



CAVMAG

News from the Cavendish Laboratory

Quantised 1D
conduction

The discovery
of pulsars

A DNA helix

Reptation

Transit dip

CMB power
spectrum

The Cavendish 3 project continues to advance at a remarkable rate. Daily, new additions to the framework of the Ray Dolby Centre appear on site with six tall cranes in continuous use to make this happen. To bring readers up to date with the state of the project and what is expected to take place over the next year, Richard Phillips, Sam Stokes and David Hunt have provided a more detailed description of the project than usual, as well as introducing the Cavendish team supporting the project.

Most notably, we are profoundly grateful to **Humphrey Battcock and the Wolfson Foundation** for generous gifts supporting the infrastructure and outfitting of two key areas of the Laboratory's future programme, the **Laboratories for Quantum Nanoscience and the Advanced Instrumentation Facility for Experimental Astrophysics and High Energy Physics** respectively. These gifts make a huge difference in ensuring that the Ray Dolby Centre will get off to a really flying start in 2022.

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COVER PAGE: the 'Signals from Physics' image was created by Richard Phillips and is prominently displayed on the hoardings along J.J. Thomson Avenue.

Cavendish 3

Ten months into construction

Excellent progress has been made on the construction of the Ray Dolby Centre. RICHARD PHILLIPS, SAM STOKES and DAVID HUNT review what has been achieved so far and the next stage of construction.

The new Ray Dolby Centre, the centerpiece of the Cavendish 3 project, has now been under construction for 10 months. As reported in earlier issues of CavMag, the new building will provide accommodation for all the activities of the Department except those destined to remain in the Battcock Centre for Experimental Astrophysics, the Cambridge Kavli Centre for Cosmology and the Physics of Medicine and Maxwell Buildings. The combined estate will be collectively known as the Cavendish Laboratory.

The announcement of £75 million of funding in the Government Spending Review in 2015 allowed the University to proceed with the project, which was already at that time well advanced as a design exercise. The Government funding is provided as a grant, through the Engineering and Physical Sciences Research Council, and this contribution will lead to some functions of the new laboratory being offered as National Facilities for physics. The combination of University and Government funding was still short of the total required to complete the building. A key step for the project took place when the estate of the sound pioneer and alumnus of the Cavendish, Ray Dolby, made the enormously generous donation of £85 million in 2017 to the Department. In acknowledgement of this gift, the building will be named the Ray Dolby Centre. Further generous donations from Humphrey Battcock and the Wolfson Foundation have recently been received and these will be used to set up quantum nanoscience laboratories and an Advanced Instrumentation Facility for astrophysics and particle physics, both to the highest standard. We are particular grateful to both of these donors, who previously supported the construction of the Battcock Centre.

Implementing the Vision

The design of the building, which has been specified in great detail by the Physics Department, embodies a new approach to the provision of facilities for teaching and research, with considerable emphasis placed on cooperative and interdisciplinary working. This extends to the Laboratory's new function as a National Facility in offering access to many specialised pieces of apparatus to other institutions. As well as welcoming external researchers, the new building has also been designed with the Department's many outreach activities in mind. The main façade in J.J. Thomson Avenue provides a unified entrance to the building, with a projecting 'public zone' in which there will be free circulation for students and visitors to the Physics Department. There will be a large and a small lecture theatre with capacities similar to those in the present Bragg Building, but these are supplemented by an innovative 'cluster seating' room, and other rooms for both undergraduate teaching and schools outreach. The public area also includes study space, administrative offices and a common room. One additional enhancement, of particular interest to the many cyclists working in the Physics Department, is the provision of underground cycle parking with a showering and changing area.

The other facilities supporting research and practical teaching are located in four Wings arranged with their long axes East-West and 'stacked' from South to North (Fig. 1). The southernmost Wing looks out over the future Central Garden area to the Shared Facilities Building which is being constructed simultaneously with the Ray Dolby Centre. This Wing houses a large hall in which the many low temperature cryostats will be brought together, as well as further laboratory and office space. Between the research Wings are internal courtyards, and there are smaller courtyards within each Wing. These maximise natural daylight and ventilation, in accordance with the target of achieving the formal 'Excellent' standard of the Building Research Establishment Environmental Assessment Method.

Extending beneath half of the southernmost courtyard, and under the entire second main Wing, there is an extensive basement



in which a high standard of environmental control is provided for experimental work. At present this is a very large hole in the ground! Moving Northwards there will be a large cleanroom which will replace the many separate cleanrooms in the present buildings, and specialised spaces for the assembly of particle physics and astronomy experiments destined for accelerator laboratories and observatories. The northernmost Wing contains the many workshops and stores, and on the top floors extensive teaching laboratories. The design separates the main service functions for each Wing in 'utilities buildings' on the western flank of each block, in order to provide some isolation of sources of vibration and electrical noise from the main laboratory spaces. The main 'energy centre' is located in the northernmost of these, adjacent to the deliveries entrance and cryogenics facility.

Introducing the Cavendish 3 Administration Team

The Department's input to the design process has been managed from the end of RIBA Stage 1 by the 'Logistics Committee' chaired by Richard Phillips, who also managed the definition of the Brief in the Stage 1 process. The demands of administration of the planning for occupation of the new building has increased considerably during Stage 4, and there is now a growing team providing the administrative support for the project within the Physics Department (Fig. 2).

FIG 1. Aerial drone view looking down onto Wings 4 to 1 (Wing 4 is towards to the top), showing the bottommost crane located within a courtyard space (August 2019). North is to the top and J.J. Thomson Avenue runs diagonally towards the top-right of the figure. The large highly specified basement area is seen in the middle of the photograph (see also Fig. 3).



FIG 2. Members of the Cavendish 3 Project Team (left to right) Fred John (Facilities Manager), Sam Stokes, David Hunt, Richard Phillips, Debbie Carminati & Peter Norman (Laboratory Superintendent).

Sam Stokes, Special Projects Officer for Cavendish 3, is the Team leader for Cavendish 3 project administration within the Laboratory and is project representative on all Cavendish 3 committees. She provides project finance oversight and is the liaison point for the Department, the School of Physical Sciences and the University and Contractor teams. She also links with the *OurCambridge* conduit to develop effective staffing structure strategies, with particular focus on technical staffing to aid both the research programmes and National Facility needs. She undertakes Departmental project work to maximise the effectiveness and efficiencies of processes, always with Cavendish 3 operations at the heart of each strategy.

David Hunt, Technical Project Manager, has the role of managing the coordination of RIBA Stage 4 between the contractor's team and the Logistics Committee, the Cavendish end users and the facilities team, including processing change control requests and monitoring progress. He is helping coordinate and support the developing furniture, specialist gases and audio-visual consultants' proposals and tenders. He is working with external project planners, the Logistics Committee, facilities team and end users to develop the migration strategy from the present buildings to the new, and is providing regular reports to the Project Board.

Debbie Carminati, Project Administrator, has recently transferred to the team to help its coordination and organization. She will be servicing meetings, managing team diaries

and visits, and arranging site tours. She will be maintaining the space allocation data and fixed asset register, and will be providing invaluable administrative support in any project-related matter.

Simon Belson, Building Information Modelling (BIM) Technician, is contracted to implement this important digital tool in contemporary construction, which is being used both by our main Contractor Bouygues UK, and by the University's Estates team. In order for the Department to benefit from this as much as possible, Simon has been appointed to set up and coordinate the information being accumulated about the Department's assets in a BIM environment compatible with that used by the construction team. This will involve surveying the main research and workshop equipment to produce a digital representation and record technical details. Ultimately this will lead to the provision of drawings and asset schedules to support the planning of the process of transfer of our activities to the new facilities, from 2022 onwards.

Building Progress

The main contractor, Bouygues UK, were appointed during the autumn of 2018 and formally started construction in November 2018, some 12 weeks ahead of schedule. Recently, the first elements of the 'cast *in situ*' floors and columns have been appearing above the decorated site hoardings, and the scale of the project is beginning to be apparent (Fig. 1). Much work has taken place over the last 10 months, including the installation of the site huts, canteen, removal of the vet school roads, and the diversion and reconfiguring of the services infrastructure. Currently four tower cranes can be seen swinging above the site (Fig. 1) and a further two are to be installed during the autumn.

The early elements of construction included installation under the northernmost block of an array of 107, one hundred and ninety-meter-deep boreholes for the ground source heat pumps, which will reduce operational energy requirement for the life of the building, and provide a robust and resilient solution for the required 24/7 operation.

The low-vibration basement has been formed with a boundary of 196 twenty-meter-deep

interlocking secant piles. The excavation required the removal of approximately 15,000m³ of earth which was taken away in up to 180 lorry loads a day during a 4-week period. The basement's structural integrity is currently retained by bright red hydraulic props up to 36m in length (Fig. 3), which will be removed during the autumn as the basement floor reinforcement and other structural elements are completed and able to take the load.

