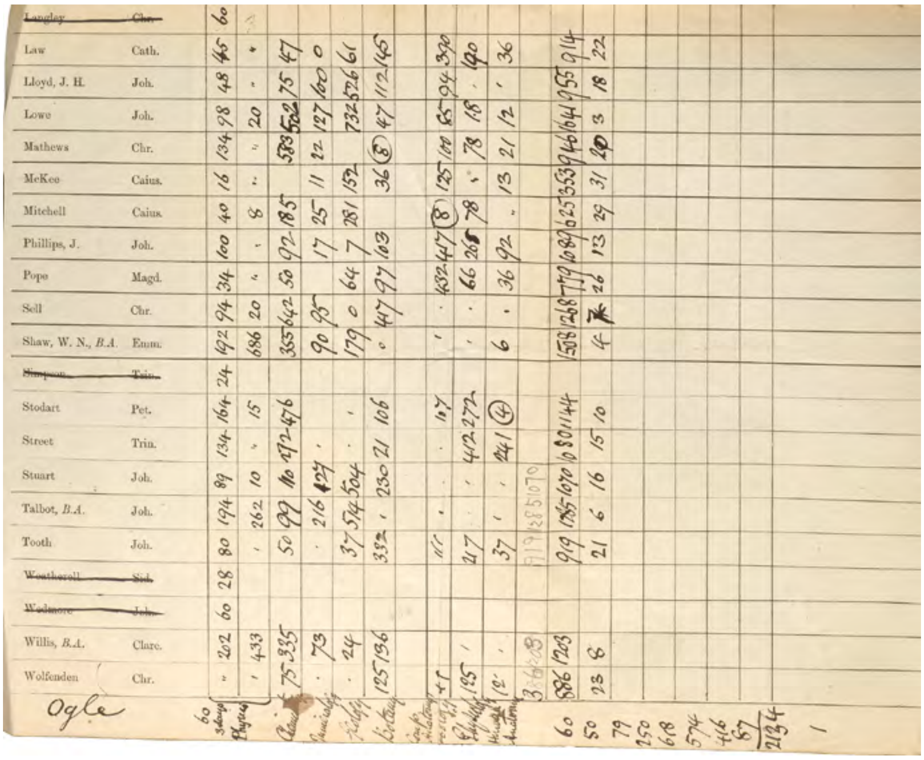


FIG 1: NST mark book for 1876. As was usual, women's marks were added as an afterthought at the bottom of the page (Courtesy of the Cambridge University Library Digital Content Unit).

Amy took six sciences in Part II, not an unusual number, coming top in zoology, second in physiology and third in botany. However, what intrigued me more was that she was the only woman in the Maxwellian era of the Cavendish to obtain a respectable mark in physics. Her modest 50 paled in comparison with the 686 of the top candidate – William Napier Shaw, the meteorologist. But 50 was still high enough to place Amy 6th out of the 16 people (15 men) taking Part II physics.

In 1874 the Cavendish had opened its doors to 'any member of the University'. But women were not members, and not until 1878, two years after Amy took the Tripos, did Maxwell reluctantly permit the Demonstrator, William Garnett, to admit women for an accelerated course during the Long Vacation. So, when, and how did Amy learn her physics?

Miss Clough, Principal of Newnham, tells us that Amy 'received her early education under her father's special superintendence.'[3] This was probably along with the boys at the small boarding school that her parents, John and Sarah Ogle, ran in a rented country house, 'St Clere', in Kent. They were strongly influenced by Pestalozzi and a belief that 'the family must be the model of the [educational] community we form. It is a Divine Institution.'[4] A corollary was mixing between the schoolmaster's family and pupils, and John's unconventional stand that teaching boys and girls together was the best way to ensure their social and moral development. The Pestalozzian emphasis on observation would have prepared Amy well for success in science and she may have gained a good mathematical grounding from the succession of teachers at St Clere that included a Cambridge wrangler Robert Tucker. Certainly at least three pupils from the school, including Amy's elder brother John Lockhart, became Cambridge wranglers.[5]

Miss Clough characterised Amy as 'industrious' and 'earnest', though 'interesting',[6] but did not remark on how determined and quietly unconventional she must have been. By the 1871 census, when her sisters were all living with their parents, Amy was teaching at a girls' school in Edinburgh. Here she may have engaged with the nascent opportunities for women's higher education offered by the Edinburgh Ladies Educational Association, or the Watt Institute, although so far I have found no evidence.

