UNIVERSITY OF CAMBRIDGE

JANUARY 2015
ISSUE 13

CAVMAG

News from the Cavendish Laboratory

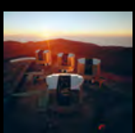
MOONS: the Next Generation Spectrograph for the Very Large Telescope

After 6 years and 12 issues, our graphic designer Matt Bilton and I decided that we should freshen up the design of CavMag, in keeping with the practice of most journals. We aim to keep the content at as high a level of interest as before, but with the ability to try out some experiments. In this edition, we experiment with instructions for an origami Kapitsa crocodile, with a suitable "brick" effect insert, inspired by the DNA origami described by Ulrich Keyser in CavMag 9 and in a further essay in this issue by Kerstin Göpfrich. Be warned, this is a significant paper-folding challenge!

We always welcome suggestions for interesting articles and for information about alumni, their distinctions and achievements. On behalf of everyone in the Cavendish, we wish readers a Very Happy and Prosperous 2015.

Malcolm Longair

INSIDE



Cover image:
Aerial view of Paranal Observatory

Maxwell Centre On-site Construction Begins

Work has begun on the £26 million Maxwell Centre. To mark the beginning of on-site activities, an opening event was hosted by the contractors SDC Builders Ltd. As is apparent from the picture, excellent progress has been maintained towards a completion date in the last quarter of 2015. Once completed, the building will offer laboratory and meeting spaces for more than 230 people.

The new facilities will result in research scientists from industry occupying laboratory and desk space alongside members of the collaborating Cambridge research groups, with the aim of creating a two-way flow of ideas and exposing the best early career researchers to scientific problem-solving that relates directly to industrial needs.

At the event, Richard Friend, Cavendish Professor of Physics, who will be the first Director of the Centre, said: "This building will affect how we work together and promote the free-flow of ideas, providing the right sort of meeting places for people to generate innovative research. The Maxwell Centre design means it is a building that brings in other departments such as Chemistry and Material Sciences. It will also very much promote engagement with industry, large and small, showing that we recognise industry as a source of intellectual innovation". ■

ABOVE: Some of those involved in the design and construction phase of the Maxwell Centre project. In the front row, from left to right, Angus Stephen (Director of Operations, Estates Management), Andy Parker (Head of Cavendish), Malcolm Longair (Cavendish Director of Development), Francis Shiner (Managing Director of SDC Builders Ltd) and Richard Friend (Cavendish Professor and Director of the Maxwell Centre).

Chris Carilli – John Baldwin Director of Research

In CavMag11, we were delighted to announce the appointment of Chris Carilli in a part-time capacity as Director of Research in the Cavendish Astrophysics Group. We are pleased that this position has been designated the John Baldwin Directorship of Research, in honour of the late John Baldwin who pioneered many advanced techniques in radio, infrared and optical astronomy.

Chris Carilli is a world leading radio astronomer, exploring the radio Universe from the Milky Way to the most distant galaxies. He was a PhD student at the Massachusetts Institute of Technology, where he performed definitive work on the physics of the archetypal powerful radio galaxy, Cygnus A. His postdoctoral work at the Harvard-Smithsonian Center for Astrophysics, and at Leiden University, extended these studies to the most distant galaxies known at the time, namely, the high redshift radio galaxies.

Since his student and postdoc years, Chris has been an astronomer at the US National Radio Astronomy Observatory. For the last 6 years he has been the Observatory Chief Scientist. Chris has been instrumental in defining the science programme and design of major radio facilities, such as the Jansky Very Large Array, the Atacama Large Millimetre Array, and the Square Kilometre Array. His edited volume, *Science with a Square Kilometre Array*, with the late Steve Rawlings of Oxford University, has stood for over a decade as the standard reference for setting the scientific programme for the next generation of mega-radio facilities. Likewise, the edited lectures on *Synthesis Imaging in Radio Astronomy II,* with G. Taylor and R. Perley, remain the standard textbook for radio astronomy schools worldwide.

Chris's current research focuses on the formation of the first galaxies in the Universe. Using centimetre and millimetre telescopes, Chris is investigating the evolution of the cool gas and dust component of galaxies within 1 Gyr of the Big Bang. These constituents represent the fuel for star formation in galaxies, driving the formation of the earliest generation of stars within galaxies.

In parallel, Chris is a pioneer in the area of *HI 21cm cosmology*. This rapidly emerging field entails using the 21cm emission line of neutral hydrogen atoms to observe the evolution of large scale structures in the Universe during the epoch of cosmic reionization, and the preceding dark ages. During these epochs, the first galaxies emerged from the diffuse intergalactic gas that pervaded the early Universe. He is involved with a team that has constructed a novel low frequency telescope in the Karoo desert of South Africa to perform the first measurements of the HI signal.

In 2005 Chris was honoured with the Max Planck Research Award, awarded jointly by the Humboldt Society and the Max Planck Society. Chris was also a visiting Humboldt Fellow in Bonn in 1999. We are delighted to have Chris as a member of the Astrophysics Group where he will support many of our activities in radio astronomy and cosmology. ■

Cavendish Kinetics – From Fundamental Research to Mobile Phones

CHARLES SMITH describes the tortuous route from fundamental physics to commercial products with the potential to be used in billions of mobile phones.

Can research into the understanding of low temperature quantum phenomena result in applications that could improve the quality of life of the wider community? There are obvious cultural benefits from knowing how the universe works, but can this type of fundamental research have more tangible rewards that could have a positive impact on our day to day activities?

My research involves investigating how carrier transport in conductors and semiconductors changes as they are made extremely small. The computer chips in mobile phones and laptops now have billions of devices on a chip of silicon a few millimetres on a side. To fit these in, the smallest feature sizes can be so small that a million devices side by side would fit in a length of just 11mm. Every two years the minimum device size shrinks to allow two times as many devices to fit on a chip of the same area making them faster and cheaper. The technological advances which have revolutionised the semiconductor industry over the last 40 years are used by the Semiconductor Physics Group for studying quantum phenomena where the wave nature of matter becomes important when the devices are cooled to 50 mK, close to absolute zero (Fig 1). This technique was pioneered by the former Group Head, Michael Pepper, and is now used in hundreds of research laboratories around the world to investigate quantum phenomena in solids.