Achieving vibration levels as low as VC-H requires special consideration of all vibration sources inside and outside the building, VC-H corresponding to less than 0.39 $\mu\text{m/s}$ rms vibration speed over the frequency range 1–100Hz. The new basement is located in the quietest area of the site with a 2 m thick foundation slab cast 8 m below ground. This combination of basement depth and slab thickness was designed to achieve the best combination of performance and cost for the ground conditions and vibration sources around the site. The basement floor is composed of 3200 m³ of concrete and steel reinforcement, with the largest single concrete pour of 770 m³, which was completed over 13 hours with over 100 lorry loads of concrete provided from two batching plants.

The drainage and ground floor slabs for Wings 2, 3 & 4 have been cast and the formwork for the first floor columns and slabs is progressing. This work includes the partial completion of the double-height columns and upper floor deck to support the split level courtyard between wings 3 & 4. The excavations for Wing 1 are underway and the trenches for the Cryostats can be clearly seen in the aerial image (Fig. 1). Excavation has just begun for the public Wing of the building, running parallel to JJ Thomson Avenue.

A mock-up of the main internal and external building elements, for both the Ray Dolby Centre and the Shared Facilities Hub, has been constructed in order to develop and test the various buildings finishes, junctions and installation processes, and to provide a quality control measure (Fig.4). The main external façades will be completed with concrete panels which are precast in Belgium in a fine, nearly white concrete, with a polished surface finish. These were selected after extensive consideration by the Logistics Committee in order to achieve a long-lasting and high quality

appearance. A total of 1000 concrete panels will be manufactured to complete the façade.

The next 12 months will see the concrete frame, with floors and structural walls, being completed for all five Wings. Construction of the structural steel frames for the courtyards, plant rooms and workshops will commence in early 2020. The installation of the external building fabric will commence in January 2020 with the aim of having water-tight fabric in some areas completed about Spring 2020 to allow internal works to commence. So far 256,600 work hours have been recorded on site with up to 200 people being involved in various aspects of the work.

FIG 3. Top: Concrete being pumped into the basement floor to cover the 2.0 m depth of steel reinforcement. Once completed the red hydraulic props can be removed.

FIG 4, bottom: The on-site mock-up is roughly a 10m cube, and its construction allows testing of design elements as well as providing a reference for subsequent construction quality. This view shows some (vertically 'squashed') elements of the J. J. Thomson frontage; projecting out to the left is part of the brise-soleil which will help control solar gain on the southern façade.



Celebrating the 10th Anniversary of the Kavli Institute for Cosmology



ROBERTO MAIOLINO and **STEVEN BRERETON** describe the activities associated with the 10th anniversary of the Kavli Institute for Cosmology, Cambridge (KICC), in particular, the future directions of the research programme.



On Thursday 18th July 2019, the Kavli Institute for Cosmology, Cambridge (KICC) marked its 10th Anniversary with a celebration day attended by Kavli Foundation Board members, the University Vice-Chancellor, Head of School, Heads of the three host departments and directors of other Kavli Institutes. The celebration day was a chance to review the past, discuss current research and look forward to the future. The Kavli Institute was created as a single site at which the University's cosmologists and astrophysicists from different academic departments share knowledge and work together on major projects. KICC brings together scientists from the University's Institute of Astronomy, the Cavendish Laboratory and the Department of Applied Mathematics and Theoretical Physics.

The morning's events began with the welcome address by the Vice-Chancellor of Cambridge University, Professor Stephen J Toope (Fig.1). He highlighted the benefits of collaboration not only between individuals, but also between departments and Universities. He took the opportunity to endorse the ethos of the Kavli Foundation's founder, Fred Kavli, of needing to be 'willing to fund science without knowledge of the benefits'.

George Efstathiou, founder and first director of the Kavli institute, and Roberto Maiolino gave overviews of the achievements of the institute during the first 10 years and the prospects for the future. The unprecedented map of the Cosmic Microwave Background (CMB) obtained with the Planck satellite, the analysis of which has provided the most compelling



FIG 1, left: Kavli atrium with the gathering of the participants. Right: Vice-Chancellor Stephen J Toope opens the day of celebration.



FIG 2. Kavli Foundation members viewing the MOONS camera in Cavendish clean room.

and precise evidence in favour of the standard Λ CDM model of the Universe, has been one of the major highlights of the Kavli Institute. Although the Planck mission involved a large international collaboration, the Kavli Institute has played a key role in the analysis of the data by leveraging on the joint expertise of scientists from the three parent departments. Our understanding of the earliest phases of the Universe achieved through the Planck map of the CMB will remain unparalleled for decades.

The Kavli institute has also made tremendous progress in understanding the formation and evolution of galaxies and of the supermassive black holes hosted at their centres, both through numerical simulations and through extensive observing campaigns. Clusters of supercomputers have been used to simulate the full evolution of large volumes of the

Universe across the cosmic epochs, providing predictions on the evolution of galaxies and of the circumgalactic medium in unprecedented detail. These theoretical predictions have been successfully tested through multi-band observations of distant galaxies using some of the largest telescopes and cutting edge facilities, including the ESO Very Large Telescope and the Atacama Large Millimetre Array.

In recent years the Kavli Institute has expanded its research scope to gravitational waves and exoplanets, enabling important advances in these areas. The highlights of these new ventures were summarized by junior researchers (including the Kavli Fellows) and students.

Particularly exciting are the ongoing efforts in new cutting edge projects that will

deliver results in the next decade. These include involvement in the next generation ground based CMB facilities, including new instrumentation at the Atacama Cosmology Telescope and the Simons Observatory. These will focus on the detection of the polarization signal of the CMB that would provide the signature of primordial gravitational waves associated with the very earliest phases of the Big Bang itself. The Kavli Institute plays a major role in the James Webb Space Telescope, which will be the largest telescope ever launched into space and which will provide orders of magnitude increase in sensitivity relative to any previous facility, and which holds the promise of detecting the first generation of galaxies and of black holes. Members of the Kavli Institute have leading roles, both scientific and technical, in the next generation multi-object spectrometers (MOONS, 4MOST, WEAVE), which will characterize and measure the location in space of millions of distant galaxies, providing constraints on the nature of Dark Energy, on the environment in which distant galaxies live and on the mechanisms regulating their evolution. The Kavli Institute is leading the UK involvement in HIRES, the high resolution spectrometer for the Extremely Large Telescope, which promises to detect the chemical fingerprint of the supernova explosions resulting from the first generation of stars as well as detecting the atmospheres of Earth-like exoplanets, with the ultimate goal of detecting bio-signatures in other planets.

The Kavli Institute also supports involvement in the next generation radio telescopes, such as HERA and the Square Kilometer Array (SKA), in which Cavendish astrophysicists are playing a leading role. The primary science goal of interest in the Kavli Institute, and more broadly in Cambridge, is the detection of the 'fog' of primeval hydrogen at the end of the 'dark ages', the epoch when the first galaxies and black holes were formed. Within this context, the Kavli Institute is also directly supporting a new 21cm experiment (REACH), led by Cavendish Astrophysics, aimed at detecting the global signal from hydrogen around such early epochs and which may deliver the first results next year (see the article by Eloy de Lera Acedo).

The Kavli Institute is also supporting the Cambridge involvement in two innovative projects aimed at detecting mid-frequency

gravitational waves, MAGIS and AION, in which the Cavendish Laboratory will play a leading role.

To illustrate these various present and future activities, various displays were deployed in the Kavli Institute and its surrounding areas. These included models of the Planck and Gaia satellites, a prototype of the SKA low-frequency antennas, the feed of the HERA antennas, 1:1 replicas of the JWST primary mirror segments, one of plates used by the Sloan Digitalized Sky Survey for positioning optical fibres, and multiple screens showing numerical cosmological simulations, artistic representations of the Extremely Large Telescope, of the Square Kilometer Array and the deployment sequence of the James Webb Space Telescope. The outreach programme of the Kavli Institute was also presented, highlighting its success in reaching the public and areas of society typically not reached by the standard channels of communication.

Rockell Hankin, Chair of the Board of Directors of the Kavli Foundation, and Kevin Moses, Vice President of the Kavli Foundation for the Science Programme, praised the achievements and success of the Kavli Institute and confirmed the commitment of the Kavli Foundation to support cutting edge scientific research. Representatives of the Kavli Foundation also visited the Cavendish's clean room where the large cameras of the MOONS multi-object spectrometer are being assembled, aligned and tested (Fig.2).

The day was a great success, not only in celebrating 10 years of very significant achievements, but also in making everyone aware of the multiple ways the Kavli Institute supports joint research across the three departments. This involves not only the coveted Kavli Fellowships, international workshops, the visitor programme and direct support of research projects, but also by bringing together the expertise of scientists with common research interests and by providing the link with other Kavli Institutes world wide.

