UNIVERSITY OF CAMBRIDGE

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News from the Cavendish Laboratory

Inside

Opening of the Battcock Centre for Experimental Astrophysics

On 14 October 2013, the Battcock Centre for Experimental Astrophysics was formally opened by the Chancellor of the University, Lord Sainsbury. This auspicious occasion marked the completion of the consolidation of astronomy, astrophysics and cosmology on the Institute of Astronomy site in Cambridge and a key stage in the redevelopment of the Cavendish Laboratory.

The Chancellor of the University, Lord Sainsbury of Turville, was joined at the opening by the Vice-Chancellor, Professor Sir Leszek Borysiewicz and the chief benefactor who made the building possible, Mr. Humphrey Battcock. Humphrey is a Cavendish Laboratory and Downing College alumnus who has been an enthusiastic supporter of the University's initiatives since the beginning of the present Cavendish redevelopment programme. His gift, together with funding from the Wolfson Foundation, has been matched by the University to enable the Centre to become a reality.

Astronomy, Astrophysics and Cosmology have historically been among the very strongest scientific disciplines in Cambridge. The construction of the Battcock Centre for Experimental Astrophysics brings together on the same site the experimental astrophysicists from the Cavendish Laboratory with astronomers from the Institute of Astronomy and Kavli Institute for Cosmology, completing the consolidation of the research efforts of the Institute of Astronomy and the Cavendish Laboratory. The consolidation will also promote collaboration with members of the Department of Applied Mathematics and

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Theoretical Physics (DAMTP) in the areas of cosmology and exoplanets.

This is the first time that most of Cambridge astronomy has been brought together under one roof in order to enhance the strength of these disciplines and put Cambridge in the best possible position for future developments in astronomy across the full spectrum of theoretical, observational, interpretative, computational and experimental astrophysics.

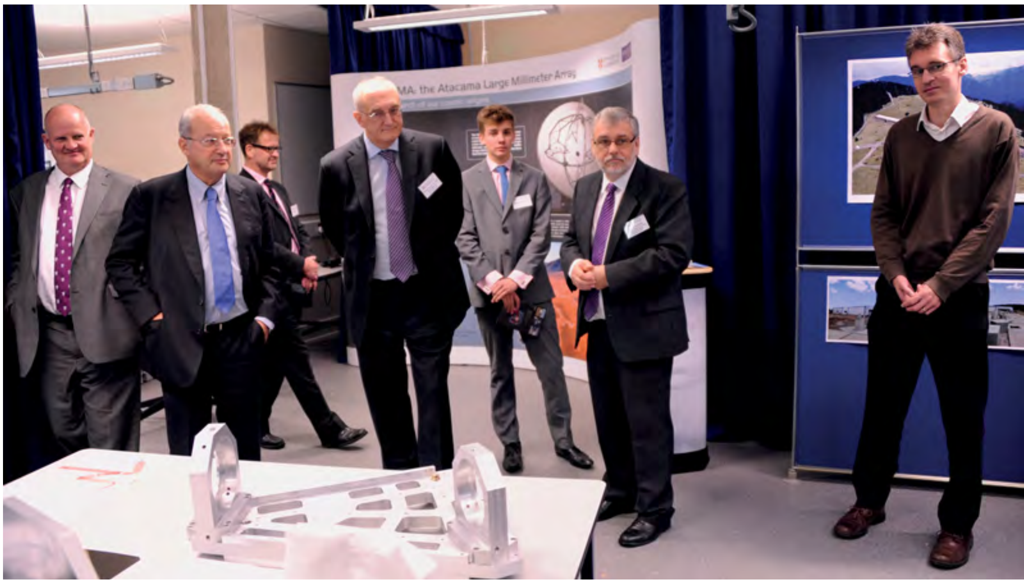
As has been reported in previous editions of CavMag, the Cavendish has been able to make two outstanding professorial appointments in Roberto Maiolino and Didier Queloz. They bring with them expertise in areas of experimental astrophysics which greatly enhance Cambridge's ability to compete for leading roles in the next generation of ground and space-based astronomy projects. These include instrumentation for the Very Large Telescope (VLT) in Chile, the next generation European Extremely Large Telescope (E-ELT), the James Webb Space Telescope (JWST) and numerous other space and ground-based astronomy projects.

Most recently, the Cavendish has appointed Professor Chris Carilli, the Chief Scientist at the US National Radio Astronomy Observatory, as a Director of Research. This will enhance Cambridge's involvement in the extended Very Large Array (eVLA) project and strengthen further the Cavendish's involvement in the Square Kilometre Array (SKA) project. Paul Alexander, Head of the Cavendish Astrophysics Group and Director of the Battcock Centre for Experimental Astrophysics, is the leader of Cambridge's involvement in the SKA. He said:

"The Battcock Centre will enable us to create the teams needed to take on big scientific challenges, which will lead to major advances in our knowledge and understanding of the Universe."

The new building, by the same architects, Anand and Mustoe, who designed the Kavli Institute for Cosmology, and constructed by the Bedford-based regional construction company SDC, contains a dedicated suite of design spaces for instrumentation and computation, and project rooms, as well as offices for the experimental, theoretical and observational astrophysicists.

The opening was a very happy occasion for everyone involved and we were delighted to welcome members of Humphrey's family.



Top: **Lord Sainsbury of Turville, Chancellor of Cambridge University, (right) with Humphrey Battcock (left) outside the new Centre for Experimental Astrophysics, named in Humphrey's honour.**

Middle: **Professor Paul Alexander (centre), Head of Cavendish Astrophysics and Director of the Battcock Centre , introducing some of the research projects being carried out in the Wolfson Design Suite.**

Bottom: **Lord Sainsbury of Turville, Chancellor of Cambridge University (left) with Professor Sir Leszek Borysiewicz, the Vice-Chancellor (far right) and Humphrey Battcock (second right) with members of the Battcock family.**

Guest Editor: Val Gibson

Welcome to CavMag11 which has a focus on women in the Cavendish Laboratory. When I was asked to be guest editor, I was delighted to have the opportunity to showcase some of the brilliant female talent in the Laboratory. This edition introduces the reader to some new faces and reflects on the contributions of just a few of the women who have made this department the world-leading institute it is today.

The academic & research staff of the Laboratory is currently comprised of 15% women, a similar percentage to other UK physics departments.[1] It is therefore refreshing to contemplate what the Cavendish would be like if the articles in this edition reflected a balance of a majority of women staff and a minority of men. I have no doubt that the quality of research would remain the same, but the day-to-day business would have a very different feel! Although I do not expect the department to turn-tables in this way, it is well on the way to achieving a more equitable balance. Our Athena SWAN and IoP Juno activities, for the advancement and promotion of women in science, have seen a 44% increase in the number of women academic staff, promotion for all our eligible female academics, a significant expansion of our mentoring and training for research staff, as well as the introduction of childcare facilities and an increase in the department's social programme. In the last 10 years, the Cavendish Laboratory has changed from focusing on research and teaching into an environment where the very best of scientists, particularly women, want to work.

This edition of CavMag contains news from many of the research areas in the Cavendish, including Soft Matter Physics, Biomedical Physics, Optoelectronics and Astronomy, as well as historical perspectives of Early Computing in Radio Astronomy and the life and contributions of Nora Sidgwick. The last two years have also been a whirlwind of activity in my own research area, High Energy Physics (HEP), most notably with the discovery of the Higgs Boson and the subsequent award of the Nobel prize to Peter Higgs and Francois Englert. The Cambridge HEP group is so fortunate to be a part of the scientific endeavour at the Large Hadron Collider, and continues to make significant progress in the search for new phenomenon beyond the Higgs Boson. I have taken the liberty to slip in an article, entitled 'High Energy Physics – Not the Higgs Boson' by three members of my own research group.

The activities of the Cavendish and in other areas also continue to flourish. We have seen the opening of the Battcock Centre for Experimental Astrophysics, the announcement of the Maxwell Centre, which links blue skies research and the industrial sector, and the launch of the Rutherford Schools Project. We have also said goodbye to the Head of Department, James Stirling, welcomed the new Head, Andy Parker, as well as congratulated Athene Donald on her election as the next Master of Churchill College and celebrated the successes and achievements of many of our members of staff.

I hope you enjoy reading all the articles and news in this edition of CavMag. I have certainly enjoyed the experience of editing the magazine (with a lot of help from the standing Editor, Malcolm Longair).

Val Gibson

Val Gibson is Professor of High Energy Physics, Head of High Energy Physics and Chair of the Cavendish Personnel Committee. She was presented with the Women in Science and Engineering (WISE) Leader award at a glittering award ceremony at the Science Museum, London, on November 14 2013 by HRH the Princess Royal. The WISE Leader Award, sponsored by AWE, was awarded for Val's major leadership role in championing women in science, particularly those pursuing physics as students, researchers and academics. In recent years she has been the driving force behind the Cavendish Laboratory's success in achieving external recognition of the Department's work in this area.

Top: **Val with her 2013 WISE Leader award.**
Bottom: **Val receiving her WISE Leader Award from HRH the Princess Royal in November 2013.**

1 Institute of Physics, "Academic Physics Staff in UK Higher Education Institutions", January 2012.

High Energy Physics – Not the Higgs Boson

The High Energy Physics (HEP) Group at the Cavendish Laboratory is a founding research group within the collaborations which have constructed, and are now analysing, the data from two of the large detectors (ATLAS and LHCb) at the Large Hadron Collider at CERN in Geneva. It also has an active research programme in HEP theory, neutrino physics and a future Linear Collider. The group is unique for many reasons. It has never focused on searching for the Standard Model Higgs Boson, instead preferring to concentrate on precision measurements of the Standard Model and searching for new phenomena beyond it, such as Supersymmetry (SUSY) and Extra Dimensions. It is renowned for its collaborative research with the HEP theory group, mostly through the Cambridge SUSY Working Group. It has always hosted an above average proportion of female staff and students; at one time women were in the majority! This article focuses on the current research of three of our staff members, Sky French (ATLAS and a Drapers' Research Fellow at Pembroke College), Susan Haines (LHCb and the Beatrice Mary Dale Research Fellow at Newnham College) and Maria Ubiali (QCD theory and Research Associate, jointly with the Department of Applied Mathematics and Theoretical Physics, bye-Fellow of Magdalene College).

Sky French

Supersymmetry is a theory that solves several flaws with the Standard Model, survives at high energy and offers an explanation for dark matter. In Supersymmetry, each known Standard Model fermion (boson) is associated with a supersymmetric boson (fermion), having the same quantum numbers as its partner except for its spin. As yet no evidence for Supersymmetry has presented itself in the ATLAS experiment, or indeed any other, experimental data. My research is thus increasingly focused on supersymmetric models, not just compatible with the recently discovered Higgs boson, but also those which could have reasonably evaded our searches so far. One such example is the direct production of 'light' scalar top squark (or 'stop') particles. Of the supersymmetric particles, those of the third generation, like the stop, can have masses significantly lower than those of the other generations. Naturalness arguments also favour top squarks being the lightest coloured supersymmetric particles. They could therefore be produced with relatively large cross-sections at the Large Hadron Collider. I am currently searching for events in the ATLAS data consistent with the production of pairs of stops that decay to final states containing two leptons (electron-like particles) or similar. My results (shown in blue in Fig.1), using the data recorded by the ATLAS experiment at the highest energy in 2012, are part of ATLAS' world leading limits on the masses of the stop and its supersymmetric decay products.

Susan Haines

One of the outstanding questions in fundamental physics is the origin of the observed matter-antimatter asymmetry in the Universe. It is postulated that the phenomenon of 'CP violation', the violation of the combined charge conjugation (C) and parity (P) symmetries in particle interactions, is necessary to explain the observed imbalance. Although matter-antimatter asymmetries have been observed in HEP experiments, so far the observations are many orders of magnitude below that required to explain our matter-dominated universe. To understand this conundrum, new sources of CP violation beyond the Standard Model are needed, and the best place to start searching for these is in the quark sector. The LHCb experiment is specifically designed to study the decays of particles containing beauty (b) and charm (c) quarks and is the ideal place to make precision measurements of CP violation. A main goal of the experiment is to use specific decays of particles containing b quarks to measure the value of the single CP phase that is present in the Standard Model.

Fig.2 shows the result of my selection of the most sensitive b-hadron decay mode, seen as a peak at a mass of ~5300 MeV/c^2, used to extract the CP phase. I am currently finalising my first result of a measurement of the CP phase, which allows LHCb to improve on the precision obtained by all previous measurements to date. My research will ultimately provide the most precise benchmark value of the CP phase, against which I can compare measurements from other decay modes that are potentially affected by processes beyond the Standard Model.