Amy came to Newnham in 1873, two years after its foundation, when she was 25. She supported herself by scholarships, was one of two students living 'out', perhaps because it was cheaper, and probably paid the reduced fees for women intending to become teachers. Although Maxwell barred them from the Cavendish, Philip Main, Superintendent of St John's College Laboratory, welcomed women and it seems likely that Coutts Trotter, Chairman of Newnham's Council, admitted them to his physics lectures at Trinity. But Amy also had another opportunity – the short summer courses for teachers offered at South Kensington. These included 'sound', 'light', and 'steam', which Amy may have attended, and biological subjects which she certainly did. In 1878 William Thiselton-Dyer reported to the Government Department of Science and Arts,

FIG 2: St Clere, which Amy's parents rented to house their boarding school (Courtesy of Oast-House-Archive)

'Miss A.H. Ogle attended my course in Botany in 1876 as a paying student. In the Michaelmas term of the same year she answered the papers set in the Natural Sciences Tripos at Cambridge, where I was one of the examiners. Although the regulations do not allow the results in the case of women to be officially published, Miss Ogle's marks would have placed her at the head of the tripos, and she did particularly well in Botany. Miss Ogle is now, I believe, head of a large middle-class school.'[7]

Unfortunately, Thiselton-Dyer was mistaken in his belief; Amy had died in childbirth a few months earlier. Following her Tripos success she lectured in Natural Sciences at Newnham for a term before marrying an evangelical Christian Jew, Dr Joseph Koppel. But marriage and incipient motherhood did not curtail her career aspirations. In November 1877, already pregnant, she was appointed Principal of the Training College being established in London's Bishopsgate by the Teachers' Training and Registration Society.[8] Her daughter Una was born on 13 January 1878 and Amy died the same day, before taking up her appointment.

Amy was among the first of a group who, over the next 40 years, forged career paths into academia for women via prestigious appointments at teacher training colleges.[9] But, in negotiating to continue her career while married with young children, she started on a different path to that that subsequently became stereotypical, of spinster academics.[10] Had she lived, might her example have prompted alternative models?

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1. William Grylls Adams to Millicent Fawcett, 7 February 1896. Manchester Central Library, Letters to Mrs Fawcett, GB127.M50/3/1/20
2. *The Athenaeum*. (6 January 1877), p.19.
3. Anne J. Clough, Correspondence, *Journal of the Women's Education Union*, Feb 15, 1878, vol 6, issue 62, pp30-31
4. John Ogle (1871) 'The application of theory in the practice of education', Lecture to the College of Preceptors, 14 June 1871, *Educational Times* 24(123), 71-78 (71)
5. John Stuart Jackson, 5th wrangler 1851, William Previté, 32nd wrangler 1860; John Lockhart Ogle, 29th wrangler 1866; ACAD https://venn.lib.cam.ac.uk/; M J M Hill, Obituary Notice : Robert Tucker, Proc. London Math. Soc. (1905), xii-xx.
6. Clough, Blanche Athena. *A Memoir of Anne Jemima Clough.* London, New York : E. Arnold, 1897, p201-202; Anne J. Clough, op. cit. 3
7. W. Thiselton-Dyer, quoted by Lieut-Col. Donnelly, 'Twenty fifth report of the Science and Art Department of the Committee of Council on Education, with appendices: Appendix B: Science Instruction', Parliamentary Papers, Command Papers, 1878, p34
8. Subsequently Maria Gray College, which merged with the West London Institute of Higher Education in 1976, and was absorbed into Brunel University in 1995.
9. Dyhouse, Carol. *No Distinction Of Sex?: Women In British Universities, 1870-1939*. Routledge, 2016, p136
10. Dyhouse, p161, notes that 79-85% of female academics in the 1884-1904 period remained lifelong spinsters

Lisa Jardine-Wright OBE

We are delighted to congratulate Lisa Jardine-Wright on the award of an OBE for her contributions to education.

FIG. 1(A) Lisa at the Institute of Physics Awards, 2019 and (B) teaching at an Isaac Physics Event. Image credit. Wikipedia and isaacphysics.org

Lisa has been recognised for her contribution to physics education, particularly for the impact of the Isaac Physics project, which she co-founded with the late Mark Warner. Isaac is an Open Platform for Active Learning (OPAL) designed to offer support and activities in physics problem solving to teachers and to students transitioning from the start of secondary school (year 7), through to Sixth Form (year 12 & 13) and to university. It combines an online study tool with face-to-face events at partner schools and institutions across the UK. As a platform Isaac Physics offers support and activities in physics problem solving to teachers and students.

