UNIVERSITY OF CAMBRIDGE

THE WINTON PROGRAMME FOR THE

Physics of Sustainability

ANNUAL REPORT

2015

The Winton Programme for the Physics of Sustainability was established in 2011 through the donation of £20 million by David Harding to the Cavendish Laboratory. The funds have been deployed to develop 'blue-skies' research in areas that could have an impact on how we can advance effectively the sustainability agenda.

Winton-supported PhD students, Advanced Research Fellows and Lecturers are now making a very large contribution to work in the Cavendish; their research is developing new interactions within the Cavendish and across the University. The Maxwell Centre is due to open later this year, this will provide new space for the Winton activities to expand - it will provide a wonderful arena for interactions between academia and industry. This annual report provides a summary of the activities of the Programme and some of the highlights of the year.

REVIEW

Richard Friend, Cavendish Professor of Physics

The Winton Programme has been running for four years and is now operating at full scale. The Programme now involves the majority of the research groups in the Cavendish Laboratory, principally through support for 'pump prime' new projects and Winton Scholar PhD students. The ambition of the Winton Programme is to support new 'blue-skies' science that also has the long-term potential to engineer a more sustainable future. This is the core of the Programme and a selection from the science projects developed within the Winton Programme is set out in this year's report. Much of this work will move into the Maxwell Centre when it opens at the end of this year. The Programme has also provided a focus for engagement with global technology projects and the Winton community's involvement has grown steadily; examples such as the Cambridge Development Initiative and the Smart Villages Initiative are included in this report.

Within the University, the Winton Programme is providing input for the organisation of future research. The technologies of the 19th and 20th centuries usually delivered more speed and more power, but the performance metric for the 21st century is 'efficiency'. The same technologies that keep a smartphone running for twenty-four hours between charges have the capacity to remove 'light poverty' in the off-grid world, as touched on in several of the presentations at the 2014 Winton Symposium. This coincidence of drivers for mainstream technology and future sustainable technology presents a real opportunity for coordination of research across many areas. To bring focus to this, the University has just launched two new 'Grand Challenges', on 'Materials for Energy Efficient Information Communications Technology (ICT)' and on 'Algorithms and Systems for Energy Efficient Computing', see www.energy.cam.ac.uk. The first of these will also provide the Cambridge component within the new Manchester-centred national Sir Henry Royce Institute for Advanced Materials.

PROGRAMME UPDATE

Nalin Patel, Programme Manager

Overview

The Winton Programme for the Physics of Sustainability is now at steady state in terms of the number of people directly supported by the Programme, but continues to grow in terms of connections across the University and beyond. This year has seen the first Winton Scholars complete their PhDs and Advanced Research Fellows move to senior positions.

The Maxwell Centre will open later this year, and this will provide space for new laboratories and offices for members of the Winton community, and provide a focus for industry-university interactions in the Cavendish and across the West Cambridge site. The laboratories will include those of Siân Dutton, Winton Fellow who takes up her University Lectureship in the Department, and Suchitra Sebastian, University Lecturer and affiliated to the Winton Programme, who are exploring new functional materials and are setting up the £2M Advanced Materials Characterisation Suite in the Centre. Optics laboratories of new Lecturer in the Department, Tijmen Euser, and Winton Fellow Akshay Rao will also be housed in the Centre, as outlined later in this report.

Programme Activities

This year has seen the first leavers from the Winton Programme, with Winton Fellow Nicholas Hine taking up an Assistant Professorship in the Physics Department at the University of Warwick. He will continue to interact with the Programme and the Department on his work related to modelling new materials. The 1st cohort of Winton Scholars, are now completing their PhDs, including Miloš Knežević, who has taken up the position of Postdoctoral Research Assistant in the Theoretical Physics group at the University of Oxford.

Project descriptions for the eight students who form the fourth cohort of Winton Scholars and who started their research a year ago are provided in the accompanying box. A similar number of Scholars will start their PhDs shortly. The scheme has been successful in attracting a large number of quality applicants from around the world.

The Winton Fellows continue to expand their research groups, attracting excellent PhD students and winning external grant funding. Andrew Morris has won an EPSRC (Engineering and Physical Sciences Research Council) grant for "New modelling capability for nano-confined phase change materials". This 3-year grant will allow him to grow his research on discovering new materials. Amalio Fernández-Pacheco and Akshay Rao have won EPSRC Early Career Fellowships, to develop their activities in investigating new magnetic nanostructures and photovoltaics with efficiencies beyond the Shockley-Queisser limit respectively.

Looking forward

The Winton International Advisory Board (IAB) brings together a group of very distinguished scientists from around the world who provide their input and guidance on the future strategic direction of the Programme. Professor Paul Alivisatos, Director of the Kavli Energy Nanoscience Institute, has chaired the board for the past four years, and will step down as chair this year and will remain a member of the IAB. We are delighted that Professor Ajay Sood, Indian Institute of Science Bangalore and recently elected as a Fellow of the Royal Society, has agreed to chair the IAB. We are also pleased to bring three new scientists to the IAB.

Professor Yoshinori Tokura, Director of Center for Emergent Matter Science at RIKEN and Professor at University of Tokyo.

Professor Winston Soboyejo, Professor of Mechanical and Aerospace Engineering at Princeton University.

Professor Jenny Nelson FRS, Professor of Physics at Imperial College London.

The Winton Programme is also working with other initiatives across the University to connect research and assess what are the future challenges that should be addressed. One activity is with Energy@Cambridge, a University wide strategic research initiative, on a new Cambridge Grand Challenge focused on Advanced Materials for Energy Efficient ICT (Information Communication Technology). Involving over 50 academics from across the Schools of Physical Sciences and Technology, this new activity focuses on materials discovery, and the development, optimisation and characterisation of the materials required to engineer change in ICT.

The field of ICT, interpreted broadly, offers a tremendous opportunity for radical technology changes, most of which will be driven by energy efficiency. Current technologies for energy usage, generation and storage all operate far below limits set by thermodynamics and there is huge potential to introduce radical changes that derive from fundamental scientific advances in materials-based technologies. Some of these topics have been covered in previous Winton Symposia on 'Energy Efficiency' and 'Materials Discovery' and will again be covered this year as part of the Symposium on 'Green Computing'.

This Cambridge-led Grand Challenge will be one of the core focus areas of the new national Sir Henry Royce Institute for Advanced Materials, announced in the Chancellor of the Exchequer's annual Autumn Statement to Parliament in December 2014. A fundamental principle of the Sir Henry Royce Institute is that ideas can be brought to application and market much faster and more effectively when world-class staff, from academia and industry, are brought together, a principle that is closely aligned to that of the Winton Programme.