Maria Ubiali

Quantum Chromo Dynamics (QCD) is the well-established theory which encapsulates our understanding of strong nuclear interactions. The precision reached in current experimental measurements at the Large Hadron Collider (LHC) must be matched by equally accurate theoretical predictions. This is necessary in order to estimate faithfully the Standard Model (SM) backgrounds and spot possible deviations with respect to the SM predictions. Crucial inputs of any theoretical prediction are Parton Distribution Functions (PDFs), which provide information on the proton's content in terms of its elementary constituents, quarks and gluons. Thanks to a novel methodology, based on the use of Neural Networks and Monte Carlo techniques, I determine these functions very

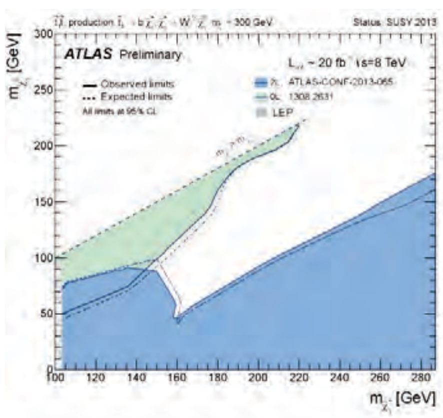


Fig.1

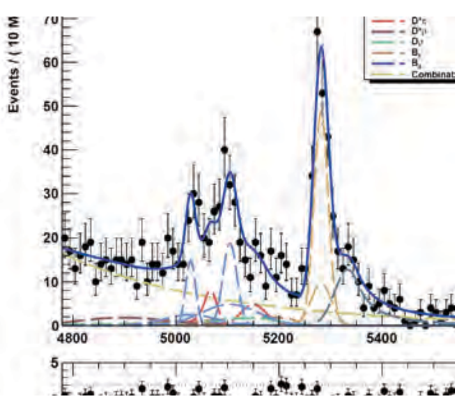


Fig.2

accurately and in a statistically-sound way. In collaboration with other scholars in the UK and in Europe, we provide several sets of PDFs, the so-called NNPDF sets, which are fitted out of an impressive quantity of experimental measurements at various colliders measuring a number of different observables. The theoretical framework of such analyses is extremely complicated and requires a deep understanding of several statistical and phenomenological aspects. Our most recent PDF set is, to date, the only PDF determination including the early LHC data (Fig.3). In the next few years it is going to be very exciting to figure out new strategies to extract most of the information on the structure of protons out of the gold mine of experimental data provided by the LHC, and assess their effect in increasing the accuracy of theoretical predictions for irreducible backgrounds and production signals.

The HEP group is now busily completing many world's-first measurements, writing papers for prestigious physics journals and preparing themselves for the restart of the LHC in 2015 when protons will be collided at nearly twice the centre-of-mass energy. The group is also looking forward to the future upgrades of the ATLAS and LHCb experiments so that they can record ten times the statistics by about 2025. The discovery of the Higgs boson arrived at the beginning of this most exciting time in particle physics; we are proud to be part of the team that discovered it. However, it is the discovery of the 'something' unexpected, and beyond the Standard Model, that we have as the ultimate goal of our research.

Sky French, Val Gibson, Susan Haines and Maria Ubiali

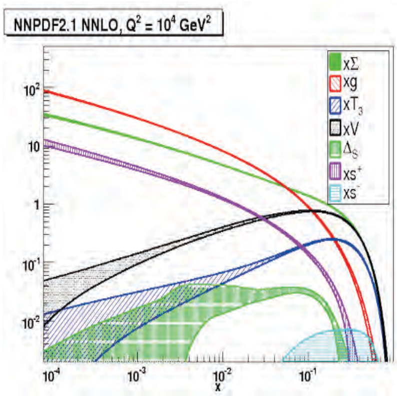


Fig.3

Ernest Walton honoured by new Sculpture

(a) Eilís O'Connell with her sculpture, with reminisences of the spheres in the Cockcroft-Walton experiment shown in (b)

The Cockcroft-Walton experiment, which first 'split the atom' with accelerated protons in 1932, is one of the great experiments carried out in the Laboratory. On 15 November 2013, a sculpture by artist, Eilís O'Connell RHA entitled 'Apples and Atoms' was unveiled at Trinity College, Dublin. It not only commemorates Trinity's Nobel Laureate and former Professor of Natural and Experimental Philosophy, Ernest T.S. Walton, but also celebrates Dublin's designation as European City of Science 2012. It is located beside the Fitzgerald Building, home of the School of Physics. Apple trees will be planted in the lawn opposite to be reflected in the spheres.

Alan Walton, son of Ernest, gave a speech on this auspicious occasion in which he said:

"Eilís O'Connell has told us that she was particularly inspired by the spheres that formed part of the original Cockcroft-Walton apparatus and which are so striking in photographs of the accelerator. These were used to measure the voltage across the accelerator tube. This was a critical part of the experiment for it allowed Einstein's famous equation $E = mc^2$ to be confirmed experimentally. In the original apparatus the spheres were 75 cm in diameter and made of aluminium – nothing like as beautiful as these stainless steel ones. Curved surfaces are ubiquitous in high voltage engineering. When the electronics giant Philips built their first commercial Cockcroft-Walton generator it incorporated a total of twenty one spheres and donut-shaped toruses.

"The atom was split on 14th April 1932. In a letter sent to his girlfriend Freda on 17th April Ernest wrote 'Last Thursday was a red-letter day for me. Not only did I get a letter from you but Cockcroft and I made what is in all probability a very important discovery in the lab. We found that we were able to smash up the nuclei of some light atoms and that these give out rays very similar to the rays given out by radium. It opens up a whole new field of work which may go a long way towards elucidating the structure of the nucleus of an atom."

The significance of the apple trees is more than a reminiscence of Newton and his apples. As Alan writes:

"One of (Ernest's) great loves was gardening. Every Saturday afternoon, come rain or shine, he would head off down the garden to - as the season demanded - prepare the ground for vegetables, cut back raspberry canes or tend the apple trees. … Every winter evening he would choose an apple which he carefully split and peeled with a penknife kept in his jacket pocket.

"But apple trees mean something more to our family. Our maternal grandfather Charles Wilson was a Methodist minister. In those days ministers moved on to a new Church every three years. This didn't stop him planting apple trees in every manse garden knowing that although he wouldn't benefit from them future generations of ministers would."

DNA coatings and new forms of colloidal self-assembly

I was, and am, fascinated by Soft Matter Physics because this field touches on so many areas of physics and adjacent disciplines – Soft Matter research requires knowledge of a wide variety of experimental techniques, statistical mechanics, thermodynamics, and polymer theory, as well as simulations. I am grateful that I have had the opportunity to learn from and collaborate with so many wonderful scientists across these different fields.

I decided to focus the work of my research group on DNA-driven self-assembly of colloids with the aim of developing new functional materials with interesting physical properties. Why colloids? And why DNA? The word colloid is a generic term for particles with sizes ranging from a few nanometres up to several micrometres. They are ubiquitous - examples include protein aggregates and oil droplets in milk and vinaigrettes, pigment particles in paints and inks, dust particles thrown into the air by volcanoes and burning coal, which was responsible for the infamous London fog, and ice cream. Other very well-known materials made from colloidal solutions are porcelain, pottery and chocolate. One of the most interesting properties of colloids is their ability to self-assemble – to aggregate spontaneously into well-defined structures, driven by nothing but local interactions between the colloid's particles. Self-assembly has been of major interest to industry, since controlling it would open up a whole host of new technologies, such as smart drug-delivery patches or novel paints that change with light. But, crucially for my research, macromolecules such as proteins and even viruses and bacteria must also obey the laws of colloid physics while performing their biological functions.

Mimicking nature, in which tissues, bones and all organs are 'self-assembled', we aim to create hierarchical colloidal systems made of colloids with varying 'flavours'. Such complex biological structures cannot be built only with non-specific van der Waals, Coulomb, or polymer-induced interactions. For these, well defined specific interactions are needed and these can be provided by the selectivity of DNA. As the two strands in double-stranded (ds)DNA are only held together by hydrogen bonds between the base pairs Adenine-Thymine (AT) and Cytosine-Guanine (CG), they can be separated by heating them up above a melt temperature that is specific to the sequence and the length of the dsDNA. Hence, the longer the double-stranded DNA 'duplex', the higher its melting temperature. Furthermore, upon cooling only complementary single-stranded (ss)DNAs can bind or hybridise again. Hence by end-grafting a specific ssDNA called A to, say, red fluorescent colloids, and the complementary strand A' to green fluorescent particles – even though the chemistry and size of the particles are the same – we have created a new binding rule that only allows red-green binding but identical colloids cannot bond.

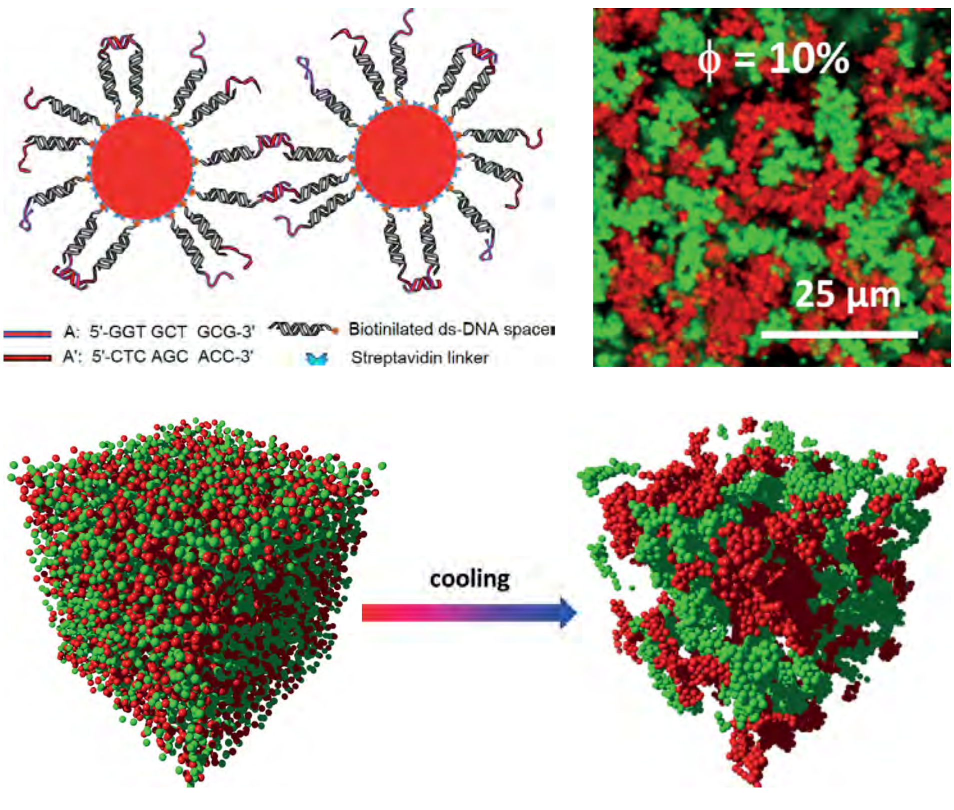
In a recent publication in *Nature Communications* we showed how elegantly these DNA binding rules can be exploited in order to build other classes of well-defined amorphous gels.[7] There we present two very similar systems, which show very different structures:

(a) In the first, we choose the DNA binding to be such that red-red AND green-green colloid binding is now allowed, while red-green binding is forbidden. Hybridisation occurs at the same temperature. The resulting structures are two percolating gels that occupy the same space. We call these bigels (Fig.1, top right).

(b) In the second system we again allow red-red binding, while now the green colloids cannot bind to each other at any accessible temperature, but they can bind to the red ones at lower temperatures. Upon cooling we obtain again a porous gel with well-defined structure, but which is now coaxially coated with a monolayer of different colloids (see Fig.1).

At this stage, these structures are only made to explore the physical principles involved, but this approach opens the way to the design of a new class of functional materials. Examples can be 3D electrode and battery materials as well as controlled drug release or scaffolding systems in medical applications.

Erika Eiser is Reader in Soft Matter Physics



Athene Donald and Churchill

Erika's brief scientific CV

In February 2008 I started my research group at the Cavendish focusing on the physics of self-assembling systems. But, how did I come to study these types of complex, but crucial, physics problems? I did my undergraduate studies in Konstanz, Germany, specialising in semiconductor science. For my Masters and PhD I moved to the Weizmann Institute of Science in Israel, where I explored the dynamics of polymer melts.[1] In particular, I studied how polymers influence the interaction and friction between solid surfaces.[2] Then, during my postdoctoral research at the University of Montpellier and the European Synchrotron Radiation Facility in France, I used *in situ* Small-Angle X-ray Scattering and rheology measurements to study the structure and flow of self-assembled polymeric gels.[3] In 2000 I joined the Science faculty of the University of Amsterdam in the Netherlands, as an Assistant Professor, pursuing research into the structural and dynamical properties of colloidal gels and glasses of clays, self-assembling surfactant systems doped with catalytically active metal-nanoparticles, proteins, and programmable self-assembly of colloids driven by DNA.[4,5]

[1] U. Steiner, J. Klein, E. Eiser, A. Budkowski and L .J. Fetters, "Complete wetting from polymer mixtures", *Science*, **258**, 1126-1129 (1992)
[2] E. Eiser, J. Klein, T.A. Witten, J.L. Fetters, "Shear of telechelic brushes", *Phys. Rev. Lett.*, **82**, 5076 (1999)
[3] E. Eiser, F. Molino, G. Porte, "Correlation between the viscoelastic properties of a soft crystal and its microstructure", *Eur. Phys. J. E*, **2**, 39-46 (2000).
[4] S. Jabbari-Farouji, D. Mizuno, M. Atakhorrami, F. C. MacKintosh, C. F. Schmidt, E. Eiser, G. H. Wegdam and Daniel Bonn; " Non-equilibrium fluctuation-dissipation theorem in an aging colloidal glass" *Phys. Rev. Lett.*, **98**, 108302 (2007).
[5] F. Bouchama, M.B. Thathagar, G. Rothenberg, D.H. Turkenburg, and E. Eiser, 'Self-Assembly of a Hexagonal Phase of Wormlike Micelles Containing Metal Nanoclusters', *Langmuir*, **20**, 477-483 (2004).
[6] F. Varrato, L. Di Michele, M. Belushkin, N. Dorsaz, S.H. Nathan, E. Eiser, G. Foffi, 'Arrested demixing: from gels to bigels', *PNAS*, doi 10.1073 (2012).
[7] L. Di Michele, F. Varrato, J. Kotar, S.H. Nathan, G. Foffi, E. Eiser, 'Multistep kinetic self-assembly of DNA-coated colloids', Nature Communications, 4:2007, DOI: 10.1038/ncomms3007 (2013).