Photographs of the event can be seen at www.kicc.cam.ac.uk/news/KICC10th_CelebrationDay

Organic spintronics

Electron spins in organic semiconductors



DEEPAK VENKATESHVARAN, SAM SCHOTT and HENNING SIRRINGHAUS describe a remarkable advance in the field of spintronics through the discovery of unexpected properties of organic spintronic materials

The field of spintronics uses the electron spin, rather than its charge as the main means of processing information and has already revolutionized the way we store information. The discovery of giant magnetoresistance, for which Albert Fert and Peter Grünberg were awarded the 2007 Nobel Prize in Physics, has enabled the fabrication of very sensitive read-heads for high density magnetic disk drives as well as magnetic random access memories (MRAMs). It also offers the potential for achieving dramatic improvements of the energy efficiency in information processing. By transmitting information not by charge currents but by pure spin currents that involve only a flow of spin angular momentum but no net flow of charge, it may be possible to significantly reduce Ohmic power dissipation.^[1]

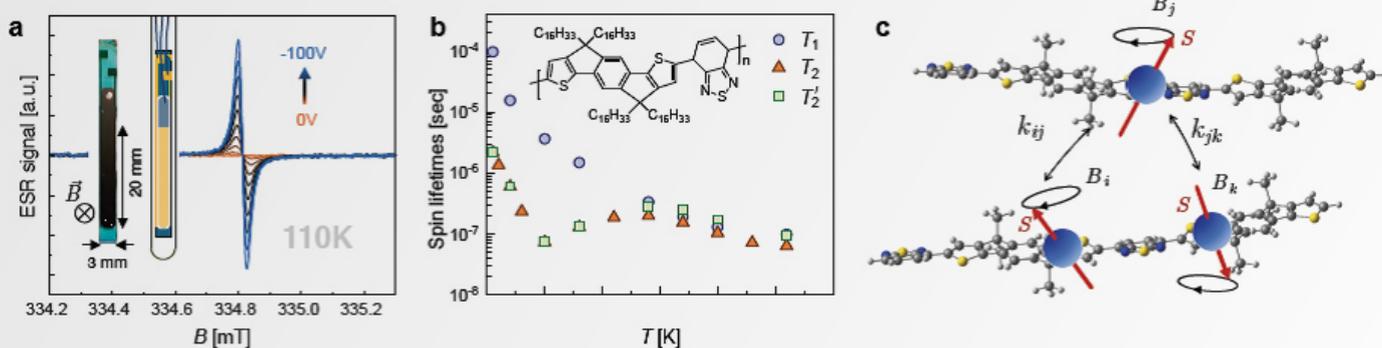
The main promise of using organic semiconductors in spintronics lies in the long spin lifetimes that can be achieved in semiconductors which are composed mainly of carbon and hydrogen. A spin's orientation and coherence often survive for several microseconds in molecular or polymer semiconductors, over a thousand times longer than in many inorganic metals. This provides more time to manipulate a spin and means that it can potentially travel further. The long electron spin lifetimes are a consequence of the light-element composition of these mainly carbon-based materials – there is little perturbation from

nuclear spins as the abundant carbon-12 has zero nuclear spin. Furthermore, the radial electric fields of the nuclei are small and, as a result, the spin-orbit interaction is weak. Weak spin-orbit coupling turns out to be a blessing and a curse. For spin-transmission layers it is highly desirable, but most spintronics devices, such as MRAMs, also require the ability to create spin polarizations from electric currents or the conversion of spin-currents to electric voltages. Such conversions require strong spin-orbit coupling. It would therefore be useful to be able to tune the strength of the spin-orbit coupling.

In 2014 we were awarded a 6-year Synergy grant by the European Research Council (ERC) to investigate the fundamental spin physics of these materials and to explore their use in spintronic devices. The project involves a collaboration between the Cavendish Organic Semiconductor Group with the Hitachi Cambridge Laboratory (Jörg Wunderlich – spintronic devices), the University of Mainz (Jairo Sinova – theory) and Imperial College (Iain McCulloch – chemistry). The capital equipment budget of the project enabled us to install a highly sensitive electron spin resonance (ESR) spectrometer in the Cavendish Laboratory.

We first aimed to understand how widely spin-orbit coupling can be tuned in molecular materials by chemical design^[2]. For this we trapped spins

FIG 1: (a) Field-induced ESR spectra as a function of gate voltage in a high mobility conjugated polymer transistor architecture; (b) temperature dependence of the spin relaxation time T_1 and T_2 ; (c) schematic diagram of different magnetic field environments encountered when charges hop from site to site.



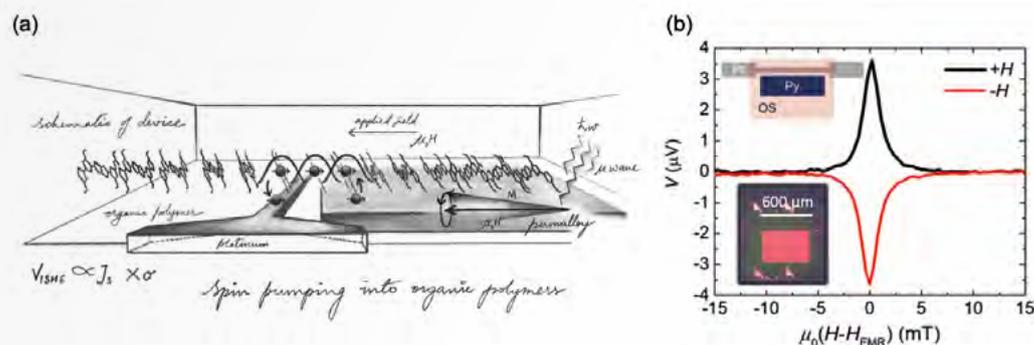


FIG 2: (a) Schematic diagram showing the generation, propagation and detection of a spin current within an organic semiconductor film using a lateral spin pumping architecture; (b) Measured voltage in the Pt spin detector in the vicinity of the ferromagnetic resonance. The bottom inset shows a photograph of an actual device.

on isolated molecules dispersed in a solution with sufficient separations to minimize interactions between one-another and then studied their ESR response. We had previously assumed that the incorporation of heavier elements such as sulphur or selenium into a molecule was the key for increasing spin-orbit coupling. We found however that changes to the molecular geometry could be just as effective. In fact, when introducing a curve in the backbone of a well-known molecule, we observed that the resulting shifts of the charge distribution drastically reduced spin-orbit coupling while increasing spin lifetimes from just over 1 μs to 100 μs . On the other hand, when aiming to increase spin-orbit coupling, we needed to be strategic about placing heavier elements at positions where their interactions with the spin would be maximized.

Next we investigated how these modified molecules affect the movement of the spins through a stack of molecules in the solid state^[3]. At low and intermediate temperatures, we observed that spin lifetimes were closely linked to the mobility of the charge carriers. The motion of charges through an environment of nuclear spins and changing spin-orbit couplings was randomizing the direction of the spin (Fig. 1). But when approaching room temperature, charge motion and spin relaxation seemed decoupled. The onset and magnitude of this effect could only be explained by vibrations of the polymer chain causing local fluctuations of charge density. Spin-orbit coupling was linking those fluctuations to the spin and eventually causing it to flip. These results have practical implications for the design of polymers. By suppressing the correct vibrational modes, one can potentially design high mobility polymers with both strong spin-orbit interactions and long spin lifetimes.

Armed with this fundamental understanding of spin relaxation mechanisms we have investigated

spin transport in device structures. One such structure, shown in Fig. 2, is based on spin current injection from a ferromagnetic electrode by a process called spin pumping, which involves microwave excitation of ferromagnetic resonance precession of the magnetisation of the ferromagnet^[4]. The injected spin current then diffuses laterally through an organic semiconductor film and is detected by a platinum electrode with strong spin-orbit coupling in which the spin current is converted into a measurable electrical voltage. The magnitude of this voltage decays exponentially with distance from the platinum detector, which allows determination of the spin diffusion length. We have obtained evidence for long spin diffusion lengths of micrometres in certain organic semiconductors. Further measurements are currently underway to validate unambiguously these surprising findings.

Our ERC project is entering its final phase and we are currently working on a number of related research directions, including achieving efficient spin-charge conversion^[5] as well as realising molecular spin qubits in these materials. Whether organic semiconductors will eventually prove their usefulness for spintronic applications remains to be seen, but the knowledge gained through this fundamental research is already providing new insight into the spin physics of these materials. The greater microscopic understanding of the fascinating and unique interplay between molecular structure, charge and spin dynamics that we have achieved has wide-ranging implications for the physical phenomena that can be observed in these materials.

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The Edwards Centre for Soft Matter Science



ERICA EISER describes the remarkable range of topics in Soft Condensed Matter Physics being carried out through interdisciplinary and inter-departmental collaborations fostered by the Edwards Centre for Soft Matter.

In 2015, shortly after Mike Cates returned to Cambridge to take up the post of Lucasian Professor of Mathematics, once held by Isaac Newton, he and Erika Eiser, Professor of Soft Matter Physics at the Cavendish Laboratory, founded the *Edwards Centre for Soft Matter* (ECSM)¹. This centre was created to continue the legacy of *Sir Sam F. Edwards*² FRS, who established Soft Matter Physics at Cambridge in his position as John Humphrey Plummer Professor of Physics at the Cavendish Laboratory in the early 1970's and later as Head of Department and Cavendish Professor. Having recognized early on the importance of this new field of physics and its relevance for large industries, Sam personally trained as PhD students or postdoctoral fellows an extraordinary generation of leading scientists such as Mike Cates, Mark Warner, Masao Doi, Jacob Klein, Robin Ball, Monica Olvera De La Cruz, Nigel Goldenfeld and others, who became world leaders in Soft Matter Physics and the related fields of statistical mechanics and computational and biological physics.