Reacting to the news Lisa said, 'I am completely stunned to have been awarded an OBE. It means a great deal to me as it recognises the importance of physics education and the impact that the Isaac Physics project has made. I feel energised to keep innovating and to do more to raise the profile of physics'.

This news first appeared on the University of Cambridge website.

"I am extremely fortunate to work with highly talented and dedicated people, in particular, the late Professor Mark Warner, an inspirational and brilliant physicist, and Professors Alastair Beresford and Andrew Rice, whose technological vision for the Isaac platform has encouraged nearly 100 million question attempts by teachers and students thus far."

Research Excellence Framework (REF 2021) Results - Cambridge Physics and Astronomy

REF2021 Research Excellence Framework

Earlier this summer, the results of the seven-yearly Research Assessment Framework (REF) were announced. This exercise is crucial in determining the level of government funding for Cambridge Physics and Astronomy, which are considered together as one unit of assessment out of 30. The submission of each unit was judged by three criteria: (1) outputs, such as publications, performances and exhibitions, (2) the societal impact of the research and (3) the environment that supports research.

99% of Cambridge's overall submissions in Physics and Astronomy were rated as 'world leading' (64%) or 'internationally excellent' (35%), demonstrating the major impact that researchers in our departments are making every day. The average weighted score – the 'grade point average' – for Physics and Astronomy was 3.63 out of 4. This moves us up from 3.29 in 2014. This metric ranked the Cambridge Physics and Astronomy submission in 3rd place nationally. Among the very large UK Physics and Astronomy Departments, Cambridge came first.

It is particularly pleasing that Cambridge Physics and Astronomy came first in the UK for impact, which measures direct contributions to society and industry over a whole variety of activities. An example of a particularly strong impact was the book *Sustainable energy – without the hot air*, the late David Mackay's influential analysis which has opened up the science of sustainability and influenced UK climate policy.

The Departments also particularly support many young research fellows at early stages in their careers who go on to provide major impact in permanent roles in UK universities and across the world.

Andy Parker, Head of the Department of Physics, said: 'This recognition of our world-leading science and how it supports society is particularly pleasing, and demonstrates the importance of our work in tackling the challenges facing the country, and indeed the world.'

Richard McMahon, Director of the Institute of Astronomy, said: 'It is an enormous pleasure to thank and congratulate all my colleagues for their research achievements, which have been recognised with these excellent results.'

Anne Ferguson-Smith, Pro-Vice-Chancellor for Research, added: 'I would like to congratulate and thank everyone who has taken part in this year's REF for all their hard work, which we believe has paid off in these results. What we see today is not just the excellence of Cambridge research, but also the breadth of its impact, with researchers across many disciplines bringing a fresh perspective on how we tackle major problems facing our world today.'

The Cambridge Physics and Astronomy REF team was led by Charles Smith, supported by colleagues from both departments. We thank them all most sincerely for their outstanding efforts and very hard work.

MALCOLM LONGAIR

Ray Dolby Centre building progress: the Architect's view

We are grateful to JUDE HARRIS, Director, and LILIANA VAZ, Project Architect, of Jestico + Whiles for providing an architect's view of the Ray Dolby Centre, now coming closer and closer to completion.

The construction of the Ray Dolby Centre is now showing many of the original design concepts developed by the architects Jestico + Whiles into built reality. It is bringing to fruition many of the ideas for the new building that were discussed and developed in close collaboration with Cavendish users from the briefing stages going back to 2016. The 33,000 m² of this world-leading facility is now fully delineated on the construction site and we can see how the five separate wings come together in their various shapes and finishes, expressing the science that will go on inside.

The completion of the building's envelope is in its final stage and we can now see the full palette of materials and how their articulation responds to the brief for a 'timeless architecture'. The materials of polished pre-cast concrete, glass and metal panels very much respond to the light of varying weather conditions and different times of day to create a subtly changing façade. This simple and robust palette also gives the sense of visual weight that we were seeking architecturally.

Facing onto JJ Thomson Avenue, we can see the vertical fins of polished concrete which are angled in response to the tracking path of the sun and, together with the angled glazing between, form a 'sawtooth' arrangement creating a dynamism and visual interest when passing along the street (Fig. 1).

The dramatic cantilevered polished concrete slabs that provide important solar shading on the south façade and the large picture windows facing the Central Gardens are now installed (Fig. 2). This façade of the building will create an active frontage with selected views into the laboratories, revealing some of the cutting-edge scientific research that will be carried out in the building.