Fig.1, left: **The top left cartoon illustrates the DNA coating of red fluorescently labelled colloids with 'sticky' single-stranded DNA overhangs A and A', which will bind to each other below 45°C. Similarly, the red beads are coated with DNA linkers B and B' with comparable melt temperature. *Binding rules*: Red colloids can only bind to red and green only to other green colloids. The confocal microscope image (top right) shows that red and green colloids form independent percolating gels separated by a continuous fluid phase shown in black. Below, simulation snapshots show the colloidal system in the gas phase above and the bigel formed below the melt temperature.[6]**

We congratulate Athene on her election as Master of Churchill College. She reflects on this latest twist of her remarkable career.

When I talk to students, be they at school, University or already embarked on their research careers, I always feel it is worth pointing out that if they haven't a clear idea of where they're heading yet they shouldn't worry. Life rarely goes according to plan and the twists and turns of opportunity and fate, malignant or otherwise, can mean you end up somewhere far removed from where you expected. Certainly my student self could never have dreamed that I would end up becoming Master of Churchill College, but that is indeed what is next in store for me, starting from next October. I will be succeeding another physicist Sir David Wallace. He arrived in Cambridge in 2006 fresh from running Loughborough University where he was their Vice Chancellor and will have completed 8 years as Master when he steps down next year. I will become the seventh Master, although the first woman in the position, but I will not be attempting to change the title of the role. The very first Master was another physicist, Sir John Cockcroft (see page 5) and the third master was the cosmologist Sir Hermann Bondi. Thus it can be seen that physicists have rather dominated the Mastership!

Churchill College is unique amongst the Cambridge colleges, because by Statute it is required to have both a student body and a fellowship that are made up of 70% scientists and technologists. Nevertheless it is clear that all disciplines flourish and I get no sense of 'them' and 'us' between the disciplines, something I tried hard to check whilst I was in the process of applying for the position: included as part of the Further Particulars for the job there was an explicit statement of the college mission which included the phrase *'to build bridges between the three estates of Science and Technology, the Arts and Humanities and the world of Commerce and Industry'*. To do this will be both exciting and non-trivial, but it is certainly a wonderful goal.

There are also less obvious 'perks' attached to the job. One that particularly excites me is the existence of the Archives. I have only had a chance to have a quick peek at these, but I look forward to being able to study them at more leisure in the years to come. Their sets of papers include those of many famous scientists, naturally including Cockcroft. Of particular interest to me will be a chance to look over the papers of Rosalind Franklin and Lisa Meitner, women who had to fight against the prevailing sexist attitudes of their times and yet still managed to produce top-notch research. In the many speeches I suspect I will be called on to give, this resource of the private papers of many extraordinary scientists will be invaluable.

This job will not take me away from the Cavendish, where I hope I will still be able to make a full contribution. But it will open up new opportunities of a kind utterly remote from my teenage dreams and aspirations.

Understanding Cancer

We are delighted to welcome Sarah Bohndiek as a new Lecturer in Biological/ Biomedical Physics. She will be working in the Biological and Soft Systems Sector and collaborating with the Cancer Research UK (CRUK) Cambridge Institute. She has recently been awarded a CRUK Career Establishment Award. Her research will investigate new molecular imaging tools to detect cancer early and to study the evolution of drug resistance in the disease.

Malcolm Longair had the pleasure of interviewing Sarah about her career to date and her aspirations for the future.

MSL: How did you come to be working in this area of research?

SB: I grew up in South-East London where I went to a state school and then on to a sixth-form college. While I was at school I really enjoyed astronomy and spent a lot of time reading around astrophysics and quantum physics. This led to me to read Physics at the Cavendish as part of the Natural Sciences Tripos. During my first year, I went to lectures on Material Science and learned about biomaterials which could be used in implants in hip replacement surgery. This made me think about more 'down-to-Earth' applications of physics. I obtained a summer placement in the UCL Medical Physics Department and this led to me studying for a PhD in Radiation Physics at UCL. I spent three years developing low cost X-ray imaging instruments for breast cancer, without really understanding what cancer was. So I wanted to work in an environment where I could combine my background in biomedical imaging techniques with training in cancer biology. I was fortunate to spend the next three years as a post-doc working with Kevin Brindle in the Cambridge Department of Biochemistry and the CRUK Cambridge Institute. This enabled me to get into research in cancer biology and to develop an understanding of many of the different experimental techniques of these disciplines. Then, I worked for two years as a post-doctoral scholar at the Molecular Imaging Program at Stanford where I was able to combine my expertise in molecular imaging with clinical challenges. Finally, I ended up here to push forward the Cavendish programmes in the Physics of Medicine.

MSL: What are you most proud of in your research career so far?

SB: This would have to be the work I did with Kevin Brindle on the use of nuclear magnetic resonance (NMR) imaging, in particular, studying the role of vitamin C in cancer (Fig.1). Using the technique of Dynamic Nuclear Polarisation, it is possible to achieve a huge increase in sensitivity of carbon-13 imaging in NMR, by a factor of more than 10,000. The carbon-13 imaging signal is about a million times weaker than that of protons in conventional magnetic resonance imaging (MRI). To obtain a strong signal, we exchanged one of the normal carbon atoms in vitamin C with a carbon-13 atom and doped the sample with free electrons. When the sample was cooled to 1 K, we could transfer polarisation from the electrons, which are almost 100% polarised at this temperature, into the carbon-13 pool. Of course, 1 K is not a useful temperature for living samples, but it turns out that if we dissolve the material and heat up the atoms very rapidly, they maintain their polarisation and can be used to image the distribution and metabolism of the labeled vitamin C in live biological samples. The exciting thing about this work was that there were a number of groups trying to do exactly this at the same time and we were the first to make this technically complex and demanding imaging experiment work.

MSL: This is wonderful work. What are you planning to do now that you are back in the Physics Department?

SB: More recently, I have been learning about high contrast mechanisms in other regions of the electromagnetic spectrum, in particular in the optical and infrared wavebands, for the imaging of biological samples and materials. These techniques are very interesting as they do not involve ionising radiation, but provide high resolution localised imaging and the associated technology is often much smaller and lower cost than, say, MRI or positron-electron tomography/computed tomography (PET/CT). They can also be used to translate biological findings between cell models in microscopy, small mammals and man. I am particularly interested in the transition points in cancer and its development in inflammatory regions. It is not clear, for example, whether inflammatory lesions precede the development of cancer or if early cancer is the cause of some of the inflammation. Another transition point I am interested in is the elevation of anti-oxidant capacity associated with drug resistance. Resistant cells often mutate in order to increase their production of anti-oxidants and so manage to escape the toxic insult generated by chemotherapy treatment.

MSL: Will these be research topics of your five-year Award?

SB: Yes, part of my research will be developing optical imaging techniques applied in endoscopy, in particular, to a small mouse endoscope to study the role of anti-oxidant status in the development of colon cancer. We aim to correlate our 'tumour level' imaging data in endoscopy with what happens in cancer cell microscopy. We are setting up the instrument development for this programme in the Physics of Medicine building, which we will transfer to the CRUK Cambridge Institute once we are at the prototype stage. The problem is that, while many people believe that the study of redox balance is central to the understanding of cancer development, there has been no way of studying how the tumours develop *in vivo*. That is the goal of the instrument development programme that I will be leading.

MSL: What have been the most important influences on your research career to date?

SB: Undoubtedly these have been my supervisors and mentors, who have been very strongly supportive and encouraging throughout my career to date.[1] I am privileged to have received a great deal of academic freedom to pursue ideas and obtain funding of my own.

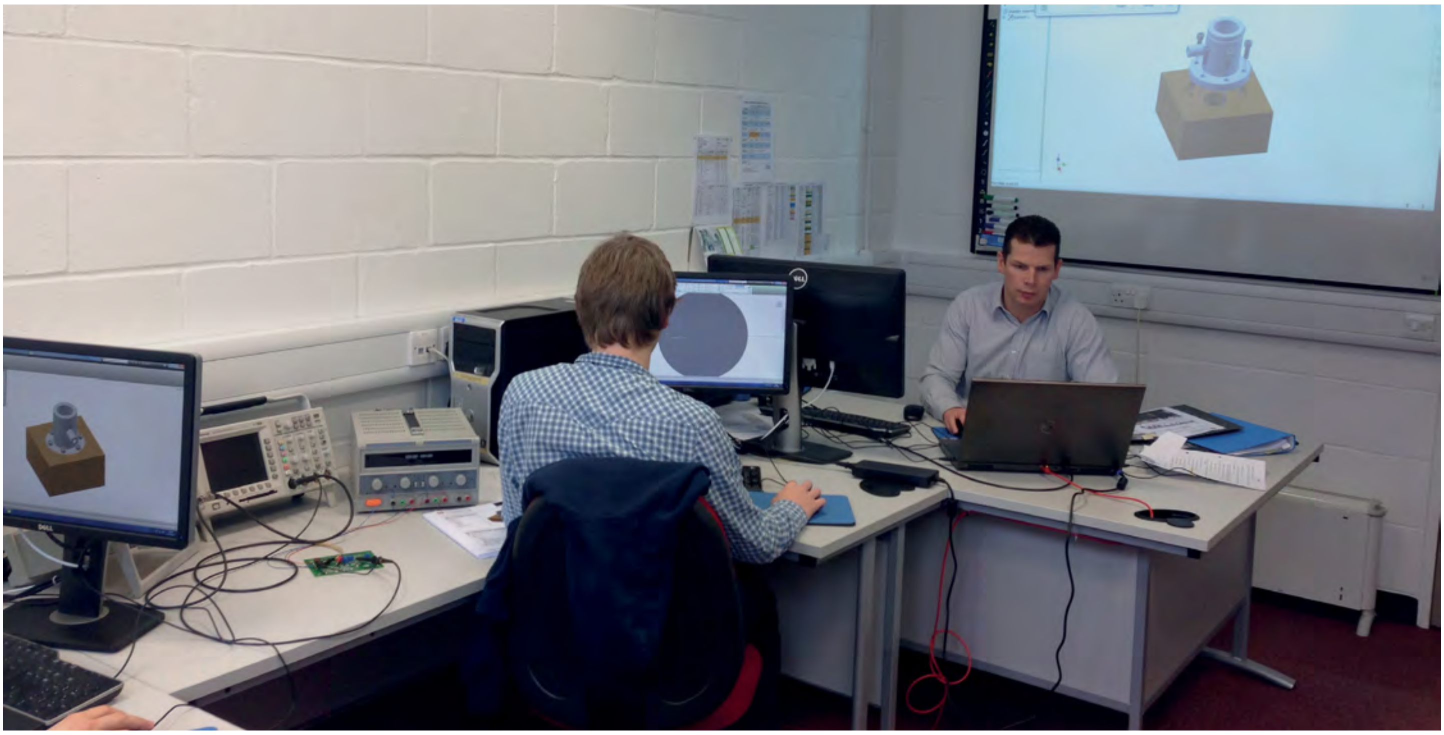
MSL: How have you found the transition back to Cambridge as a new staff member?

SB: Everyone has been very supportive, particularly in getting my grants submitted and set up in Cambridge. The administrative element of the job came as a bit of shock, but the practical teaching of the principles of NMR is proving very popular with the students. I am looking forward to teaching the Medical Physics Part III course in the Lent term.

MSL: And outside the Laboratory?

SB: I love sport. My summer passion is long distance cycling and snow-boarding in the winter – I am keen to learn lots of new tricks!

Inventors Teaching Room



The success of the Workshop Training course, which has now been running for three years, has encouraged the Laboratory to go ahead with the next stages of graduate student training in the latest techniques in mechanical and electronic design. Thanks to the generosity of Dr. Marianne Ehrenberg, we have refurbished and equipped a Mechanical Design and Electronic Training Facility for graduate students with state of the art Computer-Aided Design (CAD) facilities and electronics training equipment. The course began last year and is now settling down into a pattern where groups of four students undergo an intensive one-day course in CAD techniques.

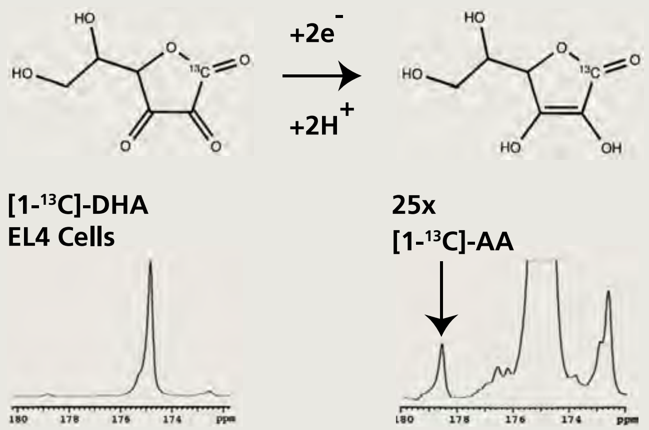
Gavin Ross, who has masterminded the course and produced a splendid course manual, takes the students all the way from the conceptual design, to the outline model in the computer and then to a detailed model designed to the required specifications. The final model can be viewed on screen from any angle and a movie made which demonstrates the item in action and also how it can be assembled and disassembled. The room is also used for hands-on training in the design and use of electronic equipment.