Unlike many traditional disciplines in physics, Soft Matter research is highly interdisciplinary; hence the members of the Edwards Centre are located in various departments including Physics, Applied Mathematics & Theoretical Physics, Chemistry, Chemical Engineering & Biotechnology, Materials Science & Metallurgy, Engineering, and others. The ECSM brings together researchers for twice yearly one-day workshops, giving PhD students and Postdoctoral Fellows a platform to present their most recent exciting findings, not only to their peer group but also to senior scientists including visitors from industry. The Centre also organises industry-oriented workshops fostering dialogue with local companies and a better understanding of applied research problems, such as those relevant to developing more sustainable foods, coatings and pharmaceuticals. Often these can only be solved by researching the underlying physics and chemistry principles, which are in most cases highly complex. In addition, ECSM's annual Edwards Symposium, now in its 4th year, is held every September. This is a fully international event, attracting around 100 participants drawn from both academia and industry. It shines a spotlight on recent advances worldwide in Soft Matter

science, emphasising, as Sam Edwards always did, those results that are not only fundamental but can also inform or improve industrial practice.

The diversity of Soft Matter systems, including polymer melts, colloidal suspensions and glasses, liquid crystals, gels, complex fluids such as blood or paints, and granular materials, is reflected in the multitude of high profile research projects led by members

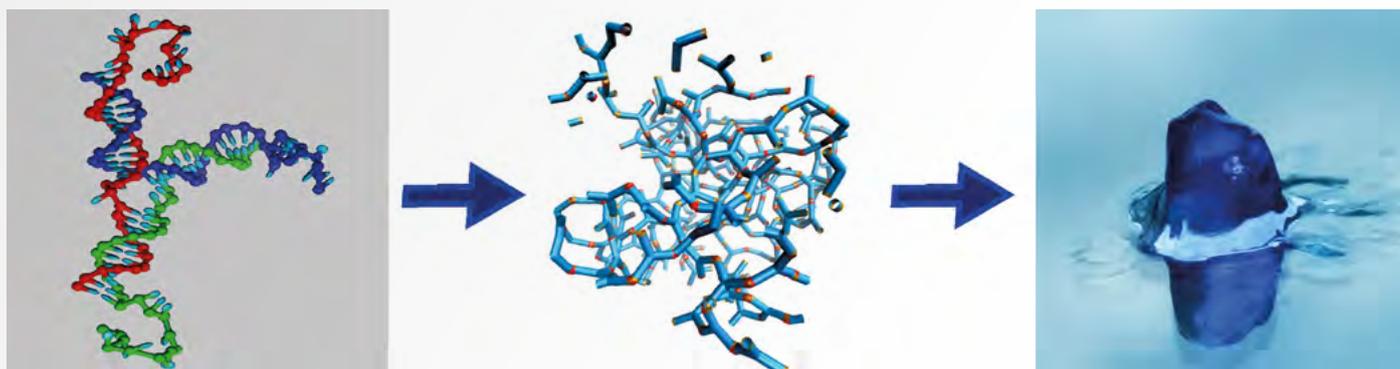
of the ECSM. For instance, the group of Tuomas Knowles³, of the Departments of Chemistry and Physics, the Cambridge Centre for Protein Misfolding Diseases, and founder & CEO of Fluid Analytics⁴, has developed microfluidics-based research to understand the self-assembling process of proteins leading to neurodegenerative diseases such as Alzheimer's disease [1–3]. It is known that prions, a class of short protein chains, self-assemble irreversibly into amyloid fibrils when they start losing their secondary structure, thus exposing their hydrophobic so-called β -sheets [2]. While we know today the driving forces for the formation of these filamentary aggregates and that they are present in diseased human bodies, the kinetics of the growth mechanism and in which state these aggregates become toxic is still unresolved. This is partly due to the vast parameter space that needs to be explored to understand fully the relevant growth mechanism. The micro-fluidic



Sam Edwards (1928–2015) who, as Cavendish Professor, started many new research initiatives in the Laboratory with strong connections with industry.

experimental approach [4] developed in the Knowles group has overcome this challenge, allowing the controlled, direct study of the thermodynamics of amyloid assembly as a function of protein concentration and solvent conditions.

In a team effort, the groups of ECSM members Erika Eiser, Oren Scherman, Silvia Vignolini and Chris Abell employed classic colloid synthesis and physical behaviour studies to shed light on the well-known DLVO (mean-field) theory describing the aggregation behaviour of charged colloidal particles with well-defined 'roughness' [5]. Following the discovery of a novel synthesis route [5, 6] enabling the creation of roughly 300 nm large 'raspberry-like' particles, this team also showed that it is the specific roughness of these charged particles that prevents them from aggregation in



aqueous solution even in the presence of high amounts of added salts. Moreover, because of their very narrow size-distribution and size, these colloids are able to crystallize into dry films displaying structural colours. These colours stem from the physical microstructure rather than the presence of dyes; examples include butterfly wings and iridescent minerals. Such colloids are not only interesting from the physics point of view but are of great interest in the paint and display industry and, for different reasons, as possible additives for use in enhanced oil recovery.

Yet another exciting Soft Matter system relying on self-assembly has been explored by the mixed experimental and theoretical efforts of the groups of Oren Scherman, Daan Frenkel and Jeremy Baumberg, who have developed nano-actuators based on thermo-responsive polymers bound to gold nanoparticles that are capable of reversibly storing elastic energy and thus allow a strong force production upon light irradiation, relevant in nano-machines [7, 8].

Celebrating and continuing the legacy of the discovery of the structure of DNA by Watson, Crick, and Franklin, a number of the ECSM research groups study different aspects of DNA. While the group of Rosana Collepardo-Guevara focuses on how data is stored in DNA packaging [9] using various computational methods, Erika Eiser's group studies the viscoelastic properties of hydrogels made of DNA 'nanostars', meaning molecules linked into a star-shaped topology, with new micro-rheology analysis, theory and simulations [10, 11]. The group of Ulrich Keyser studies transport phenomena through nano-pores made of DNA-origamis, and together with Jeremy Baumberg's group they use DNA-scaffolds for positioning metal nano-particles at well-defined separations to study surface enhanced Raman spectroscopy [12]. The world leading computational group of Daan Frenkel has contributed to collaborative works on the statistical mechanics of the collective binding kinetics of highly specific but weak binders such as DNA or membrane proteins at colloidal and cell interfaces [13–15].

Another branch of Soft Matter that has emerged over the past 15 years focuses on the out-of-equilibrium dynamics of 'Active Matter'. This term describes systems of many particles or subunits that continually consume energy locally. Examples are flocks of birds, and, at a more microscopic scale, swarms or colonies of bacterial or fungal cells, or the beating of cilia, micrometre-sized hairs, to facilitate motion either of cells or of adjacent fluids such as in the airways of our lungs. Optical Tweezer experiments, combined with

video-microscopy, enabled the group of Pietro Cicuta to study the requirements for swimming at low Reynolds numbers [16], while the groups of Ray Goldstein and Eric Lauga have made many advances in understanding cellular locomotion in fluids [17,18]. Alongside this, Mike Cates' group has developed important theoretical concepts to understand the emergent properties of active matter at scales much larger than the individual particles [19].

The above-mentioned systems and scientists are only a small selection of the research covered by the members of the Edwards Centre, illustrating the impact of Soft Matter science on our society, as well as its fundamental intellectual interest. As Sam Edwards realized long ago, in the field of Soft Matter Physics, there is an unusually close connection between these various reasons for soft matter research.

1. www.edwards.phy.cam.ac.uk
2. <https://doi.org/10.1098/rsbm.2016.0028>
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4. www.fluidic.com/company/about-us/team/tuomas-knowles

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FIG, top: (left) Visualization of a Y-shaped DNA building block consisting of three partially complementary single-stranded DNAs, obtained from the semi-coarse-grained oxDNA model. (middle) Typical, percolating aqueous network made of these Y-DNA building blocks using a more coarse-grained model. (right) Photograph of an experimental realization of a DNA-hydrogel made of these Y-shaped DNA building blocks [10].

REACHing for first light in the Cosmos



When were the first luminous objects in the Cosmos born? How did they shape the Universe? **ELOY DE LERA ACEDO** describes two fundamental questions in modern cosmology which will be addressed by the REACH experiment (Radio Experiment for the Analysis of Cosmic Hydrogen) in the next 2 years. Eloy is the Principal Investigator for the REACH project.



The Big Bang model for the origin and initial evolution of the Universe is by now a familiar and well-studied research field. The subsequent, late-time, evolution of stars and other celestial objects over billions of years is perhaps even better understood. Less is known, however, about the time between these periods, from about 0.35 to 1 billion years after the Big Bang. During this time the Universe transitioned from being a vast volume filled with a cooling neutral gas to become the realm of cosmic objects we now observe from the Earth.