Winton Scholars that started in 2014/15

Mr Jerome Burelbach
Supervisor: Dr Erika Eiser
Optoelectronics Group
"Thermophoresis in colloidal suspensions"

Mr Gabriel Constantinescu
Supervisor: Dr Nicholas Hine
Theory of Condensed Matter Group
"Van-der-Waals heterostructures"

Mr Yago Del Valle-Inclan Redondo
Supervisor: Professor Jeremy Baumberg
Nanophotonics Group
"Microcavity polaritons"

Ms Paromita Mukherjee
Supervisor: Dr Siân Dutton
Quantum Matter Group
"Exploring the viability of complex lanthanide oxides for magnetic cooling"

Mr Bhaskaran Nair
Supervisors: Professor Neil Mathur and Dr Anoop Dhoot
Materials Department and Optoelectronics Group
"Electrocaloric effects in ionic liquids"

Mr Johannes Richter
Supervisor: Professor Richard Friend
Optoelectronics Group
"Hybrid organic-inorganic perovskite semiconductors for photovoltaics"

Mr Sam Schott
Supervisor: Professor Henning Sirringhaus
Optoelectronics Group
"Spin and charge transport in organic materials, investigated by electron spin resonance"

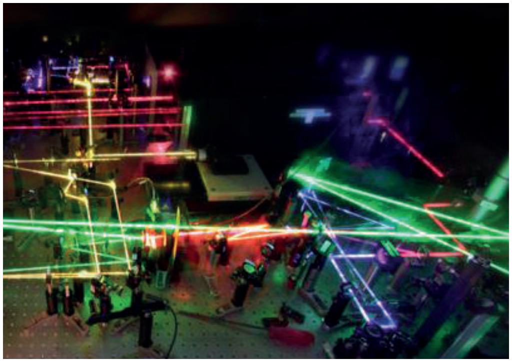
Ms Leah Weiss
Supervisors: Professor Richard Friend and Dr Alex Chin
Optoelectronics Group and Theory of Condensed Matter Group
"Triplet dynamics in singlet fission and hybrid materials via optical and electron spin resonance spectroscopy"

The Maxwell Centre is about to open its doors to the first occupants later this year. The Centre has been designed to stimulate interactions, and enable partnerships to flourish between the University and businesses, with a range of brainstorming corners, meeting rooms and boardrooms and a business lounge. The building will accommodate 230 people over four floors with state-of-the-art laboratories. The Centre will enable activities working across disciplinary boundaries in the physical sciences and technology; two of the first users are Tijmen Euser and Akshay Rao, who describe some of the work they will perform. For further information on the Maxwell Centre contact Dr Aga Iwasiewicz-Wabnig (**aga@maxwell.cam.ac.uk**).

Akshay Rao
(Winton Advanced Research Fellow)

We use ultrafast spectroscopic tools to elucidate the quantum mechanical behaviour of a new generation of molecular and hybrid organic-inorganic semiconductors. One of the fascinating processes we are currently studying in detail is singlet fission. In this process as photons come into contact with electrons within the material, the electrons are excited by the light, and the resulting 'excited state' splits into two. If singlet exciton fission can be controlled and incorporated into solar cells, it has the potential to double the amount of electrical current produced from highly energetic blue and green light, capturing a great deal of energy that would normally be wasted as heat and significantly enhancing the efficiency of solar cells.

Over the past year we have made several breakthroughs in this area, for instance we showed that there is link between the fission process and the vibration of the molecule that occurs when light comes into contact with the electrons. By monitoring these molecular vibrations in real time we have obtained a better understating of the intricate interplay between photons, vibrations and electrons in these system [1]. We have also shown that these molecular vibrations couple to the electrons in the system to create new mixed 'vibronic' states, which drive the actual singlet fission process. The experimental data allowed our colleagues Dr Alex Chin (Winton Advanced Research Fellow) and Sarah Morgan (Winton



Scholar) to build a comprehensive theoretical model, which for the first time self consistently explains the fission process [2]. This opens up the possibility of designing new singlet fission materials that would enable the process to be effectively integrated into a new generation of highly efficient solar cells. Another important development was our demonstration that the energy of the excited states formed via singlet fission can be transferred to more conventional inorganic semiconductors [3]. Combining the advantages of molecular semiconductors, which are low cost and easily processable, with highly efficient inorganic semiconductors, could enable us to increase further the efficiency of inorganic solar cells, such as those made of silicon.

But in order to keep pushing the scientific horizon we need to update and improve our experimental toolkit constantly. Key to this process will be the development of our new state of the art laser laboratories in the Maxwell Centre.

These temperature, humidity and dust controlled laboratories will provide a stable and protected environment for the development of our next generation laser system, which will eventually allow us to observe processes as fast as 7fs with 100 times more sensitivity than possible today. Further down the road we hope to add a spatial dimension to our experiment, combining both spectroscopy and microscopy, allowing us to 'image' samples with sub 10nm precision. The Maxwell Centre will provide a perfect home for this exciting new 'blue skies' science, as we push the limits of solar cells.

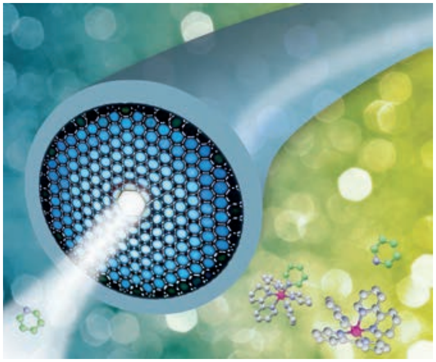
[1] "Evidence for Conical Intersection Dynamics Mediating Ultrafast Singlet Exciton Fission", Andrew J. Musser, Matz Liebel, Christoph Schnedermann, Torsten Wende, Tom B. Kehoe, Akshay Rao, Philipp Kukura. ***Nature Physics***, **11**, 352–357 (2015)

[2] "Real-Time Observation of Multiexcitonic States and Ultrafast Singlet Fission Using Coherent 2D Electronic Spectroscopy", Artem A. Bakulin, Sarah E. Morgan, Tom B. Kehoe, Mark W.B Wilson, Alex Chin, Donatas Zigmantas, Dassia Egorova, Akshay Rao. ***Nature Chemistry*** (Accepted).

[3] "Resonant Energy Transfer of Triplet Excitons from Pentacene to PbSe Nanocrystals", Maxim Tabachnyk, Bruno Ehrler, Simon Gélinas, Marcus L. Böhm, Brian J. Walker, Kevin P. Musselman, Neil C. Greenham, Richard H. Friend and Akshay Rao. ***Nature Materials*** 13, 1033, (2014).

Tijmen Euser

I am a new Lecturer in the Cavendish NanoPhotonics Group with research that is closely linked to the Winton Programme. Over the past years, my team at the Max Planck Institute for the Science of Light has demonstrated that



hollow-core photonic crystal fibres (PCF, see figure) act as excellent optofluidic waveguides that can be used to study highly-controlled light-matter interactions.

I am particularly interested in the interplay between optical, thermal, and fluidic forces on the nanoscale, as well as chemical reactions. In this context we have optically propelled microparticles in hollow-core PCF and used them to study optically-driven thermal flows [1]. Recently we showed that they can also be used as '*flying particle sensors*' that can map external quantities with a high spatial resolution [2]. In separate projects, we developed hollow-core PCF optofluidic microreactors that enabled strongly enhanced photochemical- and catalytic reactions on samples volumes that are five orders of magnitude smaller than in conventional methods [3,4].