This developing suite of workshop courses is of the greatest value to graduate students working on experimental programmes where the items cannot be bought off the shelf. It also equips them for the types of experimental innovation which has been the hallmark of the Laboratory from its earliest days.

Image, top: **Gavin Ross at the helm in the Inventors' Design Suite.**

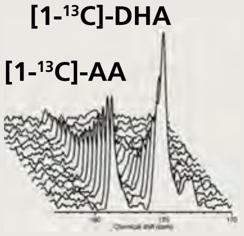
Fig.1

(a)

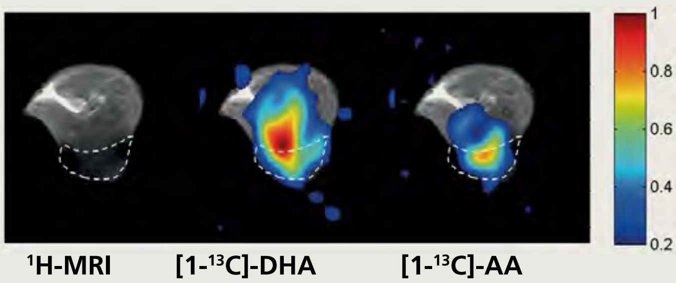


(b)

(c)



(d)



Hyperpolarised $[1\text{-}^{13}C]$-Dehydroascorbic Acid (DHA), the oxidised form of the antioxidant Vitamin C, enables dynamic magnetic resonance imaging of redox state. a) DHA is reduced to Ascorbic Acid (AA) within cells after uptake via the glucose transporters to maintain antioxidant capacity. Injection of hyperpolarised $[1\text{-}^{13}C]$-DHA into a suspension of murine lymphoma EL4 cells *in vitro* (b) and mice bearing EL4 xenograft tumours *in vivo* (c) yielded readily detectable signals from AA in magnetic resonance spectra, indicating rapid reduction of the hyperpolarised substrate in cancer cells. Chemical shift imaging (d) showed that, while the injected $[1\text{-}^{13}C]$-DHA is widespread, reduction is predominantly localised within the tumour (dashed while line), indicative of the redox adaptation in cancer cells *(Images adapted from Bohndiek* et al *J Am Chem Soc, 2011 and Proc ISMRM, 2012)*

Sarah has written a very helpful essay, *The Good Mentorship Guide*, for the Institute of Physics (**www.iop.org/careers/working-life/articles/page_59782.html**)

Early Computing in Radio Astronomy

Aperture synthesis is the technique whereby a telescope equivalent in resolving power to a very large single dish can be constructed by linking together a number of small movable aerials as an interferometer. It continues to be used worldwide in the very latest radio telescopes, together with state-of-the-art computing. Although the principles were well known in the 1950s, at that time the great challenge was to realise the concept in practice. Martin Ryle's genius was to succeed in implementing such systems with the use of his own innovative applications of electronics. There were great advantages in terms of construction and costs but considerable computation was required to carry out the Fourier inversion needed to generate the sky maps from the observations.

In the early days the radio astronomy group had access to a series of electronic computers set up by Maurice Wilkes at the University Mathematical Laboratory — Edsac I (1949–1957), Edsac II (1957–1965), Titan (1963–1973), each the most powerful available at the time. A number of people wrote the software, including Ann Gower (née Neville), Judy Bailey and myself.

The first use of Edsac I was for a synthesis instrument built by John Blythe in 1954. The computer had only 512 words of 35 bits and it took 15 hours to carry out the required 380 1-D transforms, each of 38 points. I joined the group in 1960 and started writing programs for analysing the output from the early surveys. Ann was then a research student working with Martin on setting up a new experimental system to test his brilliantly simple extension of aperture synthesis which made use of the rotation of the Earth to provide relative motion of the aerials as seen from the fixed stars.

This, however, needed 2-D transforms and only once Edsac II was available could the experiment be tried (Fig.1). It proved a tremendous success: a region of diameter 8° about the North Celestial pole was mapped with a resolution of 4.5 arcmin and with some eight times the sensitivity of earlier surveys (Fig.2). Ann was responsible for the huge programming task of organising the raw data and coding the Fourier transform, while I contributed the graphics, both of us helped by Tony Hewish.

Computing on Edsac II was quite a challenge. It was operated by paper tape and, having thousands of thermionic valves of limited life, was likely to fail every few hours. Not infrequently a rack would burst into flames — a fire-extinguisher was always to hand. The engineers and operators nursed it along during normal working hours and we ‘users' had only two short program-testing periods each day while they were having their morning and afternoon tea-breaks. For serious ‘production runs' we had to book longer evening and night-time sessions when authorised users were allowed to operate the machine themselves. There was intense competition for computing time in many different fields — economics, number theory, genetics, atomic wave-functions, geophysics and, in particular, crystallography and molecular biology. On the whole camaraderie prevailed. A tangled tape was recognised instantly as a crisis and everyone rallied round to help.

Programming was in machine code. There were then only 1K 40-bit words of memory — with some magnetic tape back-up — and a single floating-point multiplication took 0.5 ms, so great economy of space and time was required. Unlike today, the skill was to use as few orders as possible and sophisticated techniques like run-time program modification were needed. Ann's calculation of her final map eventually took a whole night of machine time. The only way of displaying it was on the computer's cathode-ray tube. My code directly controlled both the movement of the spot on the screen and the appropriate synchronisation of the associated camera. The final plot consisted of a series of cross-sections through the sky-brightness distribution from which the intensities of the sources could be measured, some of the first ever graphics on a digital computer.

After such a convincing demonstration of earth-rotation aperture synthesis, Martin was able to continue with his design for the One-Mile telescope, the first fully-steerable Earth-rotation aperture synthesis radio telescope system. A key consideration was that a new computer, Titan, was soon to replace Edsac II. Titan was a great step forward: it had transistors instead of valves, a time-sharing rather than a batch-processing system, a high-level language and the option of on-line access, as well as paper tape. However, the memory was only 32K (later 128K) 48-bit words, so, because of our large quantities of data, we had to continue to use low-level machine code involving much manipulation of bit patterns. Our great expert was Sidney Kenderdine. Thanks to help from David Wheeler at the Maths Lab, we were able to use the fast-Fourier-transform algorithm some years before it was published, but, even so, mapping an area of sky of about 10 square degrees still took an hour or more of machine time.

A number of us wrote programs for the One-Mile telescope (OMT); in 1963 Judy Bailey joined the group, becoming a main-stay of radio-astronomy software for some five years. She was a heroine with the highly complex programs that generated the control tapes for the telescope and developed two innovative modes of its operation. One was for obtaining more accurate positions of pulsars than had been possible with the original pulsar array, to facilitate searches for optical counterparts. The other was for making so-called ‘drift-scan' observations in which, instead of tracking a particular region of the sky, the telescope simply recorded the signals as the sky drifted past, producing rapid coverage of considerable areas.

Exciting results soon began to emerge from the OMT observations. Maps were produced showing sources some 100 times fainter than had been seen before. The distribution in intensity of the sources was of great significance for cosmology, providing strong evidence for an evolving universe. Beautiful plots were obtained showing the structure of individual sources, and it became possible to begin to understand the physical processes involved. Ann remembers the historic occasion when everyone gathered round Edsac II to watch the first line profiles of Cas A appear on the plotter: `it was an amazing moment... almost unbelievable...in that instant one could see the leap in knowledge that each map might reveal' (Fig.3).

All this depended on Maurice Wilkes' pioneering work on early computers. To continue Martin Ryle's sentence: *'...it is interesting to speculate how our work in Cambridge would have proceeded if, for example, computer development had been five years behind its actual course.'* His remarks were prescient; today the designs for the Square Kilometre Array, an aperture synthesis instrument with some millions of elements, depend on future computing power not yet fully developed.

Elizabeth Waldram

“The development of aperture synthesis has...been very closely linked to the development of more and more powerful computers.”

Martin Ryle, Nobel Prize lecture 1974

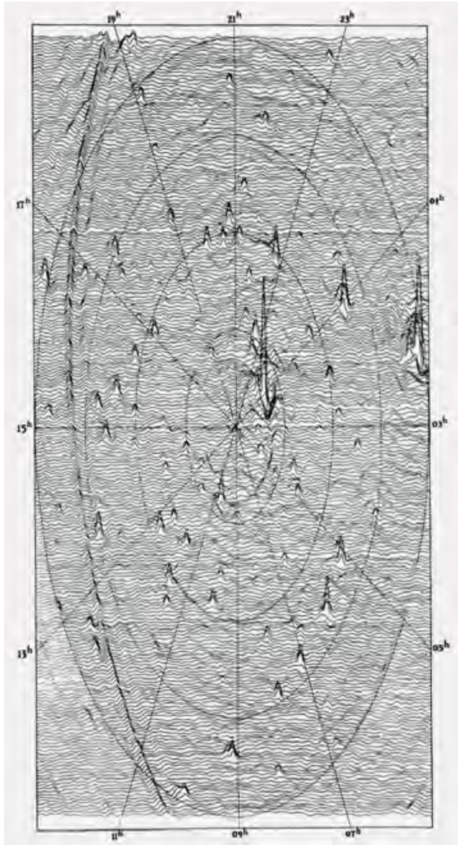


Fig.1 (above left). **Ann Neville feeding paper tapes from observations for the North Pole Survey into Edsac II.**

Fig.2 (above right). **The radio map of the region around the north celestial pole created by Ryle and Neville (1962). This was the deepest image of the sky at the time and provided the first direct evidence for the cosmological convergence of the number counts of radio sources.**

Fig.3(a) **A photograph of the first plot made by Edsac II of the radio image of the supernova remnant Cassiopaeia A (Cas A) from observations by the One Mile Telescope.**

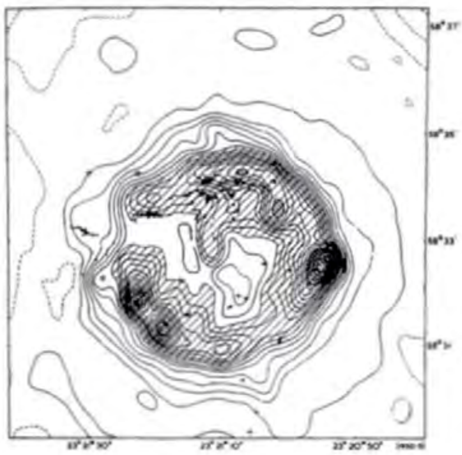


Fig.3(b) **The One Mile Telescope image of the supernova remnant Cas A showing its characteristic shell-like appearance, coincident with the optical filaments produced by the catastrophic stellar explosion.**

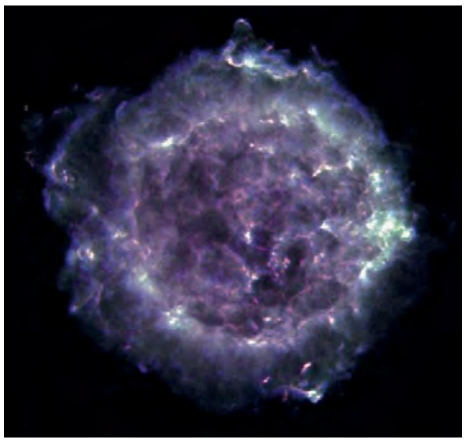


Fig.3(c) **The radio image of Cas A as observed by the Very Large Array, illustrating the remarkable developments in angular resolution and sensitivity since the first maps in the 1960s. ©NRAO**

Nora Sidgwick at the Cavendish Laboratory

The 'rogues' gallery' of graduate students in the Cavendish Laboratory from 1897 onwards is a popular display for alumni and visitors, who enjoy seeing themselves, their colleagues and lecturers as they were in their younger days. Questions are often asked about the women in the photographs. It should be emphasised that they are all research workers, on a par with the men. But women were active in the Laboratory almost from the beginning. Among the more remarkable of these was Nora (Eleanor) Sidgwick.

John William Strutt was elected to the Cavendish Professorship in 1879, following the death of Maxwell. On the death of Strutt's father in 1873, he had succeeded to the Baronetcy as the third Lord Rayleigh. It was not a common occurrence for a senior member of the aristocracy and major landowner to become a professional academic, but Rayleigh had already demonstrated outstanding ability in theoretical and experimental physics. He had been senior Wrangler in 1865 and first Smith's prize winner. By the time his name came forward as a candidate for the Cavendish chair, he was already known for his explanation of the colour of the sky through the process of Rayleigh scattering and he had written profusely on a very wide range of topics in the physical sciences, including experimental researches carried out at the family home at Terling Place in Essex.