A schematic diagram illustrating the standard picture of the formation and evolution of galaxies and the large scale structure of the Universe is shown in Fig. 1. The Cosmic Microwave Background radiation we observe today originated from a 'surface' of cosmic recombination about 378,000 years after the Big Bang at a redshift of about 1100, well before the current 'realm of the galaxies'. The stars and galaxies we see today formed some time after the epoch of cosmic recombination, over the period about 1 to 13.7 billion years after the Big Bang. The radiation from the very first luminous sources heated and re-ionized the neutral hydrogen that pervaded the primordial cosmos. Probing these epochs, the 'Dark Ages' before the first galaxies, through cosmic re-ionization and first new light in the Universe, represents the frontier in studies of cosmic structure formation.

Neutral hydrogen has a hyperfine transition at a rest wavelength of 21 cm due to the spin flip of the electron and by observing at low radio frequencies we can study directly its red-shifted radio emission and absorption from the gas clouds that were the raw material that formed the first luminous cosmic structures at these early epochs. While the future Square Kilometre Array (SKA) telescope will aim to carry out full tomography of the hydrogen emission from the Cosmic Dawn (CD) and the Epoch of Re-ionization (EoR), a simpler way in principle to attempt the detection and study of this signal is to observe the monopole emission. By monopole emission, we mean the average emission from all directions in the sky through cosmological time, red-shifted from 21-cm to a few metres due to the expansion of the Universe (Fig. 2) using a stand-alone radiometer system.

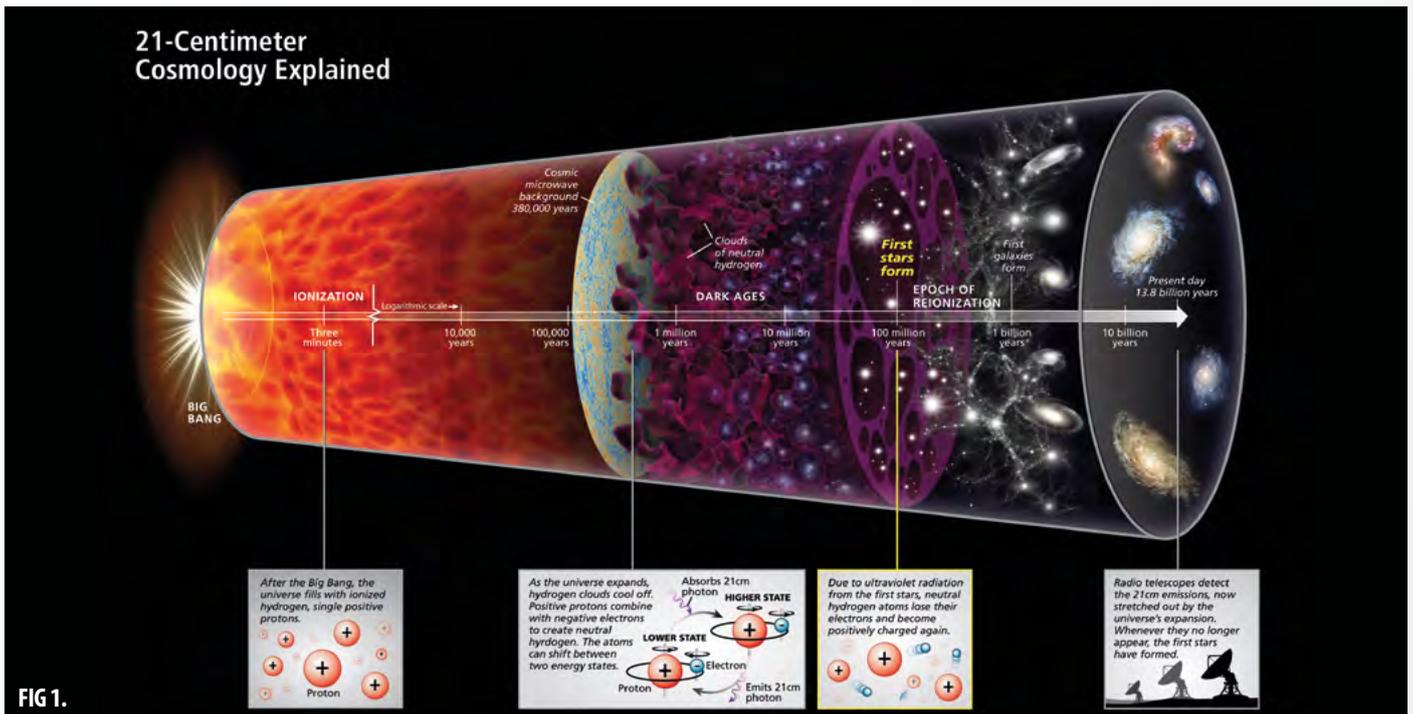


FIG 1.

During the Dark Ages, the neutral hydrogen gas expanded and cooled, becoming colder than the microwave background photon gas. At redshifts of about 25–30 we expect the first stars to shine in the Universe during the so-called ‘Cosmic Dawn’. The resulting ambient radiation field is coupled to the electron spin temperature of the colder hydrogen gas through the Wouthuysen-Field effect. This effect leads to a ‘deep’, few tens of hundredths mK absorption trough at a redshift of about 20 (Fig. 2): the depth, width and position of this trough encode information about the nature of the very first luminous sources, as well as the sources responsible for the heating of the intergalactic medium (IGM). As the formation of the first sources progresses, X-rays heat the intergalactic medium, causing the absorption trough to disappear and eventually reappear as an emission feature. As heating and star formation progress further, the UV photons produced in galaxies escape into the IGM, causing its widespread ionization which is expected to be concluded at a redshift of about 6, the end of the Epoch of Re-ionization. Measurement of the 21-cm signal throughout this epoch will not only determine the time evolution of the process of reionization but will also tell us about the nature of the first galaxies in the Universe and their interplay with the IGM.

The REACH¹ project will open a window to these early epochs of the Universe by observing the radio signals associated with neutral hydrogen. We will in essence be looking at these first stars through their interaction with the hydrogen clouds in the same way one would infer a landscape by looking at the shadows in the fog covering it.

Recent results from the EDGES experiment² caused a stir in the cosmology community with the report of a potential detection of an absorption feature at 78 MHz. The absorption feature was deeper than expected, and if confirmed, would call for new physics. Our colleagues in Cambridge, including Kavli Fellows, have however re-analyzed the EDGES data and questioned the reliability of the signal³. These issues call for an urgent confirmation of the signal detection through an independent experiment, which should include results at higher frequencies at the EoR band.

The aim of REACH is to improve and complete the current observations by tackling some of the challenging issues faced by EDGES and other current instruments. These include: the chromatic effects of the antenna beam across a larger bandwidth, a joint foreground + instrument calibration and the use of advanced Bayesian techniques for the signal analysis.

REACH is a joint experiment between the University of Cambridge and Stellenbosch University in South Africa. With primary funding from the Kavli Institute for Cosmology in Cambridge, REACH will be deployed in the semi-desert land of the Karoo radio reserve in South Africa, a unique Radio Frequency Interference (RFI) quiet site which is also home of the future Square Kilometer Array telescope (see Fig. 3). The team consists of 33 people in 16 institutions from 7 countries. The collaborators are world experts in the fields of theoretical cosmology, Bayesian data analysis and radio instrument design, with experience in leading the designs and development of telescopes such as the SKA, Planck and HERA, amongst others. In Cambridge, REACH has collaborators in the Cavendish Astrophysics Group, the Cambridge Kavli Institute for Cosmology and the Institute of Astronomy.

The instrument will operate between 50 and 150–200 MHz in order to explore both the Cosmic Dawn and the Epoch of Re-ionization. REACH is a wideband radiometer using state of the art ultra-smooth wideband radio antenna designs, using between 1 and 3 different antennas to tackle the challenging systematics and aiming at reducing the contamination of the cosmic signal. REACH is furthermore making use of advanced Bayesian data analysis tools as well as physics-based models of the instrument, the 21-cm signal and the foreground signals beneath which the cosmic signal is buried. This detection is extremely challenging due to the accuracy and precision needed to make a measurement of absolute power on the sky in the presence of much brighter foregrounds, about 100,000 times brighter than the cosmic signal, and somewhat unknown themselves.

A detection and posterior analysis of this signal will represent a giant leap in modern cosmology, finding one of the missing pieces in the puzzle of the history of the Universe.

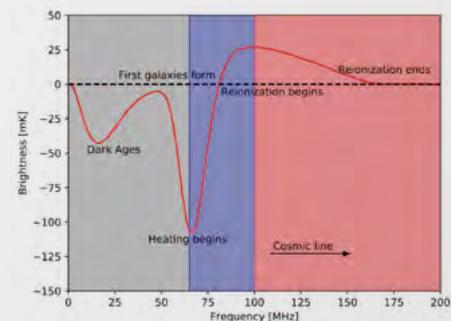


FIG2.



FIG3.

FIG 1. The standard picture of the origin and evolution of cosmic structure, showing the role of 21-cm cosmology. (Courtesy of Roen Kelly, Discover Magazine).