A number of years ago I was making small metal bridges across a man-made Lilliputian canyon to study the quantisation of thermal properties. Ten million of these bridges set side by side would fit in 1mm and they spanned a gap one hundred times bigger than their width. At the extremely low temperature of only 300 mK above absolute zero, the thermal properties become quantised as only an integral number of lattice vibrations can fit within the wire (Fig. 2). It was while performing this research that I became interested in the idea of turning these structures into simple metal switches. I wondered how such a device would perform in comparison with the semiconductor devices used to perform binary logic computations in all semiconductor computer chips manufactured today. I made some simple estimates concerning how a metal switch would behave when shrunk to these nanoscale dimensions and to my surprise I discovered that their small mass and reduced spring constants meant that such a switch could be operated at low voltages and at very high speeds. This could provide a simple low power switch, which if designed correctly, could be made bi-stable. When manufactured into an array it could have applications for storing information with the advantage of being faster to program and erase and consume lower power.

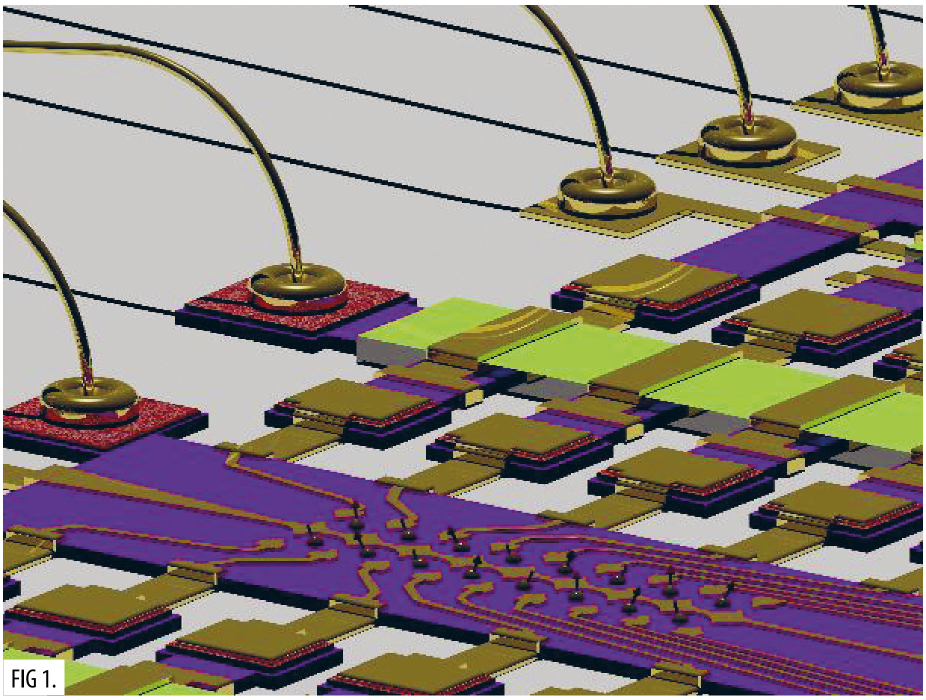


FIG 1.

> " As an academic, I was faced with a difficult choice. Either I could publish this idea and allow others to follow it up, or I could take the plunge and try to patent and develop the idea myself. "

As an academic, I was faced with a difficult choice. Either I could publish this idea and allow others to follow it up, or I could take the plunge and try to patent and develop the idea myself. I decided to take the second option, and with help of Cambridge Enterprise and local venture capital support I patented the idea and started Cavendish Kinetics Ltd to commercialise the technology. Preliminary research continued in the laboratory, and by 2001 I managed to raise a significant level of funding to set up a research team in the Netherlands. This team started developing a recipe that would allow metal switches to be fabricated in their own minute cavities using existing technology in use in leading semiconductor processing factories. In 2007 a second round of funding led to the setting up of a larger development activity in a facility in San Jose and the movement of the head office to California.

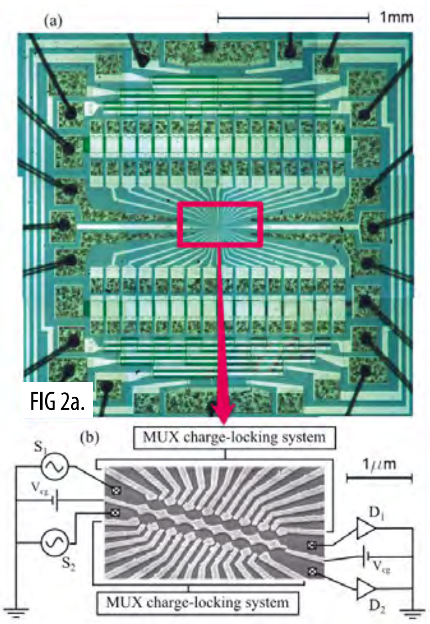


FIG 2a.

FIG 2b.

I did not realise when I started Cavendish Kinetics what a huge undertaking this would be. But now, after many years of development and many millions of dollars of investment and also a change in product application, the company has transferred its processing technology to our partner fabrication company Jazz Semiconductor who fabricate the digital variable capacitor product for us. Essentially this product consists of many small metal flaps that have two positions, allowing each one to have two different capacitance values. These metal flaps can switch more than 50 billion times without any degradation of performance allowing a finely controlled variable capacitor to be made. The capacitors work extremely well at high frequencies where their very high quality factor and low distortion are key selling points. Luckily for Cavendish Kinetics the billion high end mobile phones that are made every year are now required to tune through many different frequencies to allow fast data transfer, and as there is not space for many different antenna in a phone, tuning capacitors are required. Cavendish Kinetics 32 state digital variable capacitors are now starting to be incorporated into mobile phones[1] and will be appearing first in the ZTE mobile phone in China. The potential market for this product is several billion dollars.

Thus because of ideas stimulated by fundamental research performed in the Cavendish into quantum phenomena occurring close to absolute zero, a growing number of mobile phone users will be able transfer data to and from their phones with lower power consumption leading to a longer battery life and fewer dropped signals. So the answer to the question I originally posed is 'yes': research does not need to be focussed closely on existing commercial technologies - fundamental studies can also lead to products with commercial value.

I am not sure what to advise those who find themselves with a potentially commercial product spinning out of their research. There are many down sides, including the high risk of failure, the need to seek venture capital funds and to focus on the financial side to the exclusion of most other considerations. In my own experience I had to endure 4am starts to visit the office in the Netherlands, long trips to San Jose and late night conference calls. However, it has been a tremendous adventure and taken me far out of my comfort zone. I have enjoyed the learning that comes from watching an engineering team of over thirty engineers tackle problems in weeks that would take years in the laboratory. At least here in the Physics department I can now spend more time focussing on understanding the underlying physics and who knows what that may lead to? ■

[1] www.cavendish-kinetics.com

CAVENDISH KINETICS

FIG 1. shows an artist's impression of the lines of single electrons where the interactions of the electron spins can be studied and resemble lines of artificial atoms forming an artifical crystal. (Art work by Dr Reuben Puddy)

FIG 2a. shows a multiplexer or MUX which allows multiple electrodes to be addressed on a GaAs sample at 100mK to trap lines of single electrons.