Central to my research in Cambridge will be the creation of a joint optofluidic microreactor laboratory in the Maxwell Centre, with the aim of developing novel methods for *in situ* spectroscopy in these systems. These fundamental studies are expected to have a strong impact on the development of new catalytic and photochemical systems for advanced applications such as water-splitting, photochemical reduction of trace pollutants, and the development of novel light-activated anti-cancer drugs. The lab will also study waveguide-based optical manipulation of plasmonic- and semiconductor nanoparticles, their resonant excitation, and their interactions. This research will make full use of existing expertise in nanoparticle spectroscopy at the Cavendish and across the School of Physical Sciences.

[1] O. A. Schmidt, M. K. Garbos, T. G. Euser, and P. St. J. Russell, *Reconfigurable optothermal microparticle trap in air-filled hollow-core photonic crystal fiber*, Phys. Rev. Lett. **109**, 024502 (2012).

[2] D. Bykov. O. A. Schmidt, Tijmen G. Euser, and Philip St.J. Russell, *Flying particle sensors in hollow-core photonic crystal fibre,* Nature Photonics **9**, 461–465 (2015).

[3] A. M. Cubillas, S. Unterkofler, T. G. Euser, B. J. M. Etzold, A. C. Jones, P. J. Sadler, P. Wasserscheid, and P. St.J. Russell, *Photonic crystal fibres for chemical sensing and photochemistry,* Chem. Soc. Rev. **42**, 8629-8648 (2013).

[4] M. Schmidt, A. M. Cubillas, N. Taccardi, T. G. Euser, T. Cremer, F. Maier, H. P. Steinrueck,
P. St.J. Russell, P. Wasserscheid, and B. J. M. Etzold, *Chemical and (Photo)-Catalytical Transformations in Photonic Crystal Fibers*, Chem. Cat. Chem. **5**, 641-650 (2013).

FELLOWSHIP

The Winton Programme offers Advanced Research Fellowships to bright scientists to allow them to develop their own independent research. Five-year positions with significant support packages are available. Research activities of Ottavio Croze from the 3rd cohort and Amalio Fernández-Pacheco from the 4th cohort are described in this section.

Ottavio Croze

My group studies the physics of microorganisms in biotechnological and ecological contexts. In October 2014 I was joined by PhD student Di Jin. This autumn we welcome PhD student Hannah Laeverenz Schlogelhofer (NanoDTC), who recently completed a short project with us.

Current research focuses on photobioreactors, microswimmers and symbiosis. Photobioreactors are devices that grow algae for valuable bioproducts/bioenergy. Suspensions flow through transparent pipes or channels, but current designs fail to account for the peculiar physics of swimming in flow, described by biohydrodynamic theory (also describing the beautiful patterns in figure 1). We recently refined this theory, predicting unusual self-concentration and dispersion of swimmer suspensions in pipe flows [1]. My group is currently testing these predictions using photobioreactors, in collaboration with co-workers at DAMTP and Plant Sciences. My student, Di, has set up a photobioreactor to quantitatively image swimmer and fluid dynamics. She will soon use it, and computer simulations, to explore the intriguing effects of light-bias (phototaxis) and metabolism on swimmer dynamics and growth. Recent research has also involved the discovery of resonant ordering of microswimmer trajectories in oscillatory flows [2], and the measurement of helical swimming parameters of algae using Differential Dynamic Microscopy [1].

We are also very interested in algal-bacterial symbiosis, in particular 'at a distance': algae (needing vitamin, making sugars) and bacteria (needing sugars, making vitamin) interact remotely via a channel passing only diffusing metabolites. Our model, developed with François Peaudecerf (Goldstein group, DAMTP), predicts survival conditions for partner populations. Experimental tests are in progress, in collaboration with Professor Smith and her group (Plant Sciences). We hope our study will aid understanding of real microbial communities, e.g. microbial mats. Recently, we also started exploring metabolite detection using algae and nanophotonics. My student, Hannah, has been working with algae bearing vitamin B_{12}-responsive, fluorescently-tagged genes.

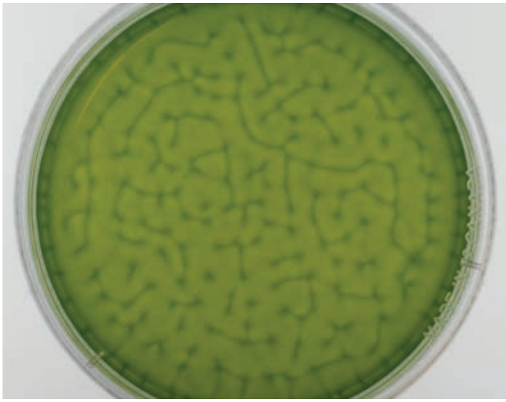


Fig 1.

Fig 1: Bioconvection pattern formed by Dunaliella salina, a swimming beta-carotene producing alga. The alga is bottom-heavy: gravity makes it swim up. In a flow, an additional viscous toque causes swimming to downwelling fluid. The pattern results from an interplay of fluid dynamics and swimming. Similar physics needs to be considered in photobioreactors to grow algae.

[1] M. A. Bees & O. A. Croze Biofuels 5, 53 (2014) http://dx.doi.org/10.4155/bfs.13.66
[2] A. Hope, O. A. Croze, W. C. K. Poon, M. A. Bees & M. D. Haw, Preprint arXiv:1507.07176

Amalio Fernández-Pacheco

My research focuses on investigating new ways of patterning magnetic materials on the nanoscale for spintronic applications. For that purpose, I use direct-write nanolithography techniques based on focused electron and ion beams [1]. Spintronics is the area of nanoelectronics which exploits the intrinsic magnetism of electrons, making possible low-power data storage and processing. The fabrication of spintronic structures using these advanced techniques opens new technological routes such as the development of new computing architectures based on three-dimensional nanowires.

During my first year as a Winton and EPSRC Fellow, I have supervised projects for three master students and one undergraduate student, as well as hosting one PhD student from abroad for several months. Together with my activity in Cambridge, I have been performing experiments with collaborators at the ALS in Berkeley (USA), University of Zaragoza (Spain) and SOLEIL synchrotron in Paris (France).

Fig. 1. Shows some of the projects developed during this year. We have investigated the local modification of the magnetic properties of magnetic films using ion (a, b) and electron irradiation under liquid environments (c). Also, we have developed new fabrication processes involving several lithography techniques for the growth of suspended nanostructures. These have been grown on top of tips for the tomographic study of the magnetism at the nanoscale using X-ray microscopy (d, e).

This coming year two PhD students will join my group, and I will start new research lines, such as the growth of advanced materials for their use in artificial multiferroic nanostructures.

[1] J. M. De Teresa & A. Fernández-Pacheco, Appl. Phys. A 117, 1645 (2014).