The visual permeability of the public wing was another key concept of the design and is now taking shape with the construction of the entrance plaza. It will express the public route as a folding plane that rises from the Central Gardens, extends into the entrance hall, folds around the public wing and terminates in the Common Room located on the top floor, with its magnificent terrace views over Cambridge.

Inside the building, we can now see the dramatic shapes of the small lecture theatre hanging above the double-height entrance hall (Fig. 3) and the larger lecture theatre over the learning resource centre. As we walk around the construction site it is encouraging to see daylight at the ends of corridors as a key design strategy to assist orientation and wayfinding across such a large building (Fig. 4). Also emerging are the spaces that have been deliberately carved out of the circulation areas to encourage breakout and collaboration.

While the public wing is only starting to take its final shape, the research and teaching wings are much more advanced with the highly complex and extensive services installations progressing well. The internal finishes are also advanced with the chosen palette and colour responding to key technical requirements alongside providing visual comfort and assisting with wayfinding (Fig. 5).

It is already possible to see some of the recently planted landscape flourishing in the internal courtyards (Fig.6). These are key design features to bring nature into the heart of the building helping to provide daylight and views to offices and laboratories, which will help promote the wellbeing of all the staff, students, and visitors.

As architects we are all delighted and proud to see our design being realised to such an exceptional standard and very much look forward to seeing its completion next year!

FIG. 3. Small lecture theatre exterior

FIG. 1. The elevation sawtooth on JJ Thomson Avenue

FIG. 2. South elevation and emerging entrance plaza.

FIG. 4. Corridor window for orientation

FIG. 5. West elevation materials palette

FIG. 6. Main courtyard landscape

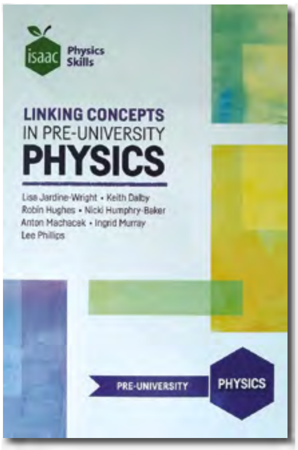
New horizons for Isaac Physics and return to in-person events

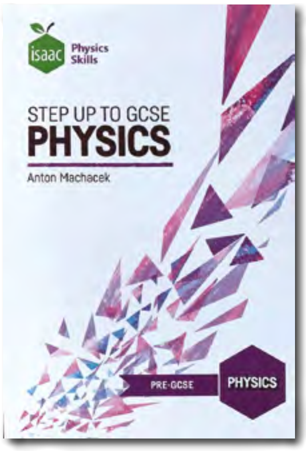
NICKI HUMPHRY-BAKER, Assistant Director of the Isaac Physics Project, describes the remarkable developments over the last couple of years.

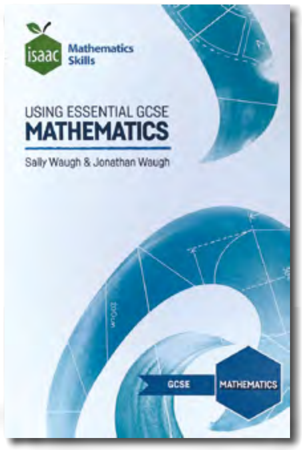
The Isaac Physics platform has expanded greatly over the past year. In preparation for the start of STEM SMART, two chemists joined the team and wrote hundreds of questions for Isaac Physics covering all the A level chemistry syllabus. Three new books were released: a new book for A Level students called Linking Concepts, focusing on rearranging equations and problem-solving skills; a second book, Step Up to GCSE, is aimed at Year 9 students to prepare them for GCSE. The latter was the first of our new materials for 11–14 year olds. We also released a book to support GCSE Maths teaching, and the use and practice of fundamental maths concepts in science teaching.

In July, we launched the first 10 lessons for Years 7 and 8. The lessons contain sets of questions for class and homework. These follow the hallmark Isaac Physics style of including maths alongside the physics. Quick teacher support videos accompany the lessons to give teachers a brief reminder and to support those teachers whose specialism is not in physics. Initial feedback from teachers has been very positive.