FIG 2b. shows a close up of the fine electrode structure in the middle of the chip (arXiv:1408.2872).

Flying UAVs above SKA antennas at Lord's Bridge

In September 2014, a group of us from the Astrophysics Group spent a week at the Lord's Bridge Observatory performing a set of tests on the latest Square Kilometer Array antennae, designed here at the Cavendish Laboratory, using a revolutionary technique based on flying an artificial signal source onboard a small hexicopter vehicle, known as a Unmanned Aerial Vehicle, or UAV, writes ELOY DE LERA ACEDO.

The Square Kilometre Array (SKA) will be the largest and most powerful radio telescope in the world at metre and centimetre wavelengths. Phase I of the SKA telescope will be located in remote areas of Western Australia (SKA-low and Survey instruments) and of the Karoo desert in South Africa (SKA-Mid instrument). One of the main science experiments of its lowest frequency collector system (50 to 350 MHz) is to observe neutral hydrogen in the very early universe, in particular the elusive Epoch of Reionisation. Here the emission from hydrogen atoms at 1420 MHz in their rest frame is redshifted to frequencies less than 100 MHz. The required sensitivity to detect such a weak signal at these frequencies requires a very large collecting area in order to overcome the high sky brightness below 150 MHz. The most practical way of achieving this is by using large numbers of phased array antennae.

The development of the SKA is technically very challenging for most aspects of the system: processing, data volumes, cost etc. The low frequency phased array, SKA-low, is no exception. The element and array design need very careful and innovative thinking in order to meet the specification. The Cavendish Laboratory has led the design of both the antenna elements and the Low Noise Amplifiers that will form the front end of this mega telescope. With more than 250,000 antennas in phase I and up to at least 3,000,000 antenna elements for Phase II, the SKA-low will be, by the time of the completion of Phase 1 in the early 2020s, the most sensitive telescope on Earth at MHz frequencies.

The Cavendish Laboratory is involved in several of the consortia undertaking the design of the SKA. Paul Alexander is the SKA Project Scientist at Cambridge and the UK scientific member of the SKA board of directors. He also leads the Science Data Processing Consortium. Furthermore, a group of us, Eloy de Lera Acedo (antennae and low noise radio receivers], Nima Razavi-Ghods (RF receivers), Edgar-Colin Beltran (EM modeling), Jack Hickish (Digital receivers), Paul Scott (radio astronomy instrumentation) and Andrew Faulkner (Low Frequency Aperture Array Project engineer) are involved in the Aperture Array Design & Construction consortium, which is in charge of the development of the Aperture Arrays for the SKA-low instrument. Within the consortium, a group of research institutes and Universities in Italy (INAF, CNR-IEIIT and Politecnico de Torino) have developed an innovative technique for measuring the beam patterns of our prototype radio telescopes using a radio controlled hexacopter system. The Italian participation in the AADC consortium is led by Jader Monari and the team that came to Cambridge was led by Giuseppe Virone, Pietro Bolli and Giuseppe Pupillo.

Our team of engineers and technicians, Clive Shaw, Ian Northrop, John Ely, Peter Doherty, Robert D'Alessandro, and Dave Hammett, built a prototype array for the SKA at the Mullard Radio Astronomy Observatory at Lord's Bridge in 2012 (Fig. 1), which has since served to test and validate the designs that have led to what is now the antenna for the SKA-low instrument. Aperture Array Verification System 0 (AAVS0) consists of 16 SKA antennas arranged in a pseudo-random configuration, sitting on top of a metallic ground plane. Each antenna has 2 low noise amplifiers, one per polarizsation, which are connected to a rack of analogue receivers, developed here at the Laboratory and to a digital back-end, developed at ASTRON in the Netherlands. The prototype radio instrument was upgraded during the summer of 2014 (Fig. 2) with new antennae and receivers as well as a new concrete foundation and a digital back end. This system allows us to form beams on the sky similar to those that will be formed by the SKA stations, which will each employ 256 antenna elements.

The tests consisted of flying a small Unmanned Aerial Vehicle (UAV) equipped with a constant wave signal source that emitted at the desired frequency. A differential GPS, gyroscope and communications system was used to control the orientation and position of the vehicle within 2 cm and the embedded transmitting antenna (Fig. 3). This signal was received by the array. The hexacopter system was also used to map the exact positions of the antennae in the array with the help of an optical system based on theodolites.

Fig. 4 shows the UAV flying over the array as well as some of the preliminary results. The modeling and calibration of the array,

FIG 1.

FIG 2.

the position of the hexacopter and the radio link are essential to understand the results of the experiment. This technique is now used for the characterisation of aperture arrays in the SKA and it is being further developed to help with the calibration of the SKA stations (FIG 5). The hexacopter team will be back in Cambridge in 2015 to tests the new antennas, amplifiers, optical links and receivers being developed for SKA.

We were supported by the IT team of David Titterington and Greg Willett during the week of tests. The Astrophysics Group senior administrator, Karen Scrivener, did a wonderful job in facilitating the work in the field and during the development of the instrument. ■

FIG 3.

FIG 4.

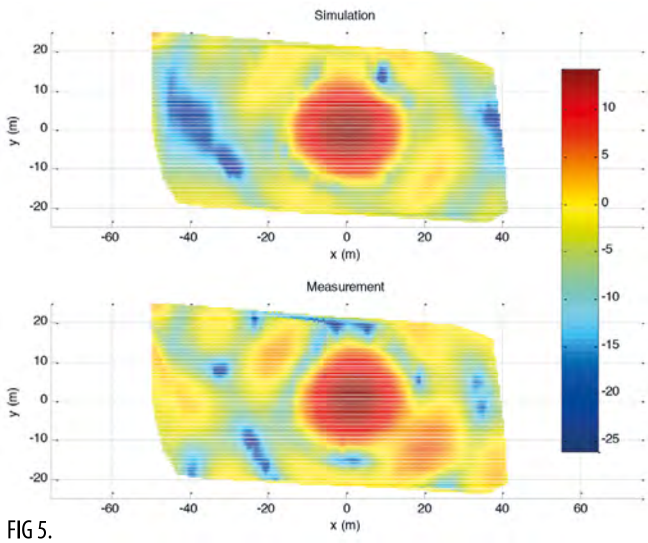


FIG 5.