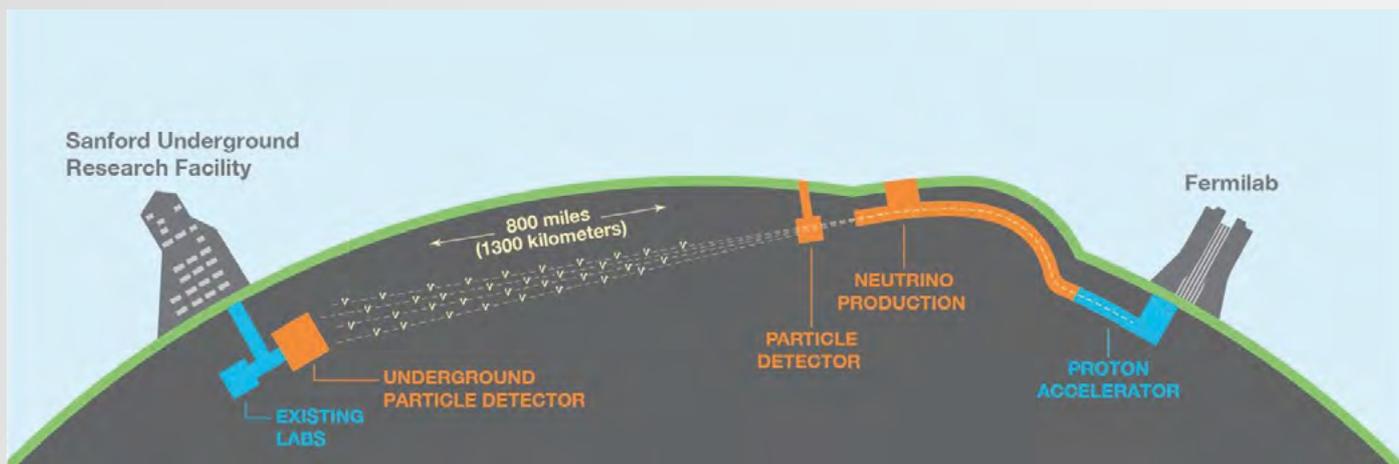
FIG 2. A theoretical model of the cosmic radio signal REACH aims to detect. The radio brightness temperature on the ordinate is measured in millikelvins.

FIG 3. A) REACH location at the Karoo radio reserve in South Africa, B) aerial view of the site.

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Neutrinos, neutrinos everywhere...

We are delighted to welcome **MELISSA UCHIDA** who has taken up a four-year lectureship in the Laboratory. She brings us up to date about current and future neutrino experiments and how they will provide new insights into particle physics and the physics of the very early Universe.



One of the most fundamental and exciting questions we can ask is 'how did our Universe come to exist?' Only 5% of the Universe is ordinary matter – the fundamental particles which make up the stuff we see all around us: us, the Earth, the stars and galaxies – and we are yet to fully understand it. Another 27% is dark matter about which we know almost nothing and have yet to detect it directly. The remaining 68% is dark energy, which is a complete mystery. But one thing we are certain about is that our present Universe is matter-dominated and, while we can get a long way with our current understanding of the standard models of particle physics and cosmology, we cannot explain why the Universe has this strange mix of known and unknown components. So how did the Universe come into existence – could neutrinos be the answer?

After photons, neutrinos are the second-smallest and second-most abundant particles in the Universe – five billion of them pass through your thumbnail every second. Most importantly, their strange and unexpected behaviour has challenged our understanding of particle physics.

There are three types or 'flavours' of neutrinos: electron neutrinos, muon neutrinos and tau neutrinos and until recently they were thought to be massless. The experimental discovery of neutrino oscillations by the Super-Kamiokande and Sudbury Neutrino Observatory experiments showed that neutrinos do in fact have mass, a discovery recognised by the award of the 2015 Nobel Prize in Physics.

Neutrino oscillation is the process by which one of the three types of neutrino changes into another over a certain distance travelled – crucially, they provide the first direct experimental evidence of physics beyond the Standard Model of particle physics which has been very successful in describing all the fundamental particles and forces. The theory of neutrino oscillations contains a charge conjugation parity (CP) symmetry-violating term δ^{CP} which suggests that neutrinos may violate matter-antimatter symmetry – this is one of the necessary conditions which has to emerge from the very early phases of the Big Bang in order for our Universe to be matter-dominated at the present day. Until recently, we had no hints as to what the value of δ^{CP} could be – it could even have been zero – or indeed, if we could measure it. However, recent neutrino data have discovered the neutrino mixing angle θ_{13} to be non-zero and 'large', work for which my colleagues and I on the T2K and four other experiments won the Breakthrough Prize in Fundamental Physics in 2016. This was the first experimental hint that δ^{CP} can be measured in the neutrino sector.

The ordering by mass of the three types of neutrino have also yet to be determined. While we know the differences between the three neutrino masses, we do not know whether the third mass is heavier or lighter than the first two, nor do we know their absolute masses. The determination of this so-called neutrino mass hierarchy is an important step in understanding the nature of neutrinos – are they Majorana particles, in which neutrinos are their own anti-particles, or Dirac particles, in which neutrinos and anti-neutrinos are different.

FIG. 1, left: DUNE will consist of two neutrino detectors placed in the world's most intense neutrino beam. One detector will characterise the beam near its source, at the Fermi National Accelerator Laboratory near Chicago. A second, much larger, detector will be installed 1300 km away at the Sanford Underground Research Laboratory in South Dakota.

FIG. 2, below: The MicroBooNE cryostat (left) and a MicroBooNE event display (right).



The measured value of δ^{CP} along with the determination of the neutrino mass hierarchy will begin to tell us the extent to which neutrinos are responsible for the matter anti-matter asymmetry of the Universe and bring us closer to a generalised theory of flavour.

The Deep Underground Neutrino Experiment (DUNE) is a billion dollar scale, next-generation long-baseline neutrino experiment designed to measure δ^{CP} and determine the neutrino mass hierarchy. The DUNE Science Collaboration is made up of over 1000 collaborators from over 180 institutions in over 30 countries plus CERN. At the Cavendish Laboratory we are heavily involved in most areas of DUNE, including the hardware, calibration, software and data analysis. Currently under construction, DUNE is set to begin data taking in 2026. The 1.2 MW wide-band neutrino beam, generated by the Long Baseline Neutrino Facility (LBNF) at Fermilab, Chicago, will be fired 1300 km towards a 40 kiloton fiducial mass liquid argon (LAr) time projection chamber (TPC), located one mile underground at the Sanford Underground Research Facility (SURF) in South Dakota (Fig. 1).

But there are yet further questions that intrigue us in the neutrino sector. One of these is a mysterious excess in possible neutrino interactions observed at low energies by the LSND and subsequently MiniBooNE experiments while searching for the muon neutrino to electron neutrino oscillation signature. This result has generated substantial theoretical interest. Could this be an experimental effect, or is there a beyond-the-Standard Model interpretation? Perhaps a fourth as-yet undiscovered sterile neutrino? These 'sterile' neutrinos

get their name from their inability to interact with other matter through any of the forces in the Standard Model other than perhaps gravity. Their discovery would be incredibly exciting as they could explain how neutrinos acquire mass, give us greater insights into the formation of the early universe and they could even be the particles that make up dark matter, which, like sterile neutrinos, seems to be impervious to all known forces except gravity.

The MicroBooNE experiment, a 170 ton LAr TPC neutrino experiment located at Fermilab (Fig. 2), is investigating these low-energy excess events observed by MiniBooNE, as well as measuring a suite of low-energy neutrino cross sections, investigating astroparticle physics, and contributing vital R+D input towards the much larger DUNE LAr TPC.

MicroBooNE has been collecting neutrino data in since 2015. One significant challenge is to develop automated software for pattern recognition and neutrino event reconstruction in order to exploit the full potential of Liquid Argon technology. The Cambridge group is developing new techniques for event reconstruction that can be applied to MicroBooNE data in order to reveal the detailed properties of neutrino interactions. The first results are beginning to appear and it is hoped that in the near future we may begin to understand the neutrino low-energy excess problem.

So how did we come to live in our matter dominated Universe? And could our study of neutrinos finally provide the answer? One thing is for sure, we getting closer and closer to finding out!

Physics and Biological Evolution

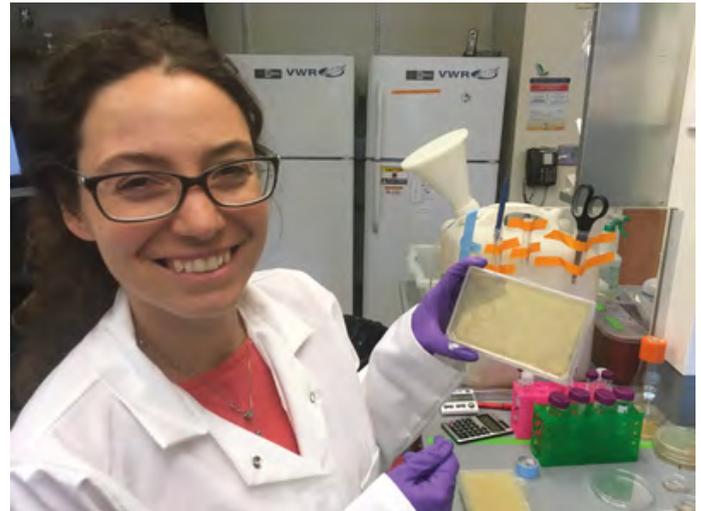
We warmly welcome **DIANA FUSCO** who took up her post as a University Lecturer in the summer of 2018. Here she describes her innovative research programme linking Biological Evolution and Physics.