In 1871 Rayleigh married Evelyn Balfour, the sister of Arthur James Balfour who was a friend of Rayleigh's at Trinity College and who was to become Prime Minister of Great Britain in 1902 – he was also responsible for the Balfour Declaration of 1917. In 1872, Rayleigh, whose health was always somewhat weak, suffered a severe bout of rheumatic fever. For convalescence, he and his wife spent the following winter in Egypt, accompanied by Eleanor (Nora) Balfour, Evelyn's sister. Nora Balfour was an outstanding mathematician and she and Rayleigh discussed physics and mathematics continually throughout his convalescence in Egypt. During this period, Rayleigh began Volume 1 of his great and influential *Theory of Sound*, which was published in 1877; Volume 2 appeared in the following year.

In 1876 Nora married the moral philosopher Henry Sidgwick, who with Anne Clough had founded Newnham College, in the previous year – Nora had been one of the very first students at Newnham. Henry and Nora Sidgwick were pioneers in promoting the cause of women in the University and were deeply involved in the struggle to gain the admission of women to University examinations. This they achieved in 1881, but they lost the battle to allow the degrees to be conferred. Instead, women only received a certificate confirming their success in the examinations. The admission of women to degrees only began in 1948.

Maxwell had not been sympathetic to the presence of women in the Laboratory, their attendance being restricted to the summer term when Maxwell was at his home at Glenlair in Southern Scotland. The formal opening of all physics classes to women on equal terms with the men took place in 1882. Undoubtedly, Rayleigh's decision to admit women to the experimental physics courses was influenced by the views of Henry and Nora Sidgwick. Nora was appointed Vice-Principal of Newnham College in 1880 and then Principal in 1892.

Rayleigh continued his broad range of research interests throughout his tenure of the Cavendish Chair from 1879–1884 and took the decision to continue Maxwell's programme of the determination of electrical standards, but increasing their precision by an order of magnitude or more, very much in the spirit of Maxwell's dictum that new science would come from improving the precision with which the laws of physics and the fundamental constants were known. At that time, the standard of resistance was only known to about 4% and the unit of current, as measured from the electrochemical equivalent of silver, was only known to 2%.

Nora Sidgwick was particularly involved in the determination of the ohm and the standard of current electricity. The former experiment is described by Richard Glazebrook, 'A circular disc rotates about an axis perpendicular to its plane in a magnetic field due to a concentric coil. By balancing the fall in potential between the centre and the edge of the disc against that due to the passage through a resistance of the current producing the field, the value of the resistance is given by the formula $R = nM$, where R is the resistance, M the coefficient of mutual inductance between the coil and the disc and n is the number of revolutions of the disc per second.'

Fortunately, Rayleigh had at hand a pair of coils which had been very carefully wound by George Chrystal so that the dimensions of the coils were very precisely known (Fig.1(a) and (b)). Rayleigh and Sidgwick describe delightfully how they made use of the existing apparatus.

'… the diameter of the disc was chosen so as to be somewhat more than half that of the coils. … The disc was of brass and turned upon a solid brass rod as axle. This axle was mounted vertically in the same frame that carried the revolving coil in the experiments described in a former communication, an arrangement both economical and convenient, as it allowed the apparatus then employed for driving the disc and for observing the speed to remain almost undisturbed. The coils were supported horizontally upon wooden pieces screwed on the inner side of the three uprights of the frame.'

The experiment involved working out the theoretical value of M, the coefficient of mutual inductance, and great attention had to be made to the many corrections to the simple relation $R = nM$. The final result of their experiments was:

1 B.A. unit = 0.98677 x 10⁹ C.G.S. units.

Two further contributions to the establishment of electrical standards were undertaken with the same meticulous care for exact measurement. The first was the determination of the absolute value of the unit of current in terms of the amount of silver deposited by electrochemical action. Again, quoting Glazebrook,

'A coil was suspended from one arm of a balance with its plane horizontal and midway between two fixed coaxial coils of larger radius. The electrodynamic attraction between the suspended and fixed coils when carrying the same current can be balanced by weights in the opposite pan; it can also be calculated in terms of the current and the dimensions of the two coils; the current is thus measured absolutely in terms of the weight and the dimensions of the coils.

If the same current also traverses a solution of nitrate of silver in a platinum bowl suitably arranged, it can also be measured in terms of the weight of silver it deposits, and thus we can express a current whose value is known in absolute units in terms of the silver deposited.'

(a)

Opposite: **Portrait of Eleanor (Nora) Sidgwick by James Jebusa Shannon, painted in 1889. © Newnham College, University of Cambridge**

This page a: **Rayleigh's rotating coil experiment. In the original experiment, the large coils were rotated using a water engine and the speed of rotation determined accurately by a stroboscopic arrangement. In Rayleigh and Sidgwick's experiment, the rotating coil was removed and replaced by the coils wound by Chrystal** (b)**. The coils in** (b) **were placed together horizontally and the copper disc rotated about the vertical axis by the water engine. (Exhibits from the Cavendish collection of scientific instruments.)**

(b)

The paper by Rayleigh and Sidgwick is a very impressive achievement, considering in detail every aspect of the experiment and the problems of obtaining a precise result. The final answer was that:

The number of grams of silver deposited per second by a current of 1 ampere = 0.00111794.

As part of the same experiment, Rayleigh and Sidgwick determined the electromagnetic force of the standard wet-chemical cell at the time, the Clark cell, invented by Josiah Latimer Clark in 1873. The feature of the cell was that it produced a highly stable voltage, which they found to be 1.4345 volts at 15 C. This was essentially the international standard adopted in 1894.

These experiments were central to establishing the reputation of the Laboratory at the leading edge of precise measurement. These standards were of fundamental importance for industry since secondary standards could then be calibrated relative to these absolute standards. Nora Sidgwick's contributions were central to these endeavours and an inspiration for the future generations of women research workers in the Laboratory.

Malcolm Longair

References:

Glazebrook, R.T., (1910) *A History of the Cavendish Laboratory 1874–1910*. Eds. Fitzpatrick, T.C., *et al* pp 40–74. London: Longmans, Green and Co.

Rayleigh, J.W. and Sidgwick, E., (1883). Experiments, by the Method of Lorentz, for the further Determination in Absolute Value of the British Association Unit of Resistance, with an Appendix on the Determination of the Pitch of a Standard Tuning Fork, *Phil. Trans. Roy. Soc.*, **174**, 295-322.

Rayleigh, J.W. and Sidgwick, E., (1884). On the Electro-chemical Equivalent of Silver, and on the Absolute Electromotive Force of Clark Cells, *Phil. Trans. Roy. Soc.*, **175**, 411-460.

Spin at the Heart of Solar Cells

As the world economy grows in the coming century, demands for an ever-increasing supply of energy need to be balanced with environmental concerns and long-term sustainability. This had led to the hope for the large-scale deployment of renewable energy technologies such as solar cells. A solar cell is a semiconductor device that absorbs photons to produce electrical charge, holes and electrons, which can then be collected in an external circuit. Invented in Bell Labs in 1954, solar cells have had a bumpy history over the past 60 years. For much of that time the high cost of the electricity they produced, compared to coal, meant that they were used only in niche applications such as the space program.

Things began to look up at the turn of the century with growing interest in renewable technologies and advances in manufacturing. As with all modern electronics, the material of choice to make solar cells has been silicon, and the best laboratory devices have efficiencies up to 25%, with commercially available panels coming in at between 16-20%. Over the past three years economies of scale and ruthless efficiency in manufacturing processes have brought the cost of these panels down to 0.62$/watt in 2012, for the first time making solar cells competitive with traditional fossil fuels in many parts of the world.

Despite these reductions in cost, there remains room for disruptive technologies that could dramatically cut costs further either by enabling cheaper manufacturing or improved efficiencies. One of these technologies is Organic Solar Cells (OSC), which use organic semiconductors rather than silicon to absorb light and generate charges. These organic materials can be dissolved in common solvents and be printed onto cheap substrates much like newspapers are printed today (Fig.1(a)). They could thus allow for cheap and very large-scale production, a hope that has led to a large research effort around the world both in universities and in industry.

At the heart of organic solar cells lies a fundamental paradox - elementary electrostatics would suggest that they should not work at all! This is because of the dielectric constant of these organic materials, which can be thought of as the ability of materials to shield charges from one another. In conventional inorganic semiconductors such as silicon the dielectric constant is high, 11.6, in comparison to organics, which is 3. This means that charges feel each other very strongly in these materials and Coulomb's Law should dominate their behaviour. Thus, photon absorption in these materials leads to the formation of strongly bound electron-hole pairs, known as Frenkel excitons. These excitons only diffuse 5-10 nm and decay in a few ns with the loss of their energy. To dissociate these excitons a heterojunction between electron donating and accepting organic materials is set up, similar to a heterojunction between p and n type inorganic semiconductors. But rather than one heterojunction, these cells have millions formed in an interpenetrating network between the donor and acceptor semiconductor (Fig.1(b)).

Dissociating the exciton is, however, only the start of the problem, because we now have the hole and electron 1nm apart on the donor and acceptor semiconductor respectively. This means that the hole and electron are bound by a coulomb attraction of 250 meV, 10 times the thermal energy at room temperature. This strong barrier would suggest that we should not be able to get charges out of such solar cells. But remarkably, in the best cells every photon absorbed produces charges which are collected in the external circuit. The fundamental question of how the coulomb barrier is overcome remained unanswered for over two decades. I began working on this problem with colleague Artem Bakulin in 2011 and together we developed a new ultrafast spectroscopic technique which allowed us to shed some light on the problem (Fig.2). Our results, published in Science in 2012[1], demonstrated that, for a few femtoseconds (10^{-15} s) after the exciton is dissociated, organic materials were capable of sustaining delocalised band states than allowed charges to escape from the heterojunction.

But even if electrons and holes escape the heterojunction, they still have to travel through an interpenetrating network of donor and acceptor semiconductors before getting to the electrodes. The Coulomb Capture Radius, the distance at which electrons and holes can capture each other, is as large as 16 nm in these materials, much larger than the typical domain size, 5 nm, of the donor and acceptor semiconductor. Thus theory predicted that charges drifting towards the electrodes would encounter opposite charges and recombine, leading to poor cell performance. Again this problem had been unresolved for many years. With colleagues Philip Chow and Simon Gélinas, we began working on this problem in 2010. Our studies seemed to indicate that in some materials charges did indeed recombine as theory suggested but that in others recombination was somehow blocked. We suspected that this might have something to do with the spin configuration of the different systems, but could not prove our hypothesis.

Two fortunate events in 2012 finally allowed us to solve the mystery. One was a chance encounter with colleague David Ginger, a Cavendish alumnus and now professor at the University of Washington at Seattle. David had been working on a set of materials in which the signatures we were trying to detect and quantify appeared to be easier to resolve. A Pump-Prime grant from the Winton Program for the Physics of

(a)

(b)

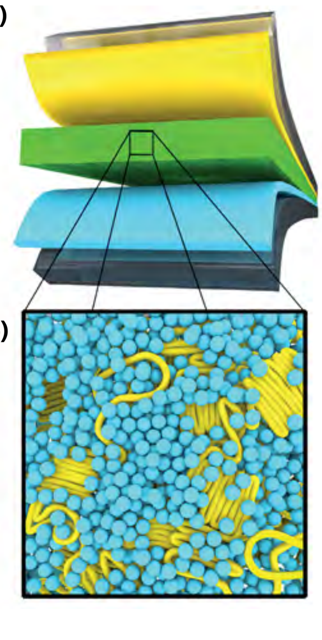


Fig.1 (left).

(a) The structure of an organic solar cell. Green: the active layer of the device with hole and electron transporting layers, blue and yellow all sandwiched between electrodes (silver).

(b) The structure of the active layer with an interpenetrating network of donor and acceptor semiconductor

Fig.2 (right). **The ultrafast laser system within the OE group on which the experiments were performed.**

Sustainability also enabled us to install sensitive near-IR detectors. Combined with our advances in optics development this allowed us to resolve spectral features in the near-IR with sensitivity two orders of magnitude better than had been previously possible.

What we discovered is that electrons and holes that encounter each other form intermediate species, so-called charge transfer (CT) states, 75% of which will have triplet (spin 1) character and 25% singlet (spin 0) character. The ground state of the system has singlet (spin 0) character and thus the triplet CT states cannot recombine to the ground, as spin is conserved. This sets up a 'Spin Blockade' in the system. We further showed that through morphological control of the heterojunction we could alter the delocalisation of electronic excited states across it such that the triplet CT states could be re-dissociated and recycled back as free charges.

These results, published in Nature earlier this year[2], and made possible through the support of the EPSRC and the Winton Program, create a new framework for understanding recombination in molecular and biological systems and may have applications both in solar cell and light emitting diodes.

[1] Bakulin, A. A. et al. The role of driving energy and delocalised states for charge separation in organic semiconductors. *Science*, **335**, 1340–1344 (2012). DOI: 10.1126/science.1217745

[2] For more details see: A. Rao, P.C.Y. Chow, S. Gélinas, C.W. Schlenker, C-Z. Li, H-L. Yip, A.K.-Y. Jen, D.S. Ginger & Richard H. Friend, 2013. The role of spin in the kinetic control of recombination in organic photovoltaics, *Nature*, http://dx.doi.org/10.1038/nature12339.

Akshay Rao is Research Fellow of Corpus Christi College and works in the Optoelectronics Group.