FIG. 1. AAVSO array when built in 2012 at the Lord's Bridge Observatory.

FIG. 2. The upgraded AAVSO array with the combined Cambridge and Italian team that performed the tests in September 2014.

FIG. 3. The hexacopter with its dipole transmitting antenna.

FIG. 4. Hexacopter flying over the AAVSO array.

FIG 5. Comparison of the measured (top) and simulated (bottom) array beam patterns before calibration.

MOONS: the Next Generation Spectrograph for the Very Large Telescope

ROBERTO MAIOLINO introduces the next major instrumental project to be undertaken by the Cavendish Astrophysics Group.

On September 26th 2014 the European Southern Observatory (ESO) officially approved and funded the construction of MOONS, a next generation optical/near-infrared multi-object spectrograph for the Very Large Telescope (VLT), a major astronomical facility consisting of four telescopes, each of them 8.2 m in diameter, located in northern Chile (see front cover). MOONS will have unprecedented capabilities, enabling astronomers to obtain the spectra of 1,000 astronomical objects *simultaneously*, over the whole wavelength range from 0.7 µm to 1.8 µm. This is a major leap forward relative to traditional single slit spectrometers, which generally can only observe a few objects per night. During its ten-year design lifetime, MOONS is expected to observe of the order of ten million objects.

The wavelength coverage which extends into the near-IR wavebands will enable astronomers to observe some of the most prominent nebular emission lines and stellar absorption features in distant galaxies, mostly in the redshift range $1 < z < 4$. At such redshifts, these features are redshifted beyond the wavelength range typically accessible to classical optical spectrometers. By obtaining the spectra of millions of galaxies it will be possible to determine the three-dimensional distribution of galaxies in large volumes of the Universe, similar to what has already been achieved in the local Universe (Fig. 1). The big difference is that the redshift range $1 < z < 3$ corresponds to the epochs when the bulk of the stars in galaxies were formed. For each of these galaxies, MOONS spectra will enable us to measure important physical quantities such as the rate at which their stars are being formed, the ages of their stellar populations, their chemical enrichment, their stellar masses, and the presence of accreting supermassive black holes. The huge statistics delivered by MOONS will enable us to investigate how these physical properties have evolved with cosmic epoch and how they are affected by the environment in which galaxies are found, for example, in regions with high density of galaxies, in interacting galaxies, in voids and so on. This information will shed light on the primary mechanisms responsible for galaxy formation and evolution throughout these cosmic epochs.

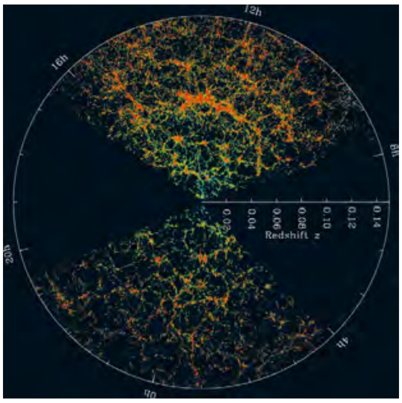
> “ The Cavendish Laboratory is heavily involved both in the construction and in the scientific exploitation of MOONS. ”

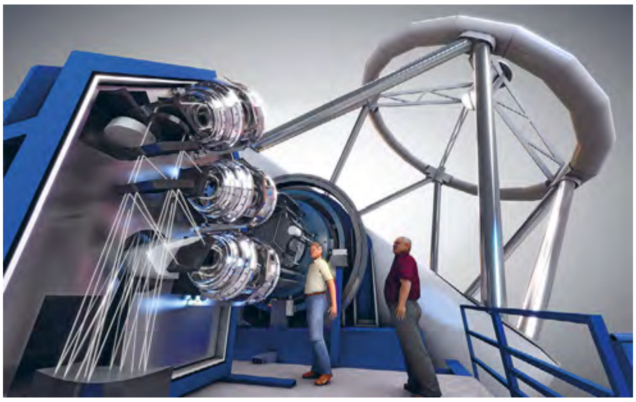
MOONS will also be capable of taking the spectra of millions of stars in our own Galaxy by providing detailed information on their velocity distributions and chemical properties. The near-IR bands are much less affected by obscuration by interstellar dust than the visible light bands. As a consequence, MOONS can penetrate deeply into the dusty disk of our Galaxy and provide spectra of stars at large distances through the disk and into the inner part of the Galactic bulge, which is inaccessible with classical optical spectroscopy. These spectra will allow us to obtain an unprecedented map of the structure and chemical enrichment history of our Galaxy, hence providing further key information for understanding the formation and assembly processes of our own Galaxy.

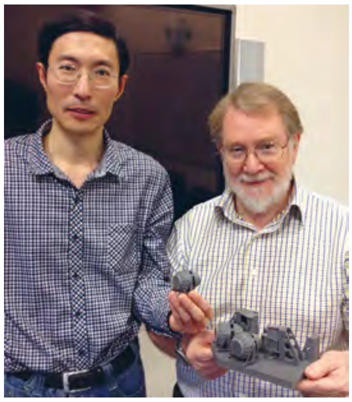
The Cavendish Laboratory is heavily involved both in the construction and in the scientific exploitation of MOONS. Members of the Astrophysics Group of the Laboratory, in particular, Martin Fisher, David Sun, David Buscher, Chris Haniff, and Ian Parry of the Institute of Astronomy, will be responsible for designing, assembling and testing some key subsystems of the spectrograph which require extremely high accuracy. The Laboratory also hosts the Project Scientist of MOONS, Roberto Maiolino, who is responsible for defining the instrument scientific requirements and for planning the optimal observing strategy.

An artist's impression of MOONS at the VLT is shown in Fig. 2. The light from astronomical objects will be collected through 1000 optical fibres deployed at the focal plane of the telescope and these are moved by 1000 mini-robots. Each of these robots has to position the fibre on the image of an astronomical object with an accuracy of 20 μm within a few seconds, without clashing with the other robots. The light of the astronomical objects is taken by these fibres to two twin cryogenic spectrographs, each as large as the size of a van and weighing a total of about 5 tons. Inside the spectrograph the light is split by dichroics into three channels, each of them optimised for a specific wavelength range. The Cavendish Laboratory is responsible for delivering the spectrograph cameras, which are the three big, 'barrel-shaped' systems shown in Fig. 2. These three cameras have stringent requirements in terms of accuracy of their optical alignment and stability. A miniature 3D model of the spectrometer is shown in Fig. 3.