Until recently, biological systems were considered too unpredictable and complex to allow the formulation of general rules that would successfully describe their behavior. Fortunately, we are witnessing new exciting times where the advances in experimental techniques, such as high-resolution microscopy, single-cell sequencing, and synthetic biology, are enabling the generation of an unprecedented amount of data. The availability of this new information is finally bridging the gap between physics and biology allowing us not only to develop and test new models, but even to probe the most fundamental processes that are at the heart of living matter.

My group is fascinated by one aspect that is unique to living systems: their ability to evolve and adapt to new environmental challenges. In this context, viruses and microbes probably represent the winners of the evolutionary game having survived over billions of years of changes on Earth. Their adaptability is so remarkable that they can be used to manufacture novel enzymes or combat autoimmune diseases. When faced by an environmental challenge, an evolving population can almost be seen as a problem-solving machine that relies on its large number of individuals to test multiple strategies simultaneously. But how can we harness this power efficiently?

This is where physics can help. By understanding the fundamental processes that drive evolution, we can begin to predict its trajectories and eventually control the final outcome. My group, borrowing tools from statistical physics and population genetics, tackles this very question. Inspired by experimental observations of microbial and viral systems, we build and test models that characterize the genetic heterogeneity of a population. This intrinsic diversity fuels adaptation by providing a pool of traits on which natural selection can act in favoring the fittest individuals. Selection is not, however, the only evolutionary force at play. Stochastic fluctuations, or *genetic drift*, can have even stronger effects under certain circumstances, masking the effects of selection and giving an advantage to the luckiest rather than the fittest individual (Fig. 1).

One of the scenarios in which noise plays a crucial role concerns spatial range expansions, in which a population, whether viral, microbial or human, grows by invading virgin territory. In this instance, the individuals at the very front, *the pioneers*, benefit from having first access to the new territory and also from placing their offspring in such advantageous positions.



As a result, their genes are more likely to be carried by the future generations *surfing the wave* of the expansion. This phenomenon, called *gene surfing*, can be so extreme that even deleterious mutations may be able to surf and accumulate in the population, possibly leading to a growth arrest because the individuals at the front are too sick to reproduce.

My group is currently investigating ways in which the strength of genetic drift at the front of the expansion can be mitigated. Preliminary experiments suggest that some viruses and parasites can avoid this simply through an incubation period in their host. Also, cooperative individuals that require large numbers to prosper seem to be able to escape the problem. What is the common denominator defining these populations? We are in the process of determining the minimal necessary ingredients that allow a population to expand without accumulating deleterious mutations. We are testing our hypotheses using a well-controlled laboratory system based on the ecosystem of bacteriophage T7 and its host *E. coli*. Our goal is to be able then to determine to what extent a naturally occurring population would be affected by the problem. In the case of parasites or viruses, our findings could point to strategies that exploit the population dynamics to spontaneously drive the population to stop its invasion.



A SHORT CV

Diana was trained as a theoretical physics at the Università di Milano where she obtained a BSc in Physics and a MSc in Theoretical Physics. During her final year in Milan, she became fascinated with biological systems and their hidden universal behaviors. She therefore decided to pursue a PhD in Computational Biology at Duke University, North Carolina where she worked on computational methods to describe protein self-assembly with Dr. Patrick Charbonneau. Tired of looking at problems only with theoretical tools, she joined Dr. Oskar Hallatschek group at UC Berkeley as a postdoctoral researcher where she learned to use experimental microbiology to test her model of population and evolutionary dynamics. Starting in July 2018, she joined the Cavendish as group leader where she continues to tackle biological questions both theoretically and experimentally.

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FIG. 1: Two-dimensional colony of *S. cerevisiae* inoculated by mixing two fluorescently labeled strains (blue: fast growing, yellow: slow growing). Due to noise and mechanical interactions, the slow growing individuals survive the expansion for much longer than expected (1).

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Unsung heroes

ROBERT HAY reflects on a wartime tragedy in which members of the Cavendish Laboratory were closely involved.

On 7th June 1942 a modified Halifax bomber V9977 crashed near the River Wye at the small village of Welsh Bicknor in Herefordshire. Given the date in the middle of the Second World War such an event may not seem that remarkable but dig a little deeper and the tragedy, for tragedy it certainly was, reveals a story of great scientific endeavour and of brilliant minds cut down in their prime.

The plane had been on a secret mission from the Telecommunications Research Establishment (TRE), testing the H2S airborne radar system which included the only working and highly-secret cavity magnetron system at the time. The work at TRE was under the direction of Bernard Lovell, who was to become the first director of the Jodrell Bank Radio Observatory after the War. Among his colleagues was Martin Ryle who before the war had joined Jack Ratcliffe's radio group at the Cavendish in 1939. On the outbreak of war Ratcliffe joined the Air Ministry Research Establishment, later to become TRE, and Ryle joined him in 1940.

The EMI company began a collaboration with TRE devising radar equipment that would help British bombers find their targets at night. Among the EMI collaborators was their brilliant Chief Engineer Alan Blumlein who is credited with the invention in 1931 of stereo, which he called binaural sound. Also at TRE at that time were Philip Dee, a University Lecturer from the Cavendish, who was one of the key players in the development of the H2S and Sam Curran, who had been his research student, along with Geoffrey Hensby a young Scientific Officer and a key member of Lovell's team.

The night before the flight, Martin Ryle had dinner with the crew. On board the plane were 11 personnel: three from EMI; three from TRE and five from the Telecommunications Flying Unit (TFU). About 20 minutes before the plane took off Alan Blumlein asked to join the flight. As 11 was the maximum number possible, Sam Curran, who was due to be on the plane, gave up his place and his flying gear to Blumlein. The plane caught fire at 3000 ft and plunged to the ground, exploding on impact. All 11 men were killed including Blumlein and Hensby and thus two of the most promising scientists of the day were lost. Lovell was hugely affected by the tragedy, not least because he had himself flown in the plane the previous day. His diary records:

"The mass of wreckage was unbelievable. The eleven lifeless bodies near the charred remains of the bomber I had flown in the previous night was horrifying. The loss of Blumlein is a national disaster. God knows how much this will put back H2S."

The most vital part of the H2S system, the cavity magnetron, was immediately recovered from the wreckage and a new prototype built at the insistence of Churchill. The magnetron was a major advance in transmitting power over the previous klystron device and went into production in 1943. It was successfully deployed in raids over Hamburg. The device was also adapted to help Coastal Command find and destroy U-Boats at night as they crossed the Bay



The unveiling of the memorial to Blumlein and his colleagues at Welsh Bicknor. Inset: Alan Blumlein (Courtesy of the EMI archives).

of Biscay and surfaced, under the cover of darkness, to recharge their batteries. These attacks were so effective that by August 1943 the U-Boat menace was largely defeated, the Battle of the Atlantic was won and the safe passage of hundreds of thousands of American troops in time for D-Day was made possible. The value of Blumlein's and Hensby's contributions to these achievements was immense.

It may seem strange that these contributions to the war effort are not more widely known. The answer lies in the embargo that Churchill insisted be placed on reporting the crash. He believed that news of the death of such an important scientist as Blumlein would aid the German war effort.

The development of radar during the Second World War had important consequences for the surviving pioneers, Lovell, Ryle, Hewish and their colleagues. The extraordinary research efforts to design powerful radio transmitters, sensitive receivers and improved radio antennae resulted in new technologies which were to be exploited by radio astronomers, all of whom came from a background in radar. After the war in 1945 Philip Dee took up the Chair of Natural Philosophy at the University of Glasgow and Sam Curran joined him. Curran, who could so easily have been on the fatal flight, went on to become the first Principal and Vice-Chancellor of the University of Strathclyde.

In 2019 an appeal was launched under the auspices of the Hereford Times newspaper to raise funds to erect a permanent memorial to Alan Blumlein and the others who lost their lives at the site of the plane crash in Welsh Bicknor. The Cavendish was pleased to make a contribution to this appeal. The resulting memorial was unveiled at a moving ceremony on 9th June 2019. Among the guests were Alan and Doreen Blumlein's two sons, Simon and David along with relatives of others who died with him.

Robert Hay was Academic Secretary of the Cavendish Laboratory from 1999 to 2016.

David Thouless 1934–2019



Colleagues will be greatly saddened by the death of Professor David Thouless FRS, who passed away on 6th April 2019. David was born in 1934 in Bearsden, a town in East Dunbartonshire close to Glasgow, and educated at Winchester College. He became an undergraduate at Trinity Hall, Cambridge where he read Natural Sciences. He was fortunate to meet Hans Bethe who was in the Cavendish Laboratory for a year to stimulate the work of the newly founded Solid State Theory Group led by John Ziman. David was accepted as a graduate student at Cornell University where he obtained his PhD under the supervision of Bethe.