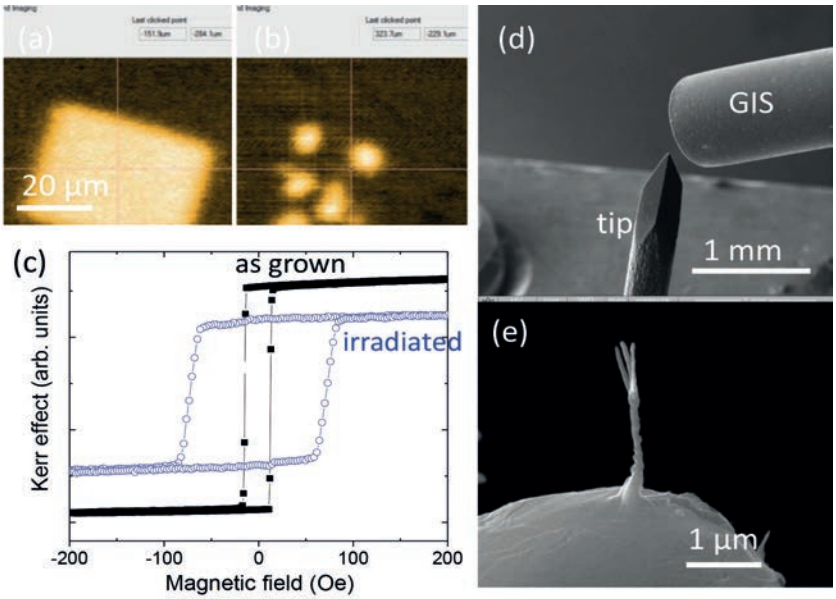


Fig 1.

Fig 1. (a, b) Magnetic images of perpendicularly-magnetised CoFeB/Pt rectangles, locally irradiated with FIB under two different ion doses, showing different reversal mechanisms (c) Magnetic reversal for NiFe thin films irradiated with electrons with liquid water on its surface. (d, e) Magnetic "nano-claw" grown by focused electron beam induced deposition on top of a tip for X-Ray magnetic tomography experiments.

SCHOLARSHIPS

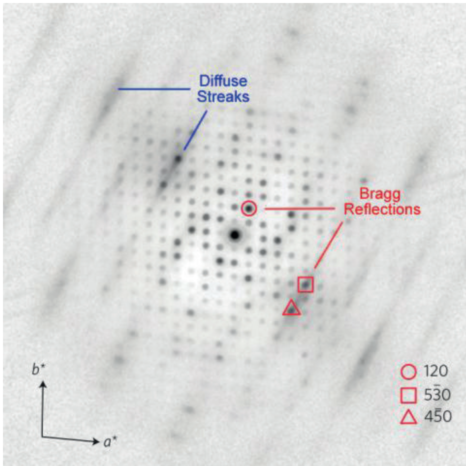
The Programme is about to welcome the 5th cohort of Winton Scholars to embark on PhDs in a broad range of topics. The majority of the 1st cohort have now completed their research work and the 2nd cohort are starting to publish work on their research. A brief description of the research projects of the 2nd cohort is included in this report.

Fig 1: Schematic of electronic states in an organic solar cell and different processes happening after excitation. The excited state can be directly separated (k_{CS}) or form charge transfer states (k_{CT}) which act as a main recombination pathway (k_R).

Fig 2. Simulation of 2D spectroscopy results for pentacene, with an arrow indicating the signal arising from the multiexcitonic state.

Steffen Illig
Dynamic disorder which arises from large-amplitude thermal vibrations governs many of the unique electrical and optical properties of organic systems. We established an electron diffraction-based method that enabled us to detect and quantify these vibrations experimentally. Our technique exploits the fact that large amplitude thermal vibrations interrupt the periodicity of the crystal, resulting in incoherent scattering and thus diffraction intensity between the Bragg reflections (see figure). Modelling this diffuse intensity allows us to identify the nature and amplitude of the thermal vibrations that have the largest impact on charge transport.

This work resulted in a publication in Nature Materials, 12, 1045 (2013) and opened a rich path for exciting experimental studies. Since then we encountered strong thermal vibrations in every single organic material we studied (14 up to date), indicating that a large degree of dynamic disorder is a universal phenomenon in organic crystals. Exploring these material systems, we managed to identify a molecular design strategy to avoid such detrimental vibrations with a second high-impact publication currently being at review stage. Understanding these underlying mechanisms is crucial to control, and ultimately avoid, dynamic disorder in order to develop the next generation of disorder free, high performance materials.



Andreas Jakowetz
Andreas Jakowetz has been investigating charge generation in organic solar cells which usually comprise a mixture of a semiconducting polymer and a fullerene. While new polymers are synthesised continuously, the fullerene acceptor, which is a football shaped cage of 60 or 70 carbon atoms, has not changed much over the past two decades. Andreas' studies have focused on the influence of different fullerenes on charge generation and have demonstrated that the number of accessible states into which the electron can be transferred onto the fullerene is more important for charge generation than the energy offset between the two materials, which so far has been considered as the main driver. His research has also provided insight into the coupling of different vibrational states to the process of charge generation and has showed that coherence is transferred between the initially excited and the charge separated states.

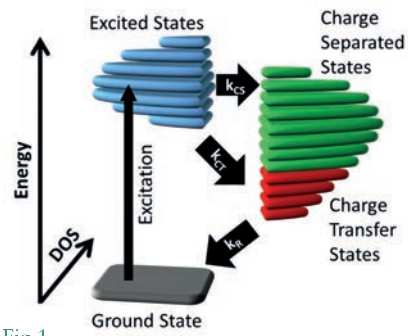


Fig 1.

Sarah Morgan
Sarah Morgan's research focuses on the theory of open quantum dynamics in nanoscale systems. In particular, she is interested in the mechanisms behind light harvesting processes in both organic and biological systems. A new experimental technique called 2D optical spectroscopy can be used to investigate these processes in greater detail than conventional spectroscopic techniques and Sarah's research involves understanding and modeling the results from these experiments. For example, a recent collaboration with experimentalists Artem Bakulin and Akshay Rao from the Optoelectronics group used 2D spectroscopy to observe the multiexcitonic triplet pair state which mediates the singlet fission process in pentacene (in press, Nature Chemistry). Sarah has also worked on 2D spectroscopy results for photosynthetic light harvesting complexes and is currently interested in using molecular dynamics simulations to learn more about the role of vibrations in the Fenna-Matthews-Olson light harvesting complex.

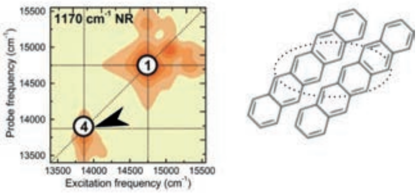


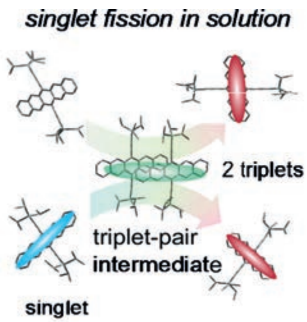
Fig 2.