MOONS will cost a total of €23m and involves a consortium of about 40 scientists from six countries - UK, Italy, France, Switzerland, Portugal and Chile - led by the UK Astronomy Technology Centre at the Royal Observatory Edinburgh. It will be commissioned at the telescope in 2019. ■







MOONS basic properties	
Number of astronomical objects whose spectra are observed simultaneously	**1,000**
Patrol field	**500 square arcminutes**
Simultaneous spectral coverage	**0.7 µm < λ < 1.8 µm**
Spectral resolution (R=λ/Δλ)	**Low resolution mode: R=4000-6000** **High resolution mode: R=20000**
Sensitivity (H-band at 1.65 µm, 1hour, 5σ)	**AB magnitude = 22.7**

FIG.1 (left) The three-dimensional distribution of galaxies in the local universe mapped by optical spectroscopy of millions of local galaxies. By accessing the near-IR spectral bands, MOONS will be capable of obtaining a similar three-dimensional map at redshifts $1 < z < 3$, corresponding to the epoch of maximum star formation in galaxies.

FIG. 2. (middle) An Artist's impression of MOONS at the VLT. The structure at the back hosts the positioners of the fibres at the focal plane of the telescope. The large structure in the front is one of the twin spectrometers, hosting the three cameras that will be delivered by the Cavendish Laboratory.

FIG.3. (right) David Sun (left) holding a 3D model of one of the cameras (weighting 250kg) being designed by the Laboratory. Martin Fisher (right) holds the 3D model of the whole spectrograph, weighting a few tons.

Global Challenges for Science and Technology

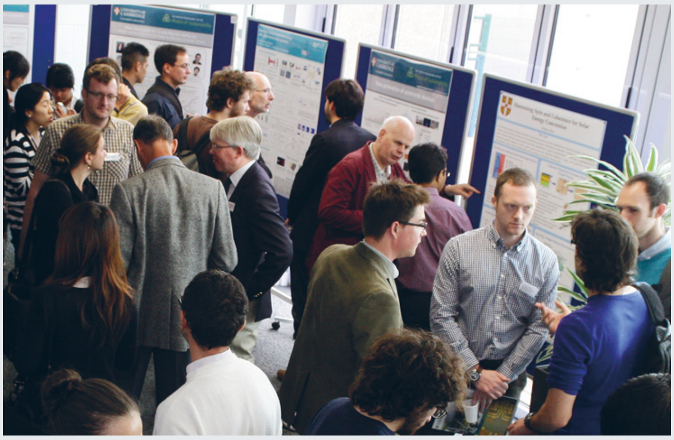
The 3rd Winton Symposium was held on 29th September 2014 at the Cavendish Laboratory, on the theme 'Global Challenges for Science and Technology'. Introducing the Symposium, RICHARD FRIEND noted that the two previous Symposia had addressed what basic science may provide to take us to a more sustainable future, but this year's Symposium was directed more to examples and opportunities for real impact. Richard and NALIN PATEL report on the Symposium.

Joseph Heremans from Ohio State University was tasked with providing a 'core' science talk on 'Solid State Heat Engines and Waste Management'. The motivation of his talk was that 93% of energy comes from thermal processes – so any improvement in the efficiency of heat engines can make a significant impact. He described how thermoelectric heat engines have no moving parts and so are robust and have high specific power. Their main drawback is lower efficiency compared to conventional heat engines, but they can be used to scavenge 'waste heat' that is hard to use with conventional systems, such as heat in automobile exhausts. He reviewed how improvements in performance of standard thermoelectric materials have been made by engineering the electronic and vibrational properties of semiconductors and semimetals. More recently new opportunities have been realised through harnessing the role of electron spin in thermoelectric systems, termed spin caloritronics. The knowledge this has generated provides new opportunities to revisit how thermoelectrics could be optimised in the future.

Nina Fedoroff, Evan Pugh Professor at Pennsylvania State University, talked about 'Food and Civilisation' and challenged the audience to think about what are the scientific and technological advances that will be needed to feed a population of ten or more billion people. She described how in the last two centuries three key scientific developments; artificial fertilisers, genetics and the internal combustion engine have had a profound impact on our ability to feed a population which has increased from 1 billion to 7 billion. To meet our future needs, a different approach will be needed which considers multiple aspects of people, water, energy, nutrients and the environment. This will necessitate continued development and investment in technology including genetically modified crops - still a major source of debate, despite the body of scientific data that indicates they are not per se any riskier than conventional breeding technologies. She closed her talk by providing her opinion on feeding the growing population, 'I think we can do it. Will we? I don't know.'

Simon Bransfield-Garth's talk 'Empowering the rural African consumer', recounted the practical learning gained from delivering electrical power in Africa. He is CEO of Azuri Technologies which is commercialising solar based energy solutions. For the technology to be commercially viable the company had to answer two questions; can they make it and does anyone want it, and he talked about how they managed to decouple the two and focus on the latter issue. The 1.3 billion people without access to grid electricity currently obtain basic lighting needs through expensive and harmful kerosene lamps. Solar lighting systems (solar panels, storage batteries and LED lamps) are available and provide cheaper lighting, but the high up-front cost constrains deployment. The PayGo solar system Azuri developed provides customers with lighting and phone charging with a small initial installation fee and then weekly purchase of access. This reduces lighting costs and brings a range of additional benefits; businesses can operate for longer, children can study in the evenings and the removal of kerosene lamps improves their health. Simon concluded his talk by challenging the audience to think about how to use new technology and energy to enable individuals in the developing world to meet their aspirations.

Winston (Wole) Soboyejo, Professor at Princeton University, spoke about 'New Frontiers in Materials for Global Development: From Health to Energy and the Environment'. Some of the content of the talk stemmed from his experience over the past four years in setting up the Nelson Mandela Research Institutes in Africa. The question he has tried to answer is how his work makes a difference to people. One of the challenges for scientists is to think holistically with an integrated effort required that brings together scientists from different disciplines with business people, developers and the stakeholders. He provided a number of examples from his work of how science can have an



Richard Friend and Joseph Heremans

impact, including the use of magnetic nanoparticles for targeted drug delivery, a mobile phone-based medical imaging device and a low cost filtration system to produce drinking water. He noted that sustainable solutions must empower people to use science and technology to address their own needs, as solutions that are simply imported from across the world lack the local knowledge base to succeed. He encouraged scientists to think about making real partnerships where everyone can make a contribution.