Returning to the UK, he first spent two post-doctoral years at Birmingham University working under Rudolf Peierls and was then appointed an Assistant Lecturer (1961–63) and then Lecturer (1963–64) in the Department of Applied Mathematics and Theoretical Physics at Cambridge. At the same time, he was appointed a Fellow of the recently-founded Churchill College, becoming the College's first Director of Studies for Physics in 1961. He then took up the Professorship of Mathematical Physics at the University of Birmingham in October 1965 where he remained until 1978. During this period, he began his collaboration with Michael Kosterlitz. He was elected a Fellow of the Royal Society in 1979.

David was a professor in the Department of Physics at the University of Washington, Seattle from 1980 until his retirement in 2003. In 1983 he was appointed Royal Society Research Professor in the Theory of Condensed Matter (TCM) Group in the Cavendish Laboratory and became a Professorial Fellow of Clare Hall. He returned to the University of Washington but was a frequent summer visitor to the Laboratory, a colleague and friend to members of TCM and the Cavendish.

David made a series of extraordinary contributions to the theoretical understanding of phases of matter, in both the classical and quantum regimes. Most notable, perhaps, were his 'theoretical discoveries of topological phase transitions and topological phases of matter' for which he was awarded one half of the Nobel Prize in Physics in 2016, the other half being awarded to Duncan Haldane and Michael Kosterlitz. The nature of these research discoveries was described in an article by Nigel Cooper in *CavMag*17. Over the last decade, the practical application of topology has boosted frontline research in condensed matter physics, not least because of the hope that topological materials could be used in new generations of electronic devices and superconductors, or in future quantum computers.

We pass on our condolences to David's wife Margaret and their family.

Bruce Elsmore 1925–2019



Members of the Laboratory will be saddened to learn of the death of Bruce Elsmore on 24 August 2019. In 1948 Bruce joined the fledgling radio astronomy group led by Martin Ryle which helped bring the discipline of radio astronomy into being just after the War. Bruce's practical skills in the design and construction of radio receivers, and the operation in the field of aperture synthesis radio telescopes made an enormous contribution to the rapid development of radio astronomy at Cambridge.

His name is particularly associated with the first paper on Earth-rotation aperture synthesis observations with the Cambridge One-Mile Telescope of the radio sources Cygnus A and Cassiopeia A. Those of us present at the time were startled by the unprecedented quality of these radio images, both in sensitivity and angular resolution. These and subsequent observations with the One-Mile Telescope and the subsequent 5-km telescope put Cambridge and the UK in the leading position in radio astronomical imaging world-wide. It also resulted in Martin Ryle's Nobel Prize in Physics in 1974. Bruce was also the Group's guru in the somewhat less glamorous subject of radio astrometry, the precise measurement of radio source positions on the sky. By using quasars as calibrators, this became the preferred means of establishing the astrometric frame of reference for all astronomy.

Bruce was a fellow of St. Edmunds College and served as Senior Tutor from 1978 to 1989. He served selflessly, loyally, and enthusiastically six Masters of the College. We all remember his quiet kindness and gentle support through what were dramatic and, at times, turbulent years in the history of radio astronomy.

We send our condolences to his wife Annette and their family.

35 years of Physics at Work



JACOB BUTLER celebrates the 35th Anniversary of the Laboratory's Physics at Work programme



This September marks the 35th anniversary of Physics at Work. This annual school's event takes place over three days and aims to showcase the many ways in which physics is used in the wider world. It features presentations and activities from academic and industry groups, and is attended by around 2000 students each year. Students and teachers vote for their favourite exhibit, with newcomers Medical Mavericks winning the 2018 student vote. Amongst many others, this year featured an exhibit from 'Seeing with Atoms', a partnership between the Universities of Cambridge and Newcastle (Australia), and took place from the 17th to 19th September (Fig.1).

<http://outreach.phy.cam.ac.uk/paw>

www.seeingwithatoms.com

Local Outreach

The Outreach Office has recently partnered with two local organisations to highlight the applicability of physics to everyday life. In July, an event was run with Cambridgeshire County Council at the Saffham Prior Primary School to inform students of the inner-workings of a proposed community ground-source heat pump network (Fig.2). This is a pilot study

to test the feasibility of refitting villages with similar networks around the country and could potentially save nearly 30 000 tonnes of CO₂ by 2050, whilst reducing heating costs for those involved. The day featured demonstrations and activities on energy and energy transference for each of the classes, culminating with the senior students producing a human-scale heat pump in the school playground.

<https://heatingswaffhamprior.co.uk/>

On the 1st September, the Outreach Office took part in an event at the newly-reopened Museum of Technology as part of the second CamCycle Festival of Cycling. The day focussed on the science and technology behind bicycles, with demonstrations on how a bicycle operates and the forces that must be overcome to travel as quickly and efficiently as possible. The Festival of Cycling aims to 'celebrate the joy of cycling, share cycling experiences,

learn new things and share in our vision for more, better and safer cycling in and around Cambridge for all ages and abilities.' By taking part, the Outreach Office hopes to give attendees a better appreciation of the complex physics of bicycles and demonstrate how an understanding of this can make them more efficient cyclists.

www.cambridgefestivalofcycling.org

Cambridge Physics Experience

October marks the beginning of the 8th year of the Cambridge Physics Experience, a school's event which takes place over eight weeks throughout the school year. Each day of the event, school groups visit a college and are given talks on higher education in the morning and then spend the afternoon doing practical physics activities at the Cavendish. Each year has spaces for up to 2400 students and booking for the year's programme is already open. The event is open to state schools and, thanks to a generous legacy, bursaries are available to help with teacher cover and travel costs. Schools can register their interest at the webpage below.

<http://outreach.phy.cam.ac.uk/cpe>



FIG 2: Pupils at Saffham Prior Primary School displaying the projects they had worked on during Science Week

Senior Academic Promotions



We congratulate **Erika Eiser** (left, see also pages 14–15) and **Austen Lamacraft** (right) on being promoted to Professorships in the 2019 Senior Academic promotion round.

Prizes and Awards



We are delighted to announce that **Jacqui Cole** has been awarded the Royal Society's 2020 Clifford Paterson Medal and Lecture for 'the development of photo-crystallography and the discovery of novel high-performance nonlinear optical materials and light-harvesting dyes using molecular design rules.

(see also CavMag 21, page 18).



We warmly congratulate **Mark Warner** and **Lisa Jardine-Wright** on being awarded the *IOP's 2019 Bragg Medal*, for 'jointly setting up and directing the *Isaac* Physics programme which has

revolutionised physics education for teachers and students in an extraordinary number of UK schools and is now attracting international attention.'



Warmest congratulations also go to **Nigel Cooper** who has been awarded the *IOP's 2019 John William Strutt, Lord Rayleigh Medal and Prize* 'for profound contributions to the quantum theory of many-particle systems, concerning both topological phases of cold atoms in artificial gauge fields and novel phenomena in electronic materials.'



The IoP Semiconductor Physics Group PhD Thesis Prize 2019 has been awarded to **Mojtaba Abdi** for his work on *Chemical Modifications and Passivation Approaches in Metal Halide Perovskite Solar Cells*. We congratulate Mojtaba on this notable success which was described in *CavMag20*.

We congratulate **Samaya Nissanke**, now of the University of Amsterdam, on winning the *2020 New Horizons in Physics Prize* with her colleagues Jo Dunkley of Princeton University and Kendrick Smith of the Perimeter Institute for the development of novel techniques to extract fundamental physics from astronomical data. Samaya was a Cambridge Physics undergraduate who began her studies of gravitational radiation in her Part III year.

Research Fellowships

We warmly congratulate **Dominik Kubicki** on his award of a Marie Curie Fellowship to be held in the Optoelectronics Group working with Sam Stranks.

New Appointments

We welcome the following who have joined the Laboratory in Administrative and Technical Roles.

Christopher Wrycraft	Kapitza Hub General Administrator
Jo Kibble	Finance Manager
Denise Rickwood	Accounts Clerk
Timothy Fitzmaurice	PoM Laboratory Manager
Lynn Campbell	Rutherford Hub General and Finance Administrator



Many congratulations indeed to **Abbie Lowe** on being awarded **Science Apprentice of the Year** at the Cambridge Regional College (CRC) Apprenticeship Awards on 7 March 2019.

Abbie joined the Department of Physics in 2017 as an Apprentice Research Laboratory Technician in the Semiconductor Physics group, having completed her A levels in Chemistry and Biology at the Long Road Sixth Form College. Abbie's keen interest in Science led her to apply for an Apprenticeship in the Department and she was delighted to be awarded the Science Apprentice of the Year award. Abbie is enjoying her apprenticeship and feels that the combination of learning on the job, working with colleagues and studying with CRC is an ideal way for her to progress her passion and understanding of science and develop her career. Abbie's top tip for learning is to focus on building her knowledge one step at a time.

ABOVE: Abbie being presented with her award by Mark Robertson, Principal and Chief Executive of the Cambridge Regional College.

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**

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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 (**mssl1000@cam.ac.uk**) or Gillian Weale (**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 (**mssl1000@cam.ac.uk**) or Andy Parker (**hod@phy.cam.ac.uk**), who will be very pleased to talk to you confidentially.