Expansion of the Outreach Team

We welcome Lizzie Bateman (centre) to the Physics Outreach team. She will be joining Lisa Jardine-Wright (left) and Steve Martin (right) who together run a variety of events throughout the year involving schools from all across the country. Lizzie graduated from Murray Edwards College in June after completing her MSci degree here in the Cavendish. She will be helping with Outreach events while Lisa's attention is focussed upon the Rutherford Project (see CavMag10). The outreach team collectively organise and run a series of events for all ages, including school workshops, museum tours and work experience. Lizzie will be also help Steve with his very successful Cambridge College's Physics Experience programme (pages 16–17).

Physics at Work

In September 2013, 2400 secondary school pupils made the trip to the Cavendish for the **29th Physics at Work Exhibition**. This annual event was once again a great success, with 26 exhibitors taking part, showcasing their physics interests and skills. The events run over three days with pupils attending either a morning or afternoon, as part of a school group. Each group visited six different exhibitors, each having a 15-minute slot. Exhibitors ranged from Cavendish research groups to multi-national commercial companies, with presentations including controlled explosions, forensic investigations and high-speed photography.

In Lisa's words, the purpose of Physics at Work 'is to stimulate interest and encourage wider participation in physics by showcasing the many opportunities available for careers in physics, either as a researcher or working in a commercial environment.' Feedback from the pupils and teachers alike has been overwhelmingly positive, with pupils especially enjoying the interactive nature of the presentations. Teachers were provided with supplementary information for follow-up lessons and sample career profiles of some of the exhibitors.

The dates for the **30th Physics at Work** exhibition are **23rd, 24th & 25th September 2014**. **Booking for schools opens in May and is usually fully booked by June.** New exhibitors are more than welcome - just send us an e-mail registering your interest.

Cambridge Physics Centre

The Cambridge Physics Centre (CPC) lecture programme has continued to deliver stimulating and engaging lectures to sixth-form students. So far this year, there have been lectures on 'The Physics of Superheroes', 'Biophysics' and 'How Wings Work.' The lectures start at **6pm** in the **Pippard Lecture Theatre** with upcoming dates shown below. The CPC committee are always looking for suggestions for lectures and speakers. Please get in touch with thoughts and ideas.

The Ever Expanding Universe and Dark Energy Tuesday 21 January
Prof. Carolin Crawford
Institute of Astronomy

Crystallography Thursday 13 February
Dr Erica Bithell
Department of Material Science & Metallurgy

Spin Tuesday 18 March
Prof. Mark Warner
Cavendish Laboratory

For further information go to:
www-outreach.phy.cam.ac.uk

Schools Workshop

The outreach team recently ran their last school workshop of 2013, on the topic 'Light, the Universe and Everything'. The event was attended by 120 year 9 students who were taken through a series of lectures and a practical session. These events are designed to encourage students to continue studying physics as they progress through school. The feedback from students and teachers has shown that they thoroughly enjoy the day and agree that it has made them think about studying physics at higher levels.

Upcoming events at the Cavendish

Monday 10th – Friday 14th February
Cambridge College's Physics Experience

Monday 17th & Tuesday 18th March
Schools Workshop
Booking now open online

Monday 5th May – Friday 9th May
Cambridge College's Physics Experience

Monday 30th June – Thursday 3rd July
Senior Physics Challenge

Widening participation project: Cambridge Colleges Physics Experience

In the year 2012–13, our collaborative widening participation project demonstrated to young people of diverse background, gender and ethnic origin that higher education is a desirable and accessible goal, which they might have previously dismissed (Fig.1). The CCPE project also promotes physics as a positive subject choice and application to Cambridge as a feasible career option.

Having completed one year of the project we have assessed its impact on the basis of responses to questionnaires, which emphasised encouraging girls to study physics and promoting the learning experience of Cambridge.

The format for each group was a whole-day student-group visit to Cambridge, jointly hosted by one of the five collaborating colleges, Christ's, Clare, Newnham, Pembroke and St Catherine's, and the Cavendish Laboratory. The 'college' part of the day consisted of a college tour combined with a discussion of admission to higher education in general and Cambridge University in particular, as well as an element of sight-seeing. The 'Cavendish' part was a programme of practical activities, research presentations and examples classes designed to raise awareness of what physics might be like as a subject of degree-level study. For the great majority this was participants' first visit to Cambridge: the event attracted an extraordinarily positive reaction, frequently exceeding young people's prior expectations (Fig.2).

Female students predominated by a moderate margin in pre-GCSE years while the male to female ratio was approximately 70/30 in Y12 - this might be the result of AS subject choice rather than by being in a high ability set for the sciences in general. The great majority of the visitors expressed a sense of privilege at being invited to spend time in Cambridge, together with an appreciation of the reputation of the University, the quality of its teaching and the life-long academic and more general benefits of higher education.

After the day's activities, participants expressed a more positive set of views of Physics as a subject, its value in the curriculum and their estimation of its worth to society. Although the day did not seem to have changed many post-GCSE intentions (rather confirming existing science-centred plans), intentions for higher education had been swayed in favour of Cambridge (Fig.3). All age groups shared the view that study at Cambridge constitutes an aspirational goal. Physics also gained some ground over technical NVQ's post-18 and notably Y12 girls showed a shift towards physics (Fig.4).

The overall positive shift to Physics is very welcome. Research elsewhere suggests that choices relating to girls and physics, which may be due to social pressures, may need intervention at a much younger age group than those addressed in this project.

Surveying *shifts* in subject choice showed similar movements towards Physics for all the age groups, whatever the starting point. Where students have made a negative change, away from physics, in most cases this was the realisation that at university there would be far more mathematics involved and deeper understanding required.

The verbal responses provided a detailed, diverse and generally positive picture. While expressing admiration for the University as an institution, many students and their teachers were concerned by the difficulty of gaining the requisite grades and the unfamiliar competitive nature of the admissions and selection process. A few teachers believed that the success rate for Cambridge applications is

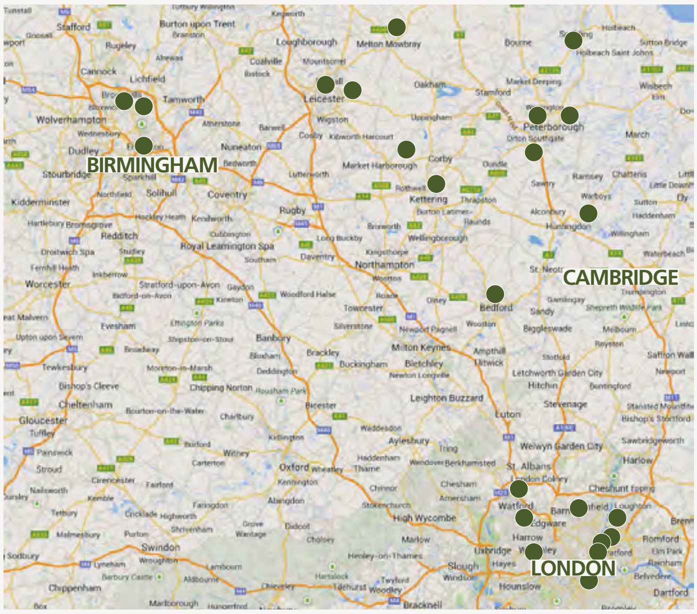


Fig.1: **Map showing locations of participating schools and colleges in the February Y12 event.**

lower than the reality by several orders of magnitude, and felt better informed after their visit. A considerable number of students were reassured regarding the costs of Higher Education and would now consider science as a financially viable life-choice. A large proportion of respondents recognised that there is an aspect to University life wider than studying a particular subject at a high level: the broadening of personal and social perspectives is also seen as having great value in the long term.

In summary, this *Widening Participation* project has been well-supported and well-received, influencing both boys and girls to consider Cambridge University, higher education and the study of Physics to be viable future career paths. The programme confirms already positive intentions and dispels myths which might influence sound career decisions.

Year 2 (2013–14): Expanding the Success

In 2013–14 the programme combines visits to the Cavendish Laboratory for year 9, year 11 and year 12 students with tours and talks at four Cambridge colleges who have contact with particularly low participating schools within their local area links (**www.study.cam.ac.uk/undergraduate/access/arealinks**).

We have expanded the programme to include other colleges, Fitzwilliam and Murray Edwards, and so make connections with other low participation neighbourhoods and schools. We have already begun offering this initiative to all colleges in 2014–15. With this expansion we are able to include 'girls into physics' days for each age group, at which only girls from single sex or mixed institutions are encouraged to attend. We have already completed a very successful Y11 week including one such girls only day, kindly hosted by Murray Edwards and Newnham - our remaining Y12 and Y9 weeks are now fully booked.

Year 3 (2014–15): How to Participate

In 2014–15 schools will be able to book through our outreach website. Until then further information about this initiative can be found at **www-outreach.phy.cam.ac.uk/ccpe**

Steve Martin and Lisa Jardine-Wright

Did the visit meet your expectations?

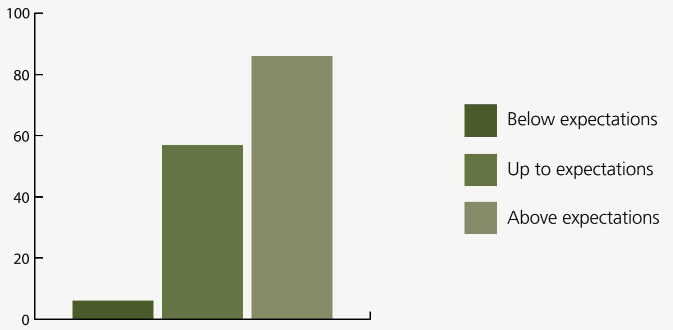


Fig.2: **Student responses on whether or not the visit met their expectations, during the May 2013 event.**

Education and Training plans beyond age 18, Y11 group, October 2012

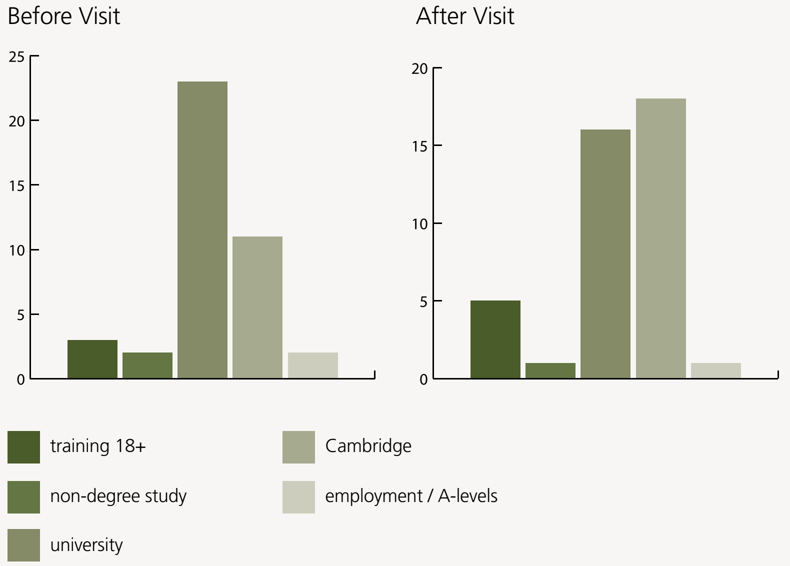


Fig.3: **This figure illustrates the opinions of visiting Y11 students in October 2012 both before and after their day visit. There is a clear shift among those who wanted to go to university; after the visit, a number changed their aspirations specifically to Cambridge.**

Career plans beyond 18, % by gender for the February 2013 Y12 Visitors

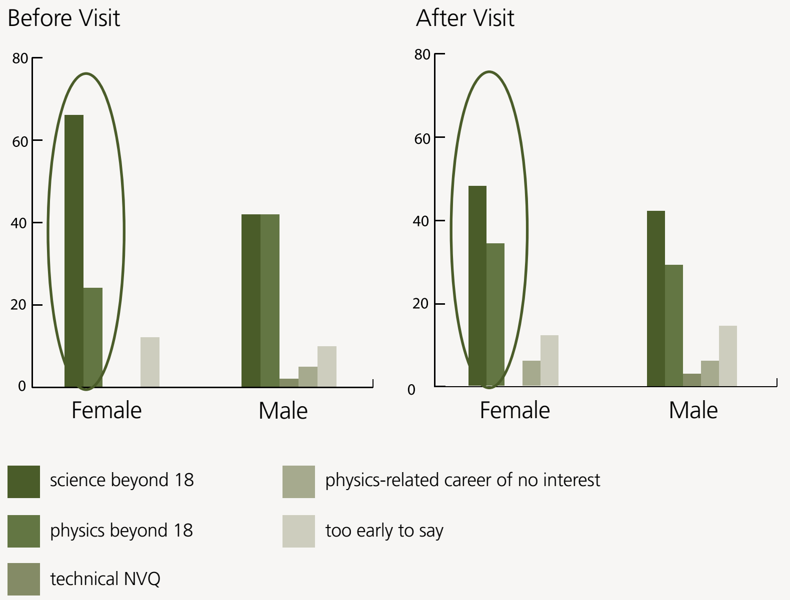


Fig.4: **This figure illustrates the career plans of visiting Y12 students in February 2013 both before and after their day visit. Here there is a clear shift among girls from science in general to physics in particular.**

Materials Discovery

Understanding and thereby developing new materials will be a key component to finding solutions to meet the growing demand on our natural resources. This is an area where physicists along with researchers in other disciplines could make a significant impact and has been a major theme of the Winton Programme for the Physics of Sustainability.