Richenda van Leeuwen, Executive Director of the Energy Access, Energy and Climate Programme at the United Nations Foundation spoke on 'Towards Sustainable Energy for All'. This work promotes one of the aims of the UN to support sustainable development with the recognition that energy provision is an essential component to this. Richenda explained how the UN Secretary-General Ban Ki-Moon launched the Sustainable Energy for All initiative with three objectives to be met by 2030; ensuring universal access to energy, doubling the global rate of improvement in energy efficiency and doubling the share of renewable energy. The UN Foundation supports these goals through engagement with the public and policy makers, as well as operating a network of over 1,000 companies and NGOs that have cutting edge technologies that are seeking solutions that are affordable and sustainable. She provided a number of examples of market-based innovations that embraced scientific advances with problem solving. When asked if we could solve the problems with today's technology, her response was 'Yes' but this could become much easier with new discoveries although it was hard to predict in which field and when these advances will take place.

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

Ajay Sood, Professor at the Indian Institute of Science in Bangalore, provided the closing remarks for the symposium. He noted the talks covered a vast range of topics, and how the event sensitised us to many issues we do not normally think about. Solutions have to be a mix of technology and lifestyles and concluded by asking the audience to think about how we can all contribute to global challenges and leave a brighter future for coming generations. ■

* www.gov.uk/government/publications/the-global-calculator

DNA Origami – Folding on the Smallest Scale

KERSTIN GÖPFRICH describes origami from the macroscopic to the molecular level where the structures can be used to create ion-selective channels for applications in cell biology. At the same time, she challenges readers to build their own origami crocodile, but not at the molecular level.

From a physicist's perspective it is fascinating to observe complexity arising from simple rules. Origami, the Japanese art of paper folding, is one example. Virtually any shape has been created by just folding and turning a piece of paper. While we are familiar with paper planes and cranes, it is hard to believe that shapes like the beetle by Robert Lang (Fig. 1) are made from just one piece of paper, without scissors or glue.

FIG 1.

Working in the Cavendish Laboratory in 1953, James Watson and Francis Crick discovered the simple rules which we use today to fold objects on a much smaller scale. The specific base pairing of DNA allows us to create arbitrary two and three-dimensional shapes. Billions of virtually identical nanostructures can be created with the help of computer-aided design tools (caDNAno) that calculate customised DNA sequences. These sequences are synthesised commercially, and by mixing and heating them, they self-assemble into the designed shape. While DNA origami has been used to create various artistic nanoscale shapes as a proof of principle, the subject is now at the exciting transition to practical applications. Ideas are diverse, ranging from DNA rulers for super-resolution microscopy and scaffolds for the assembly of carbon nanotubes, as patented by IBM, to customised single-molecule sensors demonstrated by Ulrich Keyser's group (see CavMag 9). As a biodegradable and biocompatible material, DNA origami is a prime candidate for medical applications.

Here we describe our creation of small channels from DNA origami. Channels are essential components of the membrane of every living cell. They serve as selective gatekeepers, enabling signal transduction or the transport of nutrients. Many genetic diseases are caused by defective channels in cells and fifty percent of the currently used drugs target these channels. Artificial channels can thus not only mimic fundamental transport processes, but potentially also serve as novel therapeutics. Using the DNA origami technique, we can design versatile channel architectures spanning biologically relevant diameters from sub-nanometres, like ion-channels, to larger pores mimicking natural porins (Fig. 2). We have shown that strategically positioned hydrophobic tags can guide the self-assembly of DNA-based channels into the lipid membrane[1,2,3]. Interestingly, even the simplest DNA-channel architectures, such as the four concentrically arranged DNA duplexes shown in blue in Fig. 2, exhibit multiple voltage dependent conductance states reminiscent of voltage-gating ion channels. Such simple DNA-channels can be assembled within minutes without specialised lab equipment. By exploiting DNA chemistry, we aim to create ion-selective channels that switch from a closed to an open state in a controlled manner. If these channels are targeted to a specific body tissue, they could be used to deliver and release payloads of drugs or to excite electrically active cells, like neurons or cardiac cells.

'One day, origami might even save a life' proclaims the origami artist Robert Lang. Maybe, the same will be true for DNA origami.

We had the chance to share the fascination for the art of folding paper and folding DNA in a short film which we wrote and produced, thanks to the generous support of the Winton Programme for the Physics of Sustainability and 'Cambridge Shorts'. For this film, Gabrielle Chan, a talented maths undergraduate, folded the origami crocodile with remarkably similar features to the Cavendish crocodile shown in Fig. 3 (original design: Patricio Tomic). Driven by the question 'How do you fold DNA into the shape of a crocodile?', the film takes us on a journey from the Old Cavendish Laboratory where the structure of the DNA double helix was discovered to today's Cavendish Laboratory. It is a journey through the macroscopic world of paper origami and the microscopic world of folding DNA.

After its premier in the Arts Picture House, 'DNA Origami – folding on the smallest scale' is now available on Youtube (http://youtu.be/tk4FCcX78E0) and has been transformed into a TEDEd lesson (http://ed.ted.com/on/IXN5mtsM). We hope to reach out to high-school students to show just how diverse and creative physics and physicists can be. Inspired by the idea of DNA origami, Gabrielle is now making miniature paper origami (https://gabigami.wordpress.com) - and we gladly accepted the challenge of creating the Cavendish crocodile from DNA. ■

References:
[1] Burns, Göpfrich, et al. Angewandte Chemie 52, 46 (2013).
[2] Göpfrich, Seifert et al. ACS Nano (2014).
[3] Göpfrich et al. (2014) (submitted).

FIG.1. Complexity arising from simple rules: beetle by Robert Lang (www.langorigami.com).

FIG 2. A sketch of versatile DNA channel architectures in a lipid membrane. Channel diameters mimic the diversity of natural membrane components from ion channels to large porins.

FIG. 3. Cavendish crocodiles spanning seven orders of magnitude in size. The largest is on the wall of the Mond Laboratory. Instructions for the paper origami crocodile are included on the following pages. The smallest one has been designed in CaDNAno, each rod representing one DNA double helix. It will be assembled from about 200 strands of DNA.

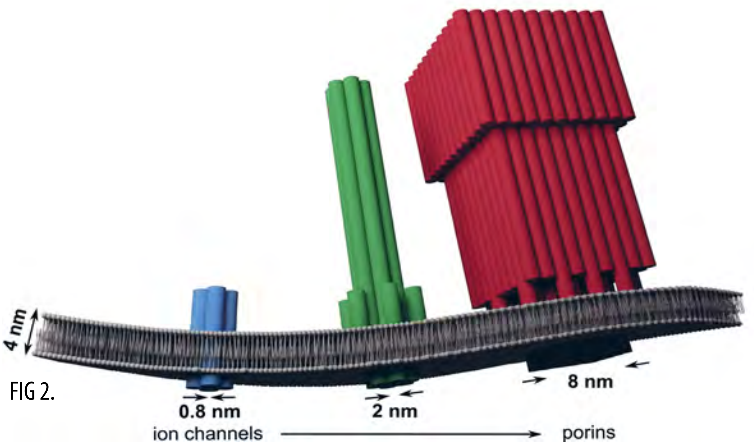


FIG 2.