Alongside the development of these new materials, the Isaac Physics team have supported strongly the ground-breaking, nationwide STEM SMART programme under the leadership of Isaac Physics Director Lisa Jardine-Wright and Subject Convenor for Natural Sciences (Physical) Michael Sutherland. The 850 Year 12 students who took part in this pilot year showed terrific dedication to







their studies attending weekly, online supervisions in each of physics, chemistry and mathematics as well as fortnightly mentoring by Cambridge students, in addition to answering over 372 000 questions on Isaac Physics since January, an average of 40 per student per week. The 340 most committed students were invited to attend a residential course at the end of August giving them a chance to see Cambridge and the colleges in person. These students are carrying on with the programme with weekly online tutorials. The course will run until 30th April 2023. Further details can be found at www.cam.ac.uk/stories/STEM-SMART-widening-participation-applications-2023. We are very grateful to the Cambridge students who have served this project as mentors, to the supervisors from the Cavendish and beyond, who have taught the students in groups, and to other members of the Isaac Physics and College Admissions and Access teams, who have worked tirelessly to bring this vision into reality. Our favourite quote is from a student who commented on a feedback form 'It's the best programme ever and it does in fact change lives!'

After 2 years of hosting events online, we were delighted to return to a mixture of online and in-person events. The pandemic enabled us to try new ways of delivering online support for students and teachers, such as our online masterclasses and online CPD for teachers, both of which will be continuing. These online activities allow us to reach many more students and teachers than we would otherwise. However, an online version of a residential is a poor substitute, which is why, in July, we were very happy to welcome back to the Cavendish four residentials: the Senior Physics Challenge (SPC) (4-7 July), the Isaac Physics Teacher Symposium (15-16 July), the Sutton Trust Physics Summer School (16-19 August), and the STEM SMART residential event. The SPC hosted

fifty of the most talented Year 12 physics students in the country, who earned a place on this free residential event by completing hundreds of challenging physics and maths questions on Isaac Physics. During the course, they were taught undergraduate level Quantum Mechanics by Lisa Jardine-Wright.

The Teacher Symposium welcomed nearly ninety UK science and mathematics teachers, mainly with specialisms in teaching Physics. The teachers networked as well as gained top tips on using Isaac Physics to improve their classroom practice and reduce workload-related stress using Isaac Physics' self-marking assessment tools. The very successful event was organised and run by our Teacher Support Manager, Ingrid Murray. The feedback to this event has been terrific, with teachers feeling valued and supported. One teacher commented: '*Did you go to #IPTS22 with @isaacphysics? I was astounded at the participation from all sectors of the communities in the UK, including large numbers of women. I really believe this outstanding community could be key in addressing this issue.*'

The Sutton Trust Summer School hosted 38 students from backgrounds who may not have thought of Cambridge or Oxford as a realistic option. The students were taught rotational mechanics and special relativity by Lisa Jardine-Wright, with a mixture of lectures and experiments. The return of these events to the Cavendish highlighted their importance in enabling students to meet with others who are as interested in physics and science as they are.

Lastly, but not least, the Isaac Physics Team were thrilled to learn that the Director and co-founder of Isaac Physics, Lisa Jardine-Wright, was awarded an OBE in the late Queen's Birthday Honours 2022 for her services to education. This also coincides with 100 million question attempts on the platform since its inception. With all the new users Isaac Physics hopes to reach, how long will it take to reach 200 million?

Year 7 and 8 materials:
https://isaacphysics.org/pages/y78_resources

Step Up to GCSE book:
https://isaacphysics.org/books/step_up_phys

Linking Concepts book:
https://isaacphysics.org/books/linking_concepts

GCSE Maths book:
https://isaacphysics.org/books/maths_book_gcse

Chemistry questions:
https://isaacphysics.org/gameboards/new?stage=all&subjects=chemistry

Upcoming Isaac Physics events:
https://isaacphysics.org/events

The Cambridge Physics Experience, Ten Years On

STEVE MARTIN and JACOB BUTLER describe the continuing success of the Cambridge Physics Experience for young people after ten years.

CavMag10 contained an article by Lisa Jardine-Wright laying the foundations for an outreach programme to schools which had a poor record of progression to higher education. It was to involve the participation of both the Cavendish and individual colleges. This enterprise also challenged the perennial issue of females' participation in physics and has evolved into a regular feature of the Department's outreach effort.