'Materials Discovery' is the research focus of the first Winton-linked lecturer, **Suchitra Sebastian**. Suchitra's research exploring new materials under extreme conditions is generating surprising results with potential applications in a range of fields from memory devices to high temperature superconductors.[1,2] This work has already led to her receiving a number of prestigious awards and appearing in the recent *Financial Times* list of '*The next big names in physics*', as well as being awarded an ERC Starting Grant to work on 'Unconventional Superconductors'. Essential to her work is the synthesis of new materials, and tuning their electronic and magnetic interactions using both chemical methods and the application of external forces such as strain, electric field and magnetic field.

This activity has a strong overlap with the research of Winton Advanced Research Fellow **Siân Dutton**, who is studying new materials for applications including batteries and solid state magnetic cooling.[3] Suchitra and Siân have both set up materials preparation facilities in the Cavendish Laboratory and are working together to set up a new comprehensive laboratory for advanced materials in the new Maxwell Centre.

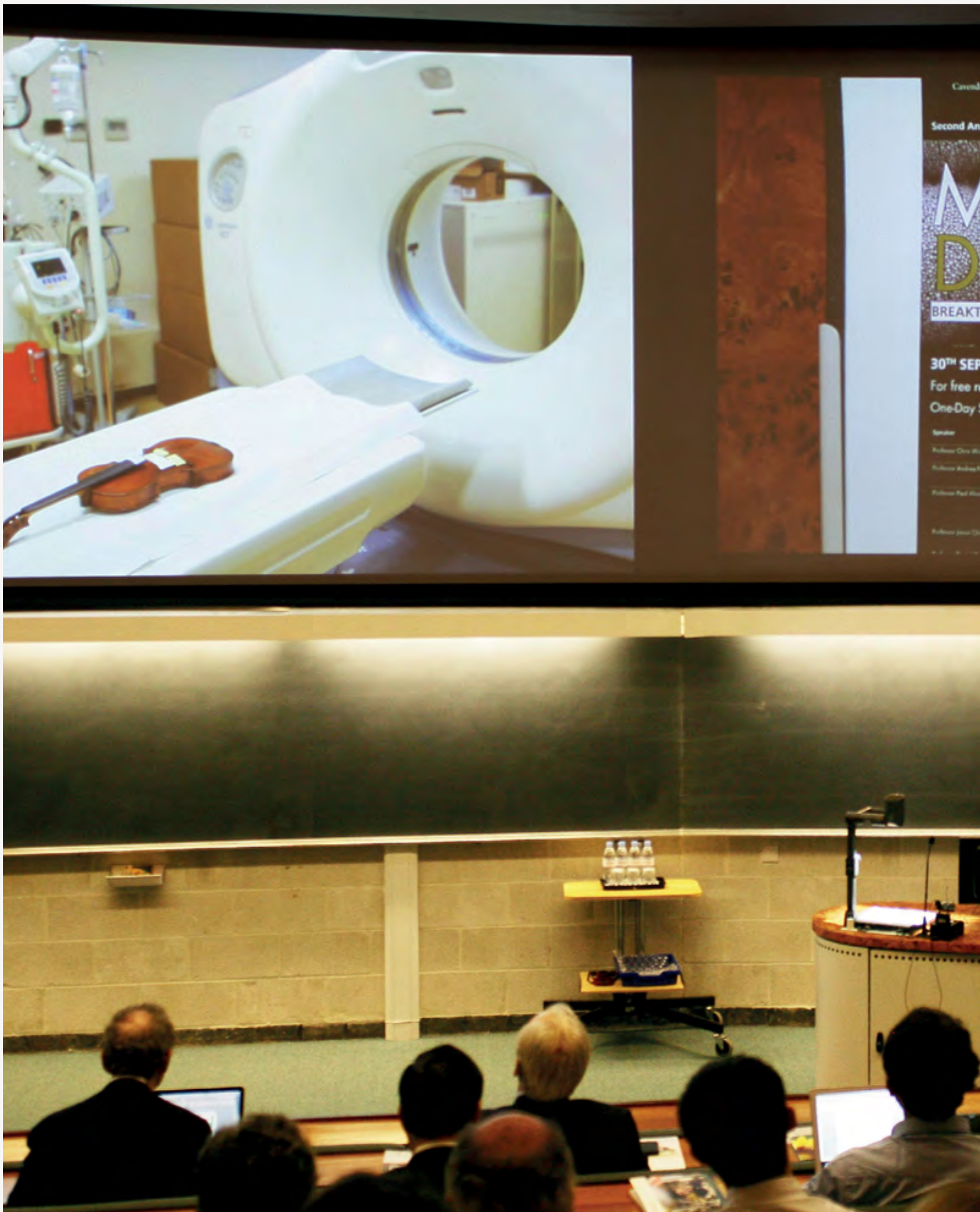
The second Winton Symposium on **Materials Discovery** was held on 30th September 2013. Speakers from a range of disciplines provided examples of recent breakthroughs and how they could make an impact on the needs of society. A capacity audience of 450 people at the Cavendish Laboratory were challenged to think about where the next major breakthroughs may emerge, in fields as diverse as electronics and the life sciences.

'We can make significant reductions in our materials usage, but why are we not?' was the challenge put forward by **Chris Wise** of Expedition Engineering and University College, London (Fig.1). As a designer of several landmark buildings, he explained how working closely with designers and manufacturers they were able to build the 2012 Olympic Velodrome with over 6 times less energy consumed than the similar sized 2008 Beijing Olympic swimming complex. The same philosophy could be applied to structural beams used in office blocks, where a 30% reduction in material requirements can be realised by a simple re-design of the shape. He concluded that we need to master how we use materials, as did Stradivarius, and there is considerable scope for reducing material usage if we overcome inertia in industry to change and are not constrained in the design by over-regulation.

Andrea Ferrari, Director of the Cambridge Graphene Centre, provided a brief history of carbon-based materials in different dimensions. The discovery that a simple 'Scotch Tape' method was able to produce graphene, a perfect 2D array of carbon atoms, has led to an explosion in research on this material. He pointed out a number of potential advantages of graphene, providing a cautionary note that, even when performance is many times improved, it is still difficult to displace an incumbent technology. One of the key new benefits of the material is the ability to make flexible components, which is attracting considerable commercial interest.

Paul Alivisatos, Director of the Lawrence Berkeley National Laboratory, described how we have learned to make intricate and complex nanocrystals that have controlled size, shape, topology and connectivity. Through developing a 'stamp collection' of nanocrystals and applying scaling laws to understand their properties, new energy applications are being developed. He provided examples of how control of nanocrystals and the environment can be used to perform catalysis, using ideas inspired by nature.

In biology, the number of different amino acids, which are the building blocks for proteins, are limited to only 20. **Jason**



Chin, Head of the Centre for Chemical and Synthetic Biology at the MRC in Cambridge, explained how this basis set can be increased, limited by only the creativity of what people can make in the laboratory. He showed how incorporation of a new photo-active amino acid into the *C. elegans* living organism leads to the normally transparent worm becoming fluorescent. The ability to label and provide new functionality to amino acids opens up a whole new area for monitoring processes and making 'designer' proteins.

Daniel Fletcher, from University of California Berkeley, predicted that in 10 years 'it will be possible from the bottom up to completely synthesise and reassemble the components that give a cell its function'. He described the complexity associated with self-organisation of biological structures and how this is influenced not only by the ingredients but also by the boundary conditions. Studies of simple biological systems have revealed a number of lessons that control the self-organisation process and how these can be used to form an instruction set to create more complex structures.

Ben Feringa, from the University of Groningen, continued the theme of studying molecular assembly in nature to produce dynamic systems. He explained how through synthetic chemistry it has been possible to design a range of molecular switches and motors to make ultimately smart materials and systems. These demonstrators, although currently primitive, show how light and chemical based propulsion can be achieved, taking inspiration from how biological systems operate.

George Whitesides, Professor at Harvard University, addressed the challenge that universities face to convert the technology it develops into applications (Fig.2). This is particularly important if the answer to 'why we do research?' is to serve society's needs, such as job creation and solving problems related to health and national security. These applications can stem from 'curiosity-driven' or 'problem-driven' research - however the former is usually slow and risky. Another barrier to development is the increasing focus on more complex and expensive systems, whereas a simpler low cost solution is quicker to realise and more likely to be adopted. This concept of 'simplicity' was highlighted in his example of a paper diagnostic system, which is a low cost, easy-to-use device that has in six years gone from the initial idea to devices in the field.

[1] S. E. Sebastian *et al. Nature* **454**, 200 (2008).
[2] S. E. Sebastian *et al. Phys. Rev. Lett.* **108**, 196403 (2012).
[3] S. E. Dutton *et al. Phys. Rev. Lett.* **108**, 187206 (2012).

Richard Friend and Nalin Patel (pictured)

Fig.1 (left). **Chris Wise delivering the opening address.**
Fig.2 (above). **George Whitesides (left) with Richard Friend.**
Fig.3 (below). **A few of the participants interact over coffee.**

Astronomy in the Freezer – CAMELs in Greenland

Summit Station at the apex of the Greenland ice sheet, 72.6° N, 38.5° W and 3211 m above sea level, is one of the few places in the world where it is possible to carry out sensitive, photometric and spectroscopic astronomical observations at millimetre- and submillimetre-wavelengths, meaning wavelengths from 3 mm to 300 µm.

There is, however, currently no observatory at Summit Station. To take advantage of the extraordinary characteristics of the site, the Harvard-Smithsonian Center for Astrophysics (CfA) and the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) have established a joint project to place a 12 m diameter, 12 µm surface accuracy submillimetre-wave telescope at Summit Station (Figs 1 and 2). The telescope, originally developed as a prototype antenna for the Atacama Large Millimetre Array (ALMA), is being upgraded for arctic conditions (Fig.3). The project is well underway and heavy moving equipment has been shipped to Greenland to start building the snow foundation. For 2 years starting in 2016, the telescope will be sited and operated at Thule on the northwest coast prior to being dismantled and sledged at a speed of only 4 miles per hour by bulldozer to the centre of the ice cap. The plan is to reconfigure the site by reorienting the runway for the C-130s, and to place the telescope on a large pre-formed bed of ice three miles to the north of the existing base.

To make the most of the Greenland Telescope (GLT), it is necessary to develop a new generation of millimetre- and submillimetre-wave spectroscopic cameras that can operate remotely under harsh conditions. To this end the Cavendish Laboratory has entered into an agreement with CfA to deploy and demonstrate chip spectrometer technology developed in the Quantum Sensors Group. The Science and Technology Facilities Research Council (STFC) has awarded a grant to construct CAMELS, the Cambridge Emission Line Surveyor, a small imaging array of chip spectrometers operating over the frequency range 100-115 GHz. CAMELS will prototype the core technology on the telescope at Thule before an automated multi-object camera is built for Summit Station. Although our initial project is aimed at observing isotopes of CO in low redshift galaxies ($0.005 < z < 0.12$), the technology and telescope are intrinsically capable of operating anywhere in the frequency range 100 GHz to 1 THz, opening up new programmes in experimental cosmology.

The weather and atmospheric conditions above Greenland have been studied extensively in the context of understanding the impact of global warming on the ice sheet. A number of years of archived radiosonde data are available for Summit Station, which together with extensive ICECAPS radiometric data, has enabled submillimetre-wave atmospheric transmission models to be established. Fig.4 shows the atmospheric transmission at Summit Station for three levels of precipitable water vapour (PWV), and the insert shows the PWV throughout the year: the bars and boxes corresponding to the 5 - 95 % and 25 - 75 % percentile ranges respectively. The excellence of the site is apparent, with good transmission in the low-frequency windows even during the summer months.

The chip spectrometer technology being developed for the GLT is revolutionary. A superconducting Nb microstrip transmission line, 2µm wide and 600 nm high, distributes the astronomical signal to 256 micro-fabricated square open-loop filters, each of which defines a spectral channel having a resolution of about R=2500. The output of each filter feeds power into its own superconducting microwave β-Ta/NbN resonator, which acts as a detector through the Kinetic Inductance effect. The superconducting resonators operate at around 3 GHz with Q factors of 20,000. Millimetre-wave power is absorbed by the Ta, which injects excited quasiparticles into the NbN, which in turn causes the frequency of the resonator to shift. By measuring the amplitude and phase of the microwave readout signal, it is possible to record the power absorbed in a spectral channel. Typically, a power change of only 5×10^{-18} W can be detected with an integration time of 1 s. The microwave resonators are themselves connected to a single thin-film transmission line, and so a complete spectrum having thousands of spectral channels can be read off a 30 × 30 mm chip using fast digital electronics and software defined radio (SDR) techniques. Because each chip is interrogated digitally, the technology is well suited to being networked so that spectra can be viewed and observing software modified remotely in real time from the comfort of one's own living room.

Although our first generation of spectrometers is aimed solely at astronomy, the submillimetre-wave part of the spectrum is of crucial importance for atmospheric science. Numerous atmospheric absorption lines are seen in the submillimetre-wave windows used by astronomers. Chip spectrometers can be customised to observe specific lines even if they are distributed widely across several hundred GHz, and therefore chip spectrometer technology has the potential to open up new observing techniques in atmospheric science, addressing key challenges in middle-atmosphere and troposphere chemistry and dynamics. Although our current emphasis is on arctic science, the ability to deploy sensitive spectrometers to other regions of the globe may have considerable scientific importance. For example, there is a close relationship between volcanic degassing and atmospheric chemistry, and the influence of major volcanoes such as Kilauea in Hawaii, Mt. Erbus in Antarctica, Lascar and Villarrica in Chile, and Eyjafjallajökull in Iceland on local and global climatic trends has been studied extensively. We are delighted that the University has recently approved a pilot study (SPECTRO-ICE) to bring together the British Antarctic Survey (BAS), the Department of Applied Mathematics and Theoretical Physics (DAMTP) and the Cavendish Laboratory to explore how advanced technology developed in the Quantum Sensors Group might now be used to address key challenges in atmospheric science.