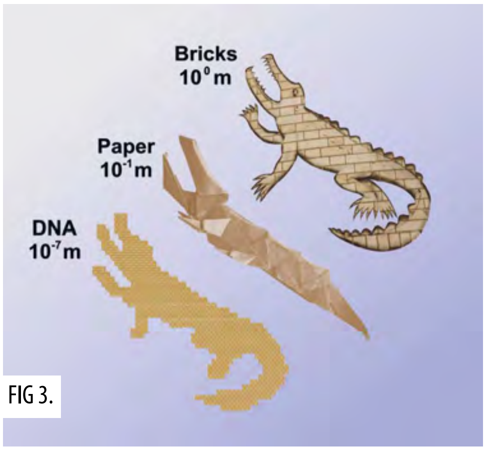


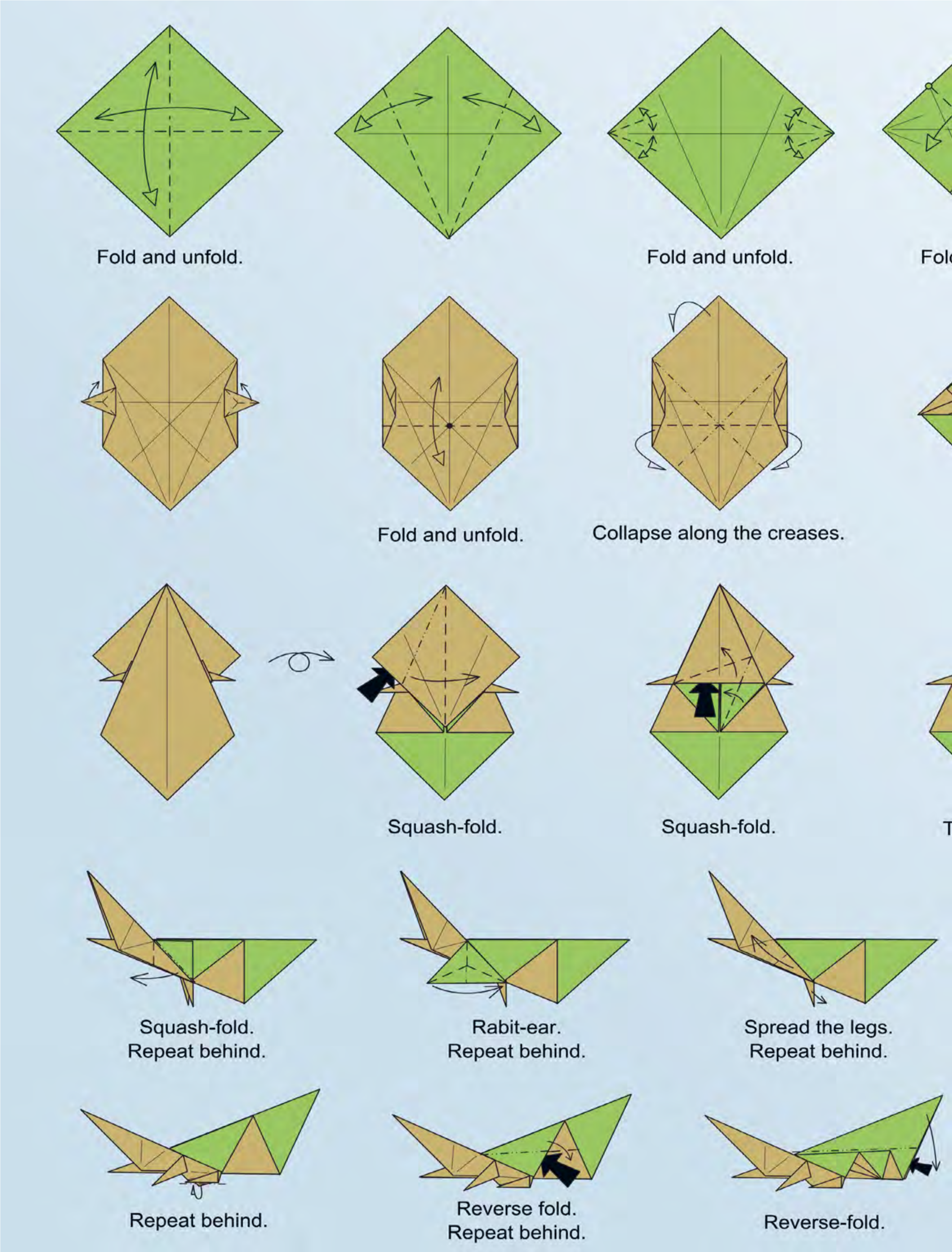
FIG 3.

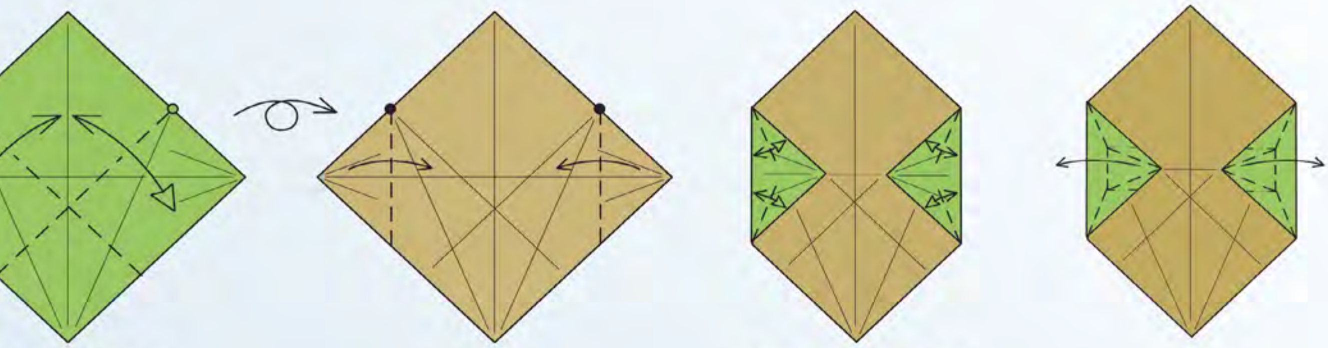
MAKE YOUR OWN ORIGAMI CROCODILE

On pages 14 and 15 of this edition of CavMag there are instructions about how to make an origami Kapitza Crocodile. This model and set of instructions were kindly provided by the origami designer Patricio Kunz Tomic who lives in Chile. His website is **www.origamichile.cl**. The instructions were taken from the book *Origami Worldwide,* published by John Montroll and Brian K. Webb, which is available at Amazon. We are most grateful to Patricio and John, the copyright holders, for permission to reproduce their plans and instructions.