Steve Martin was appointed in 2012 to support this work and, when Lisa took up new duties in the Rutherford Schools' Physics Project, he took over responsibility for the *Cambridge Colleges' Physics Experience,* as this programme was then known. Support was given first by Lizzie Bateman, who subsequently left to join the teaching profession, and it currently enjoys collaboration with Jacob Butler. The project has reached thousands of students each year, even during COVID, and attracts both a loyal core of regular participants and a steady stream of new visitors. With a minor adjustment to the content and its title in 2018, the project continues into the 2022-23 academic year as the *Cambridge Physics Experience (CPE).*

The morning part of any visit is hosted by one of the colleges, with the collaboration of their Schools' Liaison officer. As well as first-hand appreciation of a Cambridge college, an institution which is much more than a hall of residence, there is discussion of such matters as future careers, entry requirements, financing higher education and the broad spectrum of student life.

The feedback obtained from our visitors always indicates that they are reassured on all the issues which might otherwise deter them from participation in university education or from application to Cambridge. Further, this part of the day's programme gives our guests the feeling that they have been part of something really special and promotes the feeling that Cambridge is welcoming and inclusive: a genuine 'win' for public relations!

The afternoon programme is at the Cavendish and comprises presentations on age-appropriate topics and real hands-on practical work. For our sixth form visitors this comprises a shortened version of an Part 1A exercise, while more junior pupils make DIY spectrometers, Mars Rovers (in miniature) and dabble with some materials Science.

In recent years, the team from *Isaac Physics* have also supported the programme by providing a problem solving session and introducing the use of *isaacphysic.org* to students and teachers alike, to the undoubted benefit of their subsequent physics studies.

After seven very productive years, including the extension of our activities to Y7 pupils, the year 2019–20 saw the programme abruptly curtailed by the restrictions imposed to manage COVID-19. Little could be done to rescue the programme from March to May 2020 but the outreach team was determined to replicate the *Cambridge Physics Experience,* as closely as possible, in on-line format. The programmes for each year group were recorded in approximately 20 minute chunks which schools could employ flexibly, even when pupils were confined to home: practical items, likewise, were bundled into on-line activities which could either be tackled at school with minimal equipment or undertaken at home employing only 'domestic junk'! Bookable Q&A sessions with either Outreach or Isaac Physics staff were also provided. This all proved popular and reached roughly as many young people during the year as the original scheme.

And what of the future? This outreach initiative is about to re-launch for the 2022– 23 academic year, with the in-person programme enhanced by the additional availability of an on-line version. Also, with research findings that early influences can be critical in later career choices, the team are initiating work with local primary schools and have received very encouraging early responses.

As we move forward, wish us good fortune and success for the second decade of CPE!

Richard Hills FRS 1945–2022

Readers will be sad to learn of the untimely death of Richard Hills.

BELOW: The completed ALMA milllimetre array in compact configuration showing many of the 66 antennae. Courtesy of ESO/NSF/NINS of Japan and collaborators

Richard was a world-leading millimetre astronomer with extraordinary gifts as an instrument designer and builder, telescope and instrument specialist, observer and astrophysicist. His technical expertise was unparalleled. For his PhD at Berkeley, he built the world's first millimetre interferometer. During a post-doc at Bonn, he made successful application of innovative techniques for setting the surface of the Effelsberg 100-metre radio telescope to enable observations in the centimetre waveband. On his return to Cambridge, he performed outstandingly in his role as project scientist for the James Clerk Maxwell Telescope (JCMT) in Hawaii. While the JCMT was being developed he built up expertise in the Cavendish Astrophysics Group in millimetre-wave observing using other telescopes and also built a receiver for sub-millimetre observing with the UK Infra-Red Telescope (UKIRT) in Hawaii. He was subsequently appointed project scientist in Chile for the Atacama Large Millimetre Array (ALMA) on the high altitude Atacama Desert. All these projects have been outstanding successes for the benefit of the whole UK and world community of astronomers.

Richard was a brilliant observer. Among his achievements were observations of the Sgr B2 source in the Galactic Centre for which he and his students developed the technique of making measurements 'on-the-fly' – simultaneously performing a two-dimensional scanning motion with the antenna while 'switching' the beam rapidly between two positions with the sub-reflector to remove the effects of atmospheric emission. The paper on solar observations provided an early indication of what structures could be seen on the Sun at millimetre wavelengths with the angular resolution provided by the JCMT. The paper on CO observations at sub-millimetre wavelengths was one of his first efforts at observations in the 600-700 GHz band. The paper on 'fast outflows' in Orion is an example of how the angular resolution and sensitivity of the JCMT enabled him to extract the physical parameters of the high-velocity flows of gas that had been found to be associated with the process of forming new stars. One piece of work of particular importance was sub-millimetre observations of high-redshift objects. This was the first time that emission at these wavelengths had been seen from anything more distant than 'local' galaxies and paved the way for extragalactic astrophysics with the ALMA telescope array.