Hannah Stern
Hannah Stern's research is focused on understanding the mechanism of singlet exciton fission, an exciton multiplication mechanism that occurs in organic chromphores. Once an obscure phenomenon, singlet fission is now a well-studied process that has the potential to raise the efficiency of photovoltaic devices. Despite recent progress, there remain a number of major questions about the mechanism; namely the nature and role of any intermediate states present in the conversion of one singlet exciton into two triplet excitons. To investigate the role of intermediate states, Hannah has investigated singlet fission in solutions of a model material, TIPS-tetracene using transient absorption spectroscopy. This work has led to the identification of a spectrally distinct intermediate triplet-pair state in solution *(Proceedings of the National Academy of Sciences, 2015, 112, (25))*. This study indicates that a triplet-pair intermediate state plays a central role in endothermic fission systems and suggests that a similar state may also be important in the solid state.

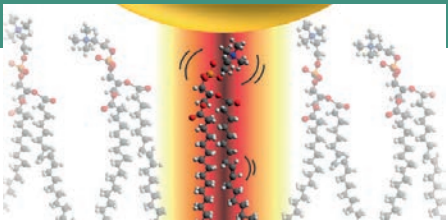
Monika Szumiło
Monika Szumiło is working in the field of organic thermoelectric materials. These allow production of electricity out of temperature differences which provide an interesting way of exploiting waste heat and raising the efficiency of more traditional power generation methods. Contrary to materials currently used in thermoelectric modules, the organic semiconductors studied by Monika are flexible, cheap, non-toxic and allow much simpler manufacturing methods, including roll-to-roll printing.

In her research, Monika focuses on investigating one of the crucial characteristics of organic thermoelectric materials, the thermal conductivity, using a modified version of the 3-omega method. A better understanding of this feature would not only lead to improving the efficiency of power generating devices but would also provide a valuable insight into both electronic and phononic heat transport properties of these materials and their correlation with their chemical and physical structures.

Vahe Tshitoyan
Vahe Tshitoyan works in the area of spin electronics, or spintronics. Here one tries to make use of the electron spin either to achieve new device functionalities or to improve on the existing ones. Recently, there has been growing interest in ferromagnet / heavy metal bi-layers for spintronics applications. The large spin-orbit interactions in the heavy metal are used to convert the electrical current into a spin-current or into interfacial spin-torques. These are then used to manipulate the spin-configuration of the adjacent ferromagnet. Vahe's studies have demonstrated that replacing the heavy metal with an antiferromagnet can lead to a several-fold increase in efficiency, making the process more efficient than for most heavy metals (arXiv:1502.04570).



RESEARCH HIGHLIGHTS



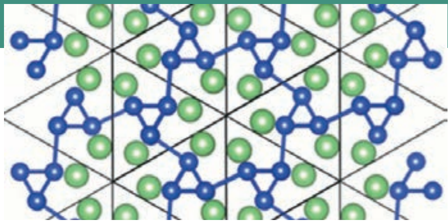
Watching molecules 'dance' in real time

Winton Scholar Felix Benz with other researchers in Cambridge and at the University of Leeds, have demonstrated how to use light to view individual molecules bending and flexing as they move through a model cell membrane, in order to understand better the inner workings of cells. Details were published in the journal *Scientific Reports, 4, 5940 (2014)*.

In order to view the behaviour of the cell membrane at the level of individual molecules, the teams squeezed them into a tiny gap between the mirrored gold facets of a nanoparticle sitting just above a flat gold surface. Analysing the colours of the light which is scattered by the mirrors allowed the different vibrations of each molecule to be seen within this intense optical field.

The new insights from this work suggest ways of unveiling processes which are essential to all life and of understanding how small changes to these processes can cause disease.

www.cam.ac.uk/research/news/watching-molecules-dance-in-real-time

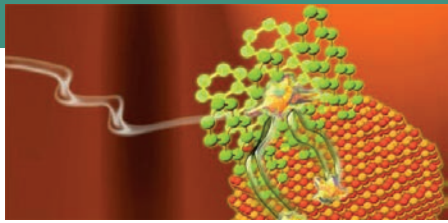


Simulation method identifies materials for better batteries

Using software to predict the characteristics of materials before they're synthesised in order to guide and interpret experiments, the researchers successfully predicted the structures of a series of lithium silicides, an important step in understanding batteries made of silicon, and have also predicted new structures for a battery based on germanium. Details are published in the journal Physical Review, B90, 054111 (2014).

"It's always exciting when we're able to successfully predict something, but it's especially gratifying to predict something that's really useful," said Dr Andrew Morris, Winton Advanced Research Fellow, the paper's lead author.

www.cam.ac.uk/research/news/simulation-method-identifies-materials-for-better-batteries



Hybrid materials could smash the solar efficiency ceiling

The team, from the University of Cambridge, have successfully harvested the energy of triplet excitons, an excited electron state whose energy is captured in solar cells, and transferred it from organic to inorganic semiconductors. To date, this type of energy transfer had only been shown for spin-singlet excitons. The results are published in the journal *Nature Materials*, 13, 1033 (2014).

"The key to making a better solar cell is to be able to extract the electrons from these dark triplet excitons," said Winton Scholar Maxim Tabachnyk, the paper's lead author. "If we can combine materials like pentacene with conventional semiconductors like silicon, it would allow us to break through the fundamental ceiling on the efficiency of solar cells."

"Combining the advantages of organic semiconductors, which are low cost and easily processable, with highly efficient inorganic semiconductors, could enable us to further increase the efficiency of inorganic solar cells, such as those made of silicon," said Winton Advanced Research Fellow Dr Akshay Rao, who leads the team behind the work.

www.cam.ac.uk/research/news/hybrid-materials-could-smash-the-solar-efficiency-ceiling

Shell Future Energy Challenge Poster Winner

Winton Scholar, Michael Price, was announced winner of the Shell Future Energy Challenge Poster Competition. The first prize of £250 was presented by Andy Brown, Shell Director of Upstream International, who gave the 2014 Shell Lecture.

Michael presented results on the tremendous improvement in efficiency in recent years of Perovskite-based solar cells as well as how these materials can be made into lasers. These materials can be solution processed offering a route to low cost manufacturing.

www.energy.cam.ac.uk/news/shell-future-energy-challenge-poster-winner-announced

DNA Origami Folding on the Smallest Scale

How do you fold DNA into the shape of a crocodile? Kerstin Göpfrich is a Winton Scholar at the Department of Physics, researching on DNA origami. DNA origami is the art of folding DNA into three-dimensional nanoscale structures. While smiley faces and various artistic shapes have been created from DNA as proof of principle, the research group of Dr Ulrich Keyser is using DNA origami to build technologies on the smallest scale. They have created tiny DNA channels, which could deliver drugs or kill malfunctioning cells. Together with film director and editor Axel Bangert, animator Elisabeth Hobbs, origami artist Gabrielle Chan and sound designer James Rogers, Kerstin takes us on a journey through the macroscopic world of paper origami and the microscopic world of folding DNA.