The book contains origami examples from the simple to the complex. **This model of the crocodile is quite a complex piece of the origami art** and may need some practice in paper-folding skills. We have provided a loose sheet with a brick pattern on one side and green on the other. You may wish to make a larger A3 copy.

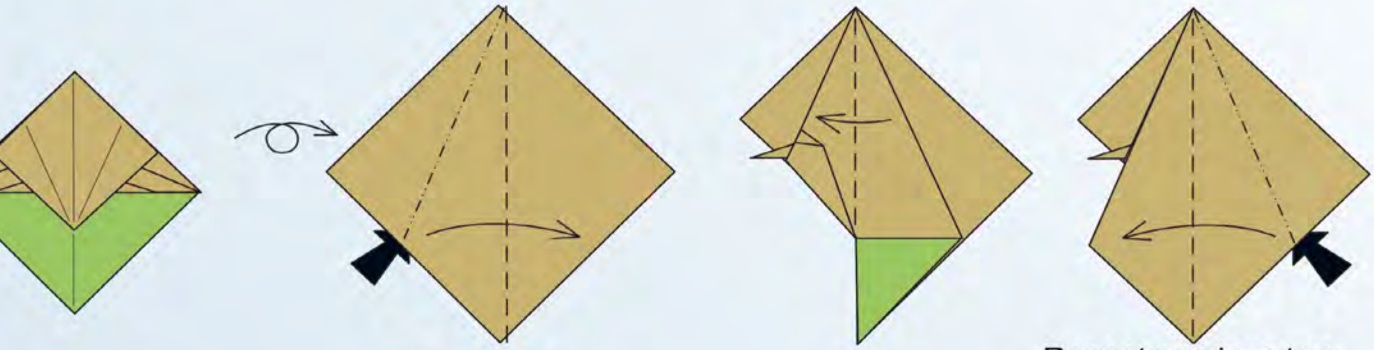
GOOD LUCK!!


Fold and unfold.
Fold and unfold.
Fold and unfold.
Collapse along the creases.
Squash-fold.
Squash-fold.
Squash-fold.
Repeat behind.
Rabit-ear.
Repeat behind.
Spread the legs.
Repeat behind.
Repeat behind.
Reverse fold.
Repeat behind.
Reverse-fold.



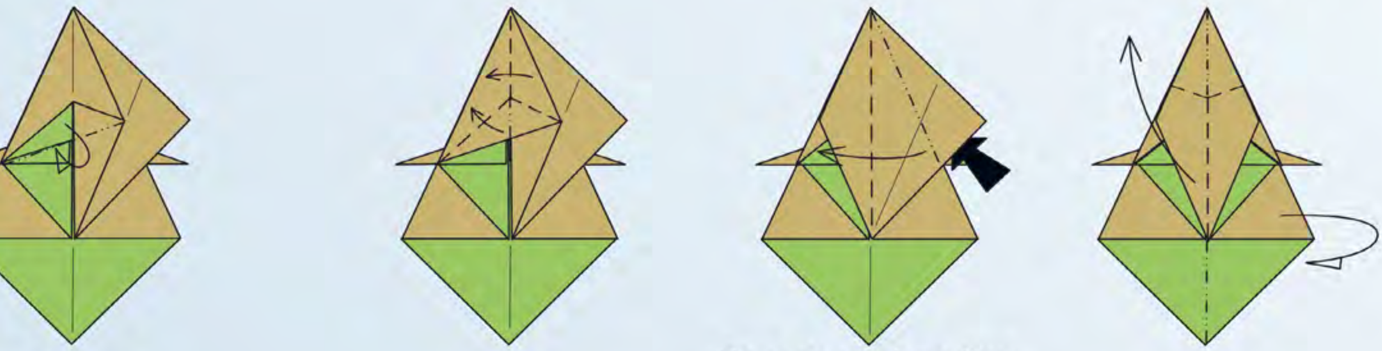
d and unfold.

Fold and unfold.



Squash-fold.

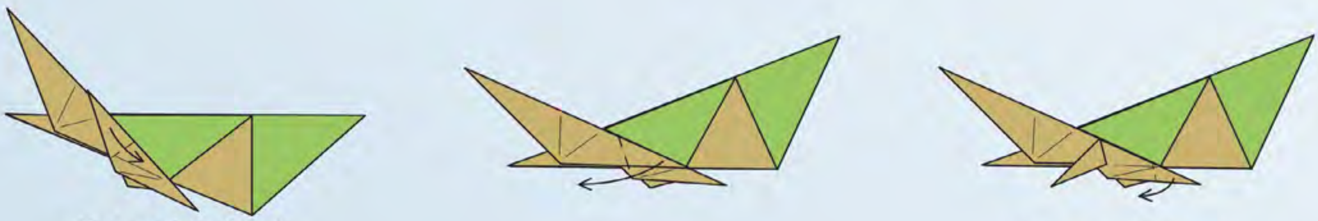
Repeat previous two steps on the right.



uck inside.

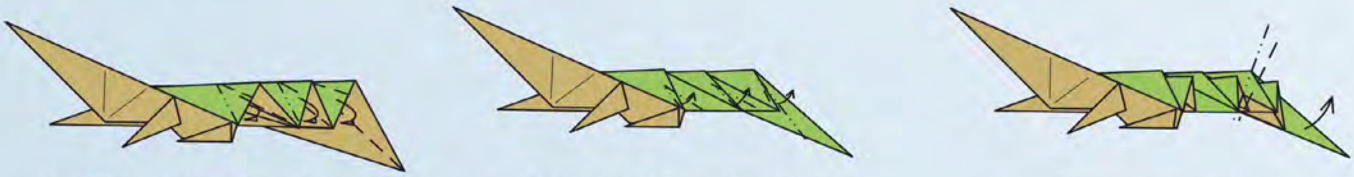
Repeat previous four steps on the right.

Rotate.



Repeat behind. Rotate.