For his major contributions to the JCMT project he was awarded the Jacksonian Gwilt Medal and Gift of the Royal Astronomical Society in 1989 as well as the MacRobert Award of the Fellowship of Engineers in 1990. He was elected Professor of Radio Astronomy (1970) in the Cavendish in 1990, the chair created by the University for his colleague and Nobel Prize winner, Antony Hewish. He was elected as a Fellow of the Royal Society for his many astronomical and technical achievements in 2014.

We pass on our sincere condolences to his wife Beverly and their sons Alex and Chris. Richard will be sorely missed by all of us as a brilliant physicist-astronomer and a splendid friend and colleague.

MALCOLM LONGAIR

Roberto Maiolino FRS

Many congratulations to **Roberto Maiolino**, Professor of Experimental Astrophysics, on his election to Fellowship of the Royal Society. His current research focuses upon the formation of galaxies using observations collected at some of the largest ground-based and space telescopes. (See pages 8 and 10–11).

New HoD transition arrangements approved

The search for the next Cavendish Head of the Department and the transition arrangements have now been concluded and approved. **Mete Atature** will be the next HoD from September 2022; Andy Parker's current tenure will be extended for another year, up to 30 September 2023. The overlap period between Andy and Mete's tenure will ensure continuity for the department. We congratulate Mete on this prestigious appointment.

Academic Staff Promotions 2022

Many congratulations to our new Professors, **Siân Dutton**, **Ulrich Schneider**, **Oleg Brandt**, **Louise Hirst**, **Hrvoje Jasak** and **Akshay Rao**, and our new Associate Professors, **Tijmen Euser** and **Melissa Uchida.** All of them have made outstanding contributions to research and teaching, while supporting the work of the Department in many different ways.

Isobel Falconer, MBE

We are delighted that **Isobel Falconer**, long-term visitor to the Laboratory who set up the Collection of Historic Scientific instruments, has been awarded an MBE for her services to education in the recent birthday honours list (see pages 16–17).

Suchitra Sebastian

Congratulations to **Suchitra Sebastian** who has been awarded the Schmidt Science Polymaths award. Schmidt Futures, a philanthropic initiative founded by Eric and Wendy Schmidt, is for up to five years to help support part of a research group.

Krishanu Dey

PhD student **Krishanu Dey** has been announced the winner of 2022 IET Hudswell International Research Scholarship, which will allow him to explore exciting light emission applications of emerging halide perovskite materials beyond his PhD.

Marlini Simoes

Marlini Simoes was the finalist from Cambridge in the Applied Physics (Engineering Science) category. The Doctoral research awards is a UK wide academic competition which is awarded annually to junior researchers who are pursuing doctoral degrees in the UK.

Royal Society University Research Fellowships

Congratulations to **Hannah Stern** and **Mohand Saed** on being awarded 2022 Royal Society University Research Fellowships. Hannah and her research team have been the first to identify single optically addressable spins in a two-dimensional material, opening new routes to atomically-thin room-temperature devices for quantum networking and sensing applications. Mohand is responsible for the 'revolution' in liquid-crystal elastomer materials that made smart materials available to everyone.

£5M grant awarded to Cavendish Astrophysics

STFC has announced that more than £15 million had been awarded to UK institutions which are delivering the crucial software 'brain' of the world's largest radio telescope. £5M of this funding will go to Cavendish Astrophysics to develop the Square Kilometre Array (SKA) science data processor and analysis software to process the extreme rates of raw data into science outputs.

Eugene Terentjev

Congratulations to **Eugene Terentjev** who has been awarded an ERC Proof of Concept Grant for his research project, Mesodamp, to explore the commercial or societal potential of reversible adhesion damping tapes based on layers of liquid crystalline elastomer.

New migration consultants - MovePlan

MovePlan has been appointed our migration consultants, to design the strategy for moving the Department from the current site to the Ray Dolby Centre. MovePlan will be working closely with the Project Team over the coming months to carefully plan and design the migration process, and with Restore Harrow Green and specialist vendors to undertake the physical, removal services.

Ukrainian Academic Support Scheme

The University is collaborating with **Cambridge4Ukraine** and has set up the Ukrainian Academic Support Scheme to help 20 Ukrainian postgraduates continue their studies and research at Cambridge. The scheme is seeking hosts to accommodate postgraduates for six to 12 months.