Acknowledgements: Special thanks are due to Dr Raymond Blundell, Dr Scott Paine, and Roberto Burgos at CfA, Dr Christopher Thomas, Dr David Goldie, Prof. Roberto Maiolino, Dr Eloy de Lera Acedo at the Cavendish Laboratory, Prof Robert Kennicutt at the IOA, Dr David Newnham and Dr Anna Jones at BAS, and Prof. Peter Wadhams at DAMTP.

www.summitcamp.org/site

Take a look at the webcam, **www.summitcamp.org/status/webcam**.
*High and Dry: New Observations of Tropospheric and Cloud Properties Above the Greenland Ice Shee*t provides a comprehensive review to date (Shupe, M.D., et. al. 2013, Bull. Amer. Meteor. Soc., 94, 1).

Stafford Withington is Head of the Quantum Sensors Group.

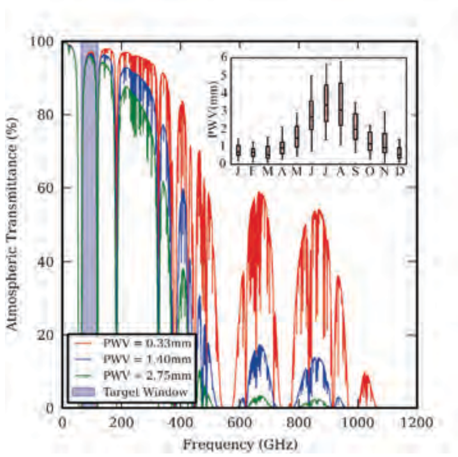


Fig.1 (left). **Tent City with halo: the accommodation block for visiting scientists at Summit Station on the Greenland Ice sheet. (Credit: Katrine Gorham)**

Fig.2 (below). **The 'Big House' at sunset at Summit Station. (Credit: Brian Nelson)**

Fig.3 (above right). **The north-American ALMA prototype is currently being upgraded for arctic conditions. (Credit: Roberto Burgos)**

Fig.4 (above). **The atmospheric transmission as a function of observing frequency at Summit Station. The precipitable water vapour (PWV) determines the transparency of the atmosphere, which is excellent during the very dry winter months.**

Cavendish News

Two Centres for Doctoral Training (CDTs) to be hosted in the Maxwell Centre


University of Cambridge academics have won six of their bids for CDT funding which is targeted by the EPSRC at areas considered to be crucial to the country's economic growth. CDTs are funded for four years and include technical and transferrable skills, as well as a research element, bringing together diverse areas of expertise to train engineers and scientists with these skills. The Cavendish is leading two of these; the **CDT in Sustainable and Functional Nano,** led by **Jeremy Baumberg**, and the **CDT in Computational Materials for Materials Science**, led by **Mike Payne**. Jeremy Baumberg is delighted, commenting that 'our high-calibre interdisciplinary student cohorts will be Nano's future leaders'.

Cavendish researchers will also collaborate with the **CDT in New and Sustainable Photovoltaics** led by the University of Liverpool and the **CDT in Integrated Photonic and Electronic Systems** in partnership with UCL.

More about Val Gibson

In *Director Magazine*, top British bosses pay tribute to the superwomen who have influenced the way we live and work today. They range from Aung San Suu Kyi to JK Rowling and the Queen. The **top 20** includes Professor Valerie Gibson nominated by Edwina Dunn, founder, Dunnhumby, and Executive Director, Starcount who states:

'Sometimes you meet people whose passion for discovery and scale of their ideas can change the way you view the world. Professor Valerie Gibson is one of those people. As an experimental physicist at CERN and the University of Cambridge, she deals with enormous sets of complex data to explore and discover things that are still unknown. The techniques she is developing will have a huge impact on the way business will understand and use data in the future, especially as everyone tries to unlock the potential of the 'big data' phenomenon.'

Hughes Medal

Henning Sirringhaus has been awarded the Royal Society's Hughes Medal for 'his pioneering development of inkjet printing processes for organic semiconductor devices, and dramatic improvement of their functioning and efficiency'. The Hughes Medal is awarded biennially for original discoveries relating to the generation, storage and use of energy; past winners have included Alexander Graham Bell and Stephen Hawking. See also:

www.cam.ac.uk/news/cambridge-scientists-honoured-by-royal-society

Henning is also the PI of a prestigious ERC Synergy grant for 'Spin-charge conversion and spin caloritronics at hybrid organic-inorganic interfaces', in collaboration with Hitachi Europe, the University of Mainz and Imperial College London.


We also congratulate **Mete Atature** (AMOP) and **Piero Cicuta** (BSS) on the awards of ERC Consolidator Grants. Mete's award is in the area of 'Photon-Spin Entanglement in Hybrid Cluster State Architectures' and Piero's in 'Hydrodynamic Synchronisation in Model and Biological Systems'.

Chris Lester – Pilkington Prize

Chris Lester, has been awarded the 2013 Pilkington Prize for excellence in Teaching. The citation states that "… he has rapidly emerged as one of the Department of Physics' most outstanding teachers. This is not only the result of an attractive personal style, but also a matter of considerable investment in preparation and careful thought about content. The key to his success is that he invariably finds new ways of interpreting and explaining concepts in physics, often relating these to the students' own experiences."

25 Years in the Saddle


We congratulate **Alan Turner (left)**, Chief Building Services Technician, **Michael Crofts (right)**, Technical Office and **Stafford Withington** (page 20), Professor of Analytical Physics (2003) on their completion of 25 years of service to the University.

New Deputy Heads of Department


Richard Phillips (left) and **Chris Haniff (right)** have been appointed Deputy Heads of Department with prime responsibilities for Finance and Resources and Education respectively. We wish them good luck in these crucial areas of the Laboratory's agenda.

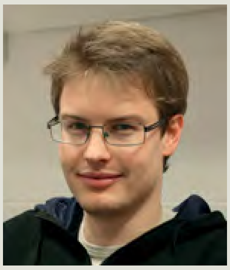
New Appointments

We are delighted to announce the following new appointments:

Sarah Bohndiek: University Lecturer in the BSS Group (see pages 8-9)
Suchitra Sebastian: University Lecturer, Winton Programme (see page 18)
Lizzie Bateman: Assistant Outreach Officer (see page 15)


Alexander Mitov (above left): University Lecturer in Theoretical High Energy Physics
Oliver Wadsworth (above right): Apprentice in Mechanical Engineering

Fellowships




Congratulations to:

Clemens Matthiesen (above left) (AMOP), who has been appointed to a Junior Research Fellowship at Clare College, and **Yvette Perrot** (above right) (AP), who has been appointed to a Junior Research Fellowship at Trinity College.

Internal Promotions

David Taylor moves from Group Administrator (TCM) to Rutherford Physics Education Project Administrator.
Charlotte King moves from Central Administration to Group Administrator, HEP.

Departures

We wish **Jenny Clark**, who was Dorothy Hodgkin Fellow in the OE Group, and **Felicity Footer**, former HEP Group Administrator, best wishes for the next stages of their careers.

Ray Dolby 1933–2013

Members of the Laboratory will have learned with sadness of the passing away of Ray Dolby, the inventor of the Dolby Noise-reduction system for audio recording and reproduction.

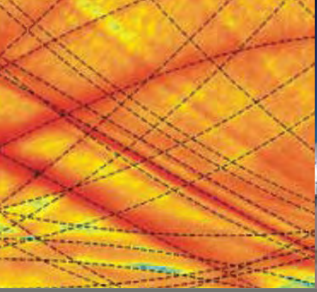
In 1957, he received his B.S. in Electrical Engineering from Stanford University. He then won a prestigious Marshall Scholarship to study for a PhD in physics at the Cavendish Laboratory. He was a member of Pembroke College and was subsequently awarded a Research Fellowship by the College. He was absolutely delighted by his Research Fellowship and, above all, by his panelled rooms in Pembroke.

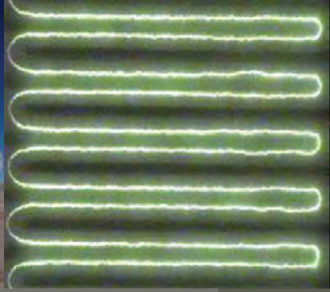
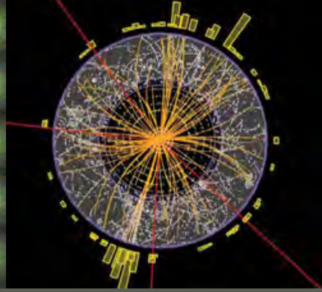
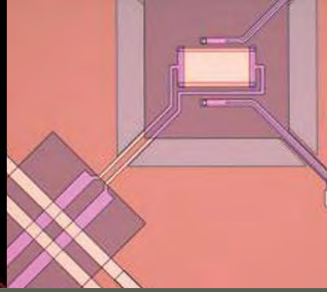
He worked in the Electron Microscope Group, situated in the Old Cavendish Laboratory in Free School Lane, under the supervision of its head, Ellis Cosslett. His PhD thesis concerned the X-ray spectroscopy of carbon, a material of great importance in materials science and yet very difficult to detect at the time because of the weakness of the X-ray signal involved. Under Cosslett's guidance and with friendly exchanges within the group, he found a means of extracting this tiny signal from the 'noise' from other X-rays. This was one of the spurs for his interest in audio noise reduction. He was interested in audio before he left Cambridge and demonstrated with pride his Quad loudspeakers in his rooms in Pembroke. He was awarded his PhD in 1961.

From 1963 to 1965, he was United Nations Technical Advisor and helped set up the Central Scientific Instruments Organisation in India. In 1965 he created the Dolby Laboratories in a South London, later also in San Francisco, to develop noise reduction and signal processing systems for improving sound quality. In this venture, he was strongly supported technically by his brother Dale. The Dolby noise-reduction system works by increasing the volume of low-level, high-frequency sounds during recording and correspondingly reducing them during playback. This reduction in high-frequency volume reduces the audible level of tape hiss. The Dolby noise reduction technologies have become an essential part of the creative process for all recording artists and filmmakers. Dolby was awarded an Honorary Degree of Doctor of Science by the University of Cambridge in 2000.

We send our most sincere condolences to his wife Dagmar and their family, recalling the high regard in which he is held in Cambridge and the deep friendships which he formed during his years here.

Malcolm Longair, compiled from the reminiscences of Ray Dolby's many friends from his Cambridge years.

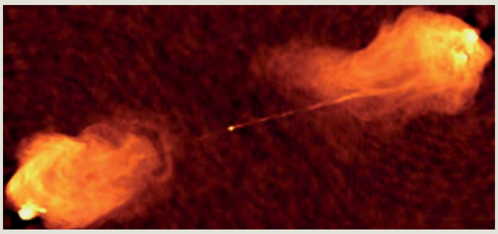


Welcome to Chris Carilli

We are delighted to report the appointment of Chris Carilli as a part-time Director of Research in the Cavendish Astrophysics Group. Chris is the Observatory Chief Scientist at the National Radio Astronomy Observatory in the USA which operates the most powerful radio astronomy facilities in the world, namely, the extended Very Large Array (seen in the picture above), the Very Long Baseline Array, US operations of ALMA and the Robert C. Byrd Green Bank Telescope. Chris is one of the world's leading radio astronomers and will spend about 20% of his time in Cambridge. His name is particularly associated with the superb radio image made of the radio source Cygnus A which reveals many of the astrophysical problems facing the high energy astrophysicist.

Recently, Chris has been searching for the cosmological signal from neutral hydrogen in the early Universe through the development of the Precision Array to Probe the Epoch of Reionisation (PAPER) in the Karoo region of South Africa.



Left: **The radio source Cygnus A as observed by the VLA, showing the nucleus, which contains a supermassive black hole, and the narrow jets which power the outer radio structures (©NRAO).**

How you can contribute

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

Online Giving

The University's Office for Development and Alumni Relations (CUDAR, formerly CUDO) 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:

www.campaign.cam.ac.uk/giving/physics

If you wish to support the graduate student programme, please go to:

www.campaign.cam.ac.uk/giving/physics/graduatesupport

If you wish to support our outreach activities, please go to:

www.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 at:

www.phy.cam.ac.uk/development

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:

www.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 will be very happy to suggest suitable forms of words to match your intentions. Please contact either Professor Malcolm Longair (**msl1000@cam.ac.uk**) or Mr. Robert Hay (**rach2@cam.ac.uk**) who will be very happy to speak to you confidentially.

Contacts

The Cavendish Laboratory
JJ Thomson Avenue
Cambridge
CB3 0HE

Tel: +44(0) 1223 337200
Fax: +44(0) 1223 363263
E-mail: hod@phy.cam.ac.uk
www.phy.cam.ac.uk

Head of Department
Professor Andy Parker
Tel: 01223 337429
E-mail: hod@phy.cam.ac.uk

Director of Development
Professor Malcolm Longair
Tel: 01223 765953
Email: msl1000@cam.ac.uk