The film was premiered at the Arts Picturehouse as part of the 2014 Cambridge Festival of Ideas, and can be viewed on youtube.

www.youtube.com/watch?v=tk4FCcX78E0

To conduct, or to insulate? That is the question

A new study has discovered mysterious behaviour of a material that acts like an insulator in certain measurements, but simultaneously acts like a conductor in others. In an insulator, electrons are largely stuck in one place, while in a conductor, the electrons flow freely. The results, published in the journal *Science, 349 (6245), 287 (2015)*, challenge current understanding of how materials behave.

"The discovery of dual metal-insulator behaviour in a single material has the potential to overturn decades of conventional wisdom regarding the fundamental dichotomy between metals and insulators," said Dr Suchitra Sebastian Lecturer at University's Cavendish Laboratory and affiliated to the Winton Programme, who led the research.

The picture shows PhD student Maria Kiourlappou, who was one of researchers on the project, holding a piece of the material SmB_6.

www.phys.org/news/2015-07-insulate.html

RESEARCH THEMES

Quantum Biology
(Alex Chin Winton Fellow)

In the last few years, a new and highly interdisciplinary field known as Quantum Biology (QB) has emerged to explore the origins and implications of a range of unexpected quantum phenomena that have been observed in biological nanostructures. These observations have not only helped overturn the idea that quantum effects, such as quantum tunnelling, delocalisation and entanglement, cannot be detected under physiological conditions, but they have also opened a vigorous debate as to how these effects might be exploited in some of the fundamental processes underlying biological functions. This debate has naturally led to the exciting question of whether or not biomolecular design principles, or even the biosystems themselves, could be exploited in new contexts, materials, or even devices.

This question was recently explored in the international conference “NEW FRONTIERS FOR QUANTUM TECHNOLOGY IN BIOLOGICAL AND BIO-INSPIRED SYSTEMS”, which has hosted in Cambridge by Dr Alex W Chin, who leads the Winton Programme’s research in this area. This meeting, generously funded by the UK’s Skills Innovation Network (Foreign and Commonwealth Office), brought together leading experts in quantum biology and related fields, and identified many novel directions for bio-inspired quantum physics, including bio-hybrid plasmonics and catalysis, spin-related effects in anaesthetics, high precision magnetic field and *in vivo* process sensing, and coherence effects in organic solar cells.

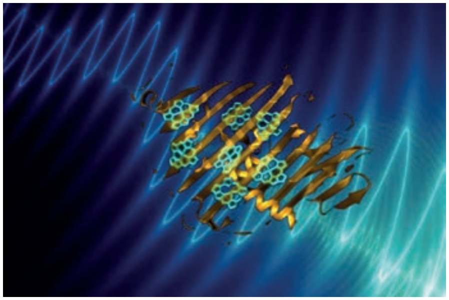


Fig 1.

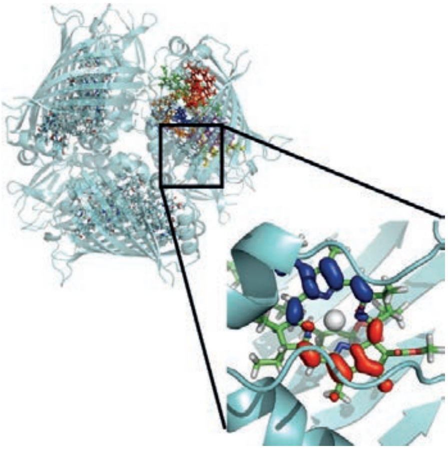


Fig 2.

The Winton Programme continues to play a strong role in the theory of photo-active proteins and organic materials, spanning the gamut of atomistic descriptions, ultrafast quantum processes, millisecond conformational dynamics and abstract network representations of entire proteins (Chin Group, ex-Winton Fellow Nick Hine, Daniel Cole and Sebastian Ahnert). Verifying our predictions requires advanced spectroscopy; collaboration with new Winton Fellow Akshay Rao has recently demonstrated the essential role of entangled states in singlet fission and unravelling multidimensional data from ultrafast optical experiments (Sarah Morgan, Winton Scholar) has yielded new insight into photosynthetic charge generation. Finally, this last year saw the establishment of an ambitious and wide-ranging collaboration across the Cavendish with Microsoft Research UK. This project uses the uniquely versatile platform of DNA Origami (Keyser Group) to create nm-scale light-harvesting complexes according to theoretical ‘blueprints’ for quantum-enhanced performance.

Fig 1. The Fenna-Matthews-Olson complex, a light-harvesting structure of Green Sulphur Bacteria

Fig 2. Electronic structure of bacteriochlorophyll in the Fenna-Matthews-Olson complex, a light-harvesting structure of Green Sulphur Bacteria. (Figure by Danny Cole, Cambridge)

Functional materials (Siân Dutton Winton Fellow and Suchitra Sebastian University Lecturer and affiliated to Winton Programme)

Materials discovery has seen a resurgence of interest in recent years. This is driven by the limitations of many emergent technologies as applied to current materials. Many of the materials of interest have strongly correlated electrons which give rise to their desired properties. These properties are sensitive to structure, composition, and applied pressure and by varying these it is possible to understand the underlying physics and ultimately optimise them.

Suchitra Sebastian, Gerie Lonzarich, Gil Lonzarich and Siân Dutton at the CDQM conference dinner.

The recent celebration of Gil Lonzarich's seventieth birthday at the Concepts and Discovery in Quantum Matter (CDQM) meeting in the Cavendish this July was attended by many international researchers active in this area. The event organised by members of the Quantum Matter group covered a diverse range of topics from high pressure measurement techniques, novel materials synthesis and characterisation, the elusive mechanism for high temperature superconductivity and cold atom experiments. The meeting culminated in a talk by Gil on his prospective of the future of research in this field. In particular he highlighted the role of the relationship between a materials discovery and the experiments required to understand fully their physical properties.

The Winton Programme is supporting research into functional materials through the appointment of Suchitra Sebastian as a University Lecturer and Siân Dutton as a Winton Fellow. They have both set up facilities within the Cavendish Laboratory for sample preparation and are studying a wide range of functional materials. Their groups study materials including superconductors, electrodes for rechargeable batteries and materials for solid state magnetic cooling. The award for an advanced materials characterization suite to be located in the Maxwell Centre jointly funded by EPSRC and the Winton Programme will expand measurement capabilities and allow for continued expansion in this area.

DEVELOPMENT

The Winton Programme is keen to encourage students and researchers to think outside the confines of their own academic boundaries, and to consider ways of applying scientific knowledge and skills to real world problems. The Programme has this year worked with the 'Smart Villages Initiative' and the 'Cambridge Development Initiative' to provide opportunities for direct interaction with developing world issues.

Smart Villages (Michael Price Winton Scholar)

The Smart Villages Initiative aims to provide people concerned with rural energy access, new insights into the real barriers to energy access in villages in developing countries – technical, financial and political – and how they can be overcome. I have just taken a position within Smart Villages as a research associate, mostly looking at the technical aspects of the projects, but also working on the general problem of how energy access can be provided and used to act as a catalyst for development in rural villages. I will also be continuing with the Winton Programme by taking on the role of 'Assistant coordinator and Smart Villages Liaison' for the Winton Programme. This will help the Programme in organising and promoting activities for Winton Scholars and academics seeking to apply their scientific skills to problems in development.

A fantastic example of the Winton Programme's engagement in these activities was provided by the Cambridge Graduate Forum on village-level solutions, held in January this year. The forum brought together Cambridge graduates from many different disciplines to think about how new research could be applied to village-level problems, and was sponsored by the Winton Programme and the Smart Villages Initiative.

Out of this forum, six project finalists were selected out of a number of team applications. These finalist teams would be supported to implement their idea for a short period in the real world. Three Winton scholars were in teams that made it to the final round:

Winton Scholar Steffen Illig is in a team that is looking at the challenges and opportunities provided by solar concentrators used for cooking and water purification. They are working with local partners in Kenya and will

Figure Mike Coto showing a local student Jonathon some biological water testing methods using an Oxfam Del Agua kit, in in the town of Vingunguti, in the Ilala district of the Dar es Salaam Region

travel there soon to continue their field tests and gauge the viability of these cheap solar cooker technologies.

Winton Scholar Kerstin Göpfrich is on a team that is trialling a 'Mobile Education for Smart Technology' (MEST) programme, that uses a scalable IT skills platform to help secondary school students in India. Her programme makes use of Raspberry Pis and a Google 'digital media bus' and partners with local NGOs to provide educational training.

Hajime Shinohara is another Winton Scholar involved in a successful team. He has recently been to Tanzania testing water purification products and water testing systems in off-grid communities.

cambridge **development** initiative

Cambridge Development Initiative (CDI) is a student led organisation that trains small teams of Cambridge students to implement innovative solutions in the developing world, with Dar es Salaam as the base for their work. The interdisciplinary teams are working on developing sustainable solutions, by engaging with the local community, working on a range of projects under the broad areas of 'Health', 'Engineering', 'Education' and 'Entrepreneurship'.

This is the second year that the initiative has been running and already some of the projects are producing significant results. For example, the health programme has joined with local medical companies and Muhimbili University to develop a sustainable model for primary healthcare, and have piloted a Health Entrepreneurship Course in collaboration with the Cambridge Judge Business School.

The summer 2015 trip sent over 30 students for a period of 8 weeks to Dar, with Winton providing funding support for 2 students. In addition CDI have provided logistical support to Winton Scholar Hajime Shinohara and Mike Coto who have gone to Dar es Salaam as part of their Smart Villages water testing project. They have been working closely with CDI's Engineering team who are building a low cost sanitation system.

For more information about CDI visit **www.cambridgedevelopment.org**

PUMP PRIME

The Pump Prime scheme provides funding of up to £50k to researchers in the Department and collaborators from other departments for new research activities. The scheme aims to fund innovative high-risk activities, rather than on going research, that if successful could have significant impact. Many of the projects have resulted in successful collaborations across departments and generated further funding.

The Pump Prime scheme is currently open to applicants from the Department, application details can be found on the Winton website at www.winton.phy.cam.ac.uk/pumpprime. An example of a recently completed project is provided below.

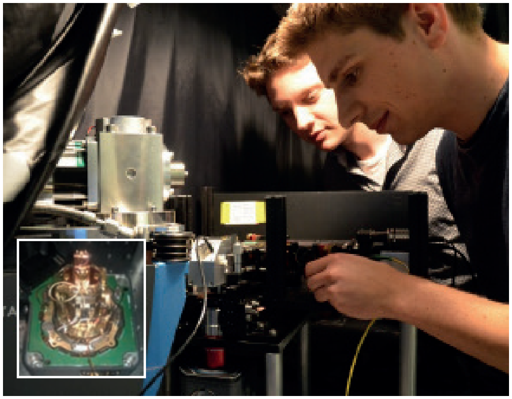
Revealing Quantum Magnetism at Oxide Interfaces via Diamond-Based nano-MRI
Dr Mete Atatüre (Atomic, Mesoscopic and Optical Physics Group) and Dr Jason Robinson (Department of Materials Science & Metallurgy)

This project utilised a recently developed magnetometry technique based on optically accessible diamond spins in order to test the predictions of emergent quantum magnetism at the interface of transition metal oxide materials.

The system studied was $LaAlO_3/SrTiO_3$ (LAO/STO) interface where charge transfer results in a quasi-two-dimensional electron gas (quasi-2-DEG) in the STO side of the interface. This system has already yielded spectacular novel functionality including, superconductivity and magnetism, but remains highly contentious because of the competing influence of oxygen defects and the unexplained role of interfacial dopants in drastically suppressing carrier density.

It was a collaborative effort between the research groups of Mete Atatüre (Cavendish) and Jason Robinson (Materials). They demonstrated that there is emergent magnetic ordering around 40 K above which the usual metallic nature of the interface electron gas is recovered. Below this critical temperature the NV (Nitrogen-Vacancy) centre spin was found to be coupled to the electron gas. The transition takes place within 1 K accuracy, which is their system resolution.

Since the support of the Winton pump prime award, they have attracted funds from the Leverhulme Trust for a three-year project worth £250,000 funding two postdoctoral fellows and consumables to continue on the nano-MRI programme with oxide interface magnetism until May 2017.



The cryostation dedicated to this project with two PhD students: Jan Beitner (a Winton Scholar) and David Jarausch (funded by EU-ITN S^3NANO). Inset: The variable temperature cryohead with the NV nanodiamond coated LAO/STO sample mounted.

WOMEN IN SCIENCE

Hannah Stern

Sarah Morgan

Cavendish inspiring women (CiW) is an initiative started by Winton scholars, Sarah Morgan and Hannah Stern, to bring PhD students and postdocs in the Cavendish Laboratory in contact with inspirational female leaders. The motivation behind the newly formed group is to raise the visibility of successful women, in a bid to inspire younger women to continue their work in science after their training. The group aims to make a difference through hosting lunchtime speaker events, and recently, the production of an outreach booklet to be distributed across UK secondary schools.

CiW's speaker events give high profile female leaders the opportunity to speak about their work in science, entrepreneurship, business and volunteer work. The group has hosted local speakers, such as Dame Barbara Stocking, members of the Department, Dr Sarah Bohndiek, Dr Siân Dutton and Dr Eileen Nugent, as well as acclaimed entrepreneur Cary Marsh and award-winning IT expert Anne-Marie Imafidon.

Outreach to younger, secondary school age, women is another major goal for the CiW. To complement the Department's outreach work, CiW has produced a short booklet that is in the process of being distributed to secondary schools across the UK. The booklet profiles young women who have studied physics and aims to show that physics degrees can lead to a wide range of interesting career paths.

The CiW is supported by the Department of Physics and appreciates the encouragement received from the Winton community. The Department is a national leader in its support for women in physics. The Department is an Institute of Physics Juno Champion and received an Athena Swan Gold Award in 2013 for boosting the role of women in science, technology, engineering, maths and medicine (STEMM) departments. The Department is the first physics department in the UK and the first in the University to receive such an accolade.

If you are interested in the CiW speaker events, or getting involved in supporting women in physics please contact us at **cavendishiw@gmail.com** or visit our page at www.cavinspiringwomen.squarespace.com.

WINTON SYMPOSIUM

The Winton Symposium is a major event in the Department's calendar, with world-renowned speakers invited to debate a topical issue. Previous events have attracted capacity audiences with attendees from different Departments across the University as well as a significant number from outside the University. The theme for this year is 'Green Computing' which will cover topics ranging from new materials and architectures for low power consumption computing, to computer-based applications which can benefit our environment.

Winton Symposium on Global Challenges for Science and Technology

The 3rd Winton Symposium was held on 29th September 2014 at the Cavendish Laboratory, on the theme 'Global Challenges for Science and Technology". Professor Richard Friend provided the opening remarks, noting that the previous two themes had been science led and addressed what can we do with science to take us to a more sustainable future. The balance of this meeting was somewhere in the society and policy space, to see how far scientific discoveries can go towards meeting some of our global challenges.

Joseph Heremans from The Ohio State University discussed "Solid State Heat Engines and Waste Management". The motivation of the talk is that 93% of energy comes from thermal processes – so any improvement in the efficiency of heat engines can make a significant impact. He described the new physics that has arisen through considering the role of spin that has led to the emergence of the field of spin caloritronics which links heat and magnetism. The knowledge this has generated provides new opportunities to revisit how thermoelectrics could be optimised in the future.

Nina Fedoroff, Evan Pugh Professor at Pennsylvania State University talked about "Food and Civilisation" with the objective of challenging the audience to think about what are the scientific and technological advances that will be needed to feed a population of ten or more billion people. To meet our future needs, a new approach will be needed which considers multiple aspects of people, water, energy, nutrients and the environment. This will necessitate continued development and investment in technology including genetically modified crops, which are still a major source of debate, despite the body of scientific data that has come to the conclusion that they are not per se any riskier than conventional breeding technologies.

Simon Bransfield-Garth's talk was entitled "Empowering the rural African consumer", where he spoke about the practical learning gained from delivering power in Africa. He is CEO of Azuri Technologies which is commercialising solar based energy solutions. The 1.3 billion people without electricity provide a huge market potential who currently are obtaining basic lighting needs through very expensive and harmful kerosene lamps. Although solar panels are available, affordability is a major constraint for these communities where people are typically earning $1-2 per day. The PayGo solar system Azuri developed provides customers with lighting and phone charging with a small initial installation fee and then weekly purchase of scratch cards. This would enable customers to nearly halve their energy bill and have a range of additional benefits that come from having access to the energy; businesses can operate for longer, children can study in the evenings and the removal of kerosene lamps improves their health.

Winston (Wole) Soboyejo, Professor at Princeton University, spoke about "New Frontiers in Materials for Global Development: From Health to Energy and the Environment". One of the challenges for scientists is to think holistically; with an integrated effort required that brings together scientists from different disciplines with business people, developers and the stakeholders. He provided a number of examples from his work of how science can have an impact, including the use of magnetic nanoparticles for targeted drug delivery, a mobile phone based imaging device and a low cost filtration system to produce drinking water. He noted that sustainable solutions must empower people to use science and technology to address their own needs, as solutions that are simply imported from across the world lack the local knowledge base to succeed. He encouraged scientists to think about making real partnerships where everyone can make a contribution.

Richenda van Leeuwen (pictured), Executive Director of the Energy Access, Energy and Climate Programme at the United Nations Foundation gave a talk entitled "Towards Sustainable Energy for All". Richenda explained how the UN Secretary-General Ban Ki-Moon launched the Sustainable Energy for All initiative with three objectives

to be met by 2030; ensuring universal access to energy, doubling the global rate of improvement in energy efficiency and doubling the share of renewable energy. The UN Foundation supports these goals through engagement with the public and policy makers, as well as operating a network of over 1,000 companies and NGOs that have cutting edge technologies that are seeking solutions that are affordable and sustainable. She provided a number of examples of market-based innovations that embraced scientific advances.

David MacKay is Regius Professor of Engineering at University of Cambridge and until recently held the post of Chief Scientific Advisor to the UK Department of Energy and Climate Change (DECC). He began his talk with, in his opinion, the most important message of the latest Intergovernmental Panel on Climate Change (IPCC) report; that climate change depends on cumulative emissions and to stop any further change the CO_2 emission rate needs not only to decrease but to drop to zero. This means any remaining positive emissions will have to be balanced by a huge 'vacuum cleaner in the sky' to suck out the excess CO_2. The challenge that David wanted to pose is that if we want to take controlling climate change seriously, negative emissions technologies have to be available and on a scale significantly bigger than the current oil industry. He then introduced his work on developing a tool to help people understand such issues with greater clarity and the options we have in the UK for controlling emissions. With assistance from staff at DECC this tool is available as an online web tool '2050 Calculator' where you can vary the energy supply and demand and visualise the impact on parameter. This tool has developed considerable international interest and has led to the 'Global Calculator' which was the title of his talk. This sort of tool helps people have informed conversations to move the debate forward.

PEOPLE

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In attendance:
Professor Robert Kennicutt FRS
Head, School of the Physical Sciences,
University of Cambridge

Opposite page, top left to bottom right:

Jan Mertens, Sarah Morgan, Michael Price, Milan Vrucinic, Hannah Stern, Dr Andrew Ferguson, Steffen Illig, Jan Beitner, Monika Szumiło, Vahe Tshitoyan, Dr Agnieszka Iwasiewicz Wabnig, Di Jin, Bhaskaran Nair, Gabriel Constantinescu, Dr Anoop Dhoot, Dr Tijmen Euser, Jerome Burelbach, Johannes Richter, Sam Schott, Dr Amalio Fernández-Pacheco, Dr Andreas Nunnenkamp, Yago Del Valle-Inclan Redondo, Leah Weiss, Dr Akshay Rao, Professor Neil Mathur, Paromita Mukherjee, Professor Eugene Terentjev, Xiaoyuan Sheng, Dr Nalin Patel, Professor Sir Richard Friend, Dr Ulrich Keyser, Professor Jeremy Baumberg, Professor David MacKay, Martin Mayo, Kerstin Göpfrich, Dr Andrew Morris, Professor Ulrich Steiner, Professor Henning Sirringhaus, Dr Nicholas Hine, Dr Siân Dutton, Zachary Ruff, Dr Ottavio Croze, Dr Erwin Reisner, Maxim Tabachnyk, Nicholas Price, Wenting Guo, Dr Alex Chin, Feliz Benz, Professor Tony Cheetham, Dr Jason Robinson, Adrien Amigues, Dr Erika Eiser, Tobias Wenzel, Sam Smith, Andreas Jakowetz, Professor Christopher Howe, Dr Suchitra Sebastian, Florian Schroeder, Hajime Shinohara, Professor Clare Grey, Dr Mete Atatüre, David Turban, Dr Felix Deschler

THE WINTON PROGRAMME FOR THE

Physics of Sustainability

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