New MPhil Programme in Data Intensive Science

The launch of our new MPhil in **Data Intensive Science** has been announced. Designed specifically for students from quantitative scientific disciplines, the course aims to prepare them for data intensive scientific research or for careers in industry as data scientists undertaking large-scale data analysis.

Congratulations to Dan Cross on crossing a 35 year milestone!

Dan Cross has recently completed 35 years of service with the University. Starting in 1987 at the Engineering Department in town and then the Whittle Lab, Dan subsequently joined the Cavendish in 1994. His current role at the Cavendish is the Cryogenics Facility Manager, where he is responsible for the production of liquefied helium and nitrogen for experimental use.

People doing Physics – new episodes available

New episodes are recorded roughly once per month. Listen now on the website or on your subscribed podcast channel. Here is the complete list of podcasts up to mid-October 2022 in chronological order:

Louise Hirst, Assistant Professor of Physics, specialist in the development of advanced, high efficiency photovoltaics for space applications, describes her hesitations between music and physics, finance and research, and also what it takes to be a woman in science.

Tina Potter, high energy physicist, tells us about her research into dark matter, answering big, fundamental questions about our universe, including how to survive the unforgiving research career pyramid.

Suchitra Sebastian and American artist **Logan Dandridge** discuss personal awakenings, taking detours, and seeking out intersections between art and science to create new dialogues and provocations.

Tom Sharp, group technician chats about apprenticeship, optoelectronics, and what it is like to walk in a grandfather's shadow.

Stuart Macpherson, Post-doctoral researcher in experimental opto-electronics talks about his early physics journey, his research at the Cavendish and his non-profit organisation Sustain/Ed.

Joanna Piotrowska, an Astrophysics PhD student looking at galaxy formation and evolution in Roberto Maiolino's Group.

Melanie Tribble is Cleanroom Manager for the Cavendish Laboratory. For the last three decades, she has kept the cleanrooms of the Cavendish up and running, going from working with one research group to providing support for the entire laboratory and external companies.

Diana Fusco, lecturer in biological physics talks about her interdisciplinary and curiosity-driven career in Biological physics, her different approach towards science and her research.

Malcolm Longair, Jacksonian Professor Emeritus of Natural Philosophy, Former Head of the Laboratory, Director of Development, astrophysical cosmologist and founding editor of CavMag, talks about a career in physics and astrophysics.

If you have any comment or suggestion for future episodes, please get in touch at **podcast@phy.cam.ac.uk**.

The West Hub opens at West Cambridge

The West Hub, opened on 26 April 2022, is an open access building that significantly expands provision for catering, study spaces and meeting rooms on the West Cambridge Site. It is open from 8am to 9pm, Monday to Friday, and is open to all – students, staff and the public. The West Hub contains a wide variety of flexible spaces for teaching and exams, meetings, conferences and events, individual or small-group work and study and food, drink and leisure.

How you can contribute

Online Giving

The University's Office for Development and Alumni Relations (CUDAR) has made it easier to make donations online to the Department and to two of our special programmes. If you wish to make a donation to the Department, please go to: **campaign.cam.ac.uk/giving/physics**

If you wish to support the graduate student programme, please go to: **campaign.cam.ac.uk/giving/physics/graduate-support**

If you wish to support our outreach activities, please go to: **campaign.cam.ac.uk/giving/physics/outreach**

If you would like your gift to be applied to some other specific aspect of the Development Programme, please contact Andy Parker or Malcolm Longair. The Development portfolio is described in CavMag 18 and can be viewed online at: **www.phy.cam.ac.uk/alumni/files/Cavmag18Aug2017online.pdf**

A Gift in Your Will

One very effective way of contributing to the long-term development of the Laboratory's programme is through the provision of a legacy in one's will. This has the beneficial effect that legacies are exempt from tax and so reduce liability for inheritance tax. The University provides advice about how legacies can be written into one's will. Go to: **campaign.cam.ac.uk/how-to-give** and at the bottom of the page there is a pdf file entitled **A Gift in Your Will.**

It is important that, if you wish to support the Cavendish, or some specific aspect of our development programme, your intentions should be spelled out explicitly in your will. We can suggest suitable forms of words to match your intentions. Please contact either Malcolm Longair (**msl1000@cam.ac.uk**) or Samantha Stokes (**departmental.administrator@phy.cam.ac.uk**) who can provide confidential advice.

If you would like to discuss how you might contribute to the Cavendish's Development Programme, please contact either Malcolm Longair **(msl1000@cam.ac.uk)** or Andy Parker **(hod@phy. cam.ac.uk)**, who will be very pleased to talk to you confidentially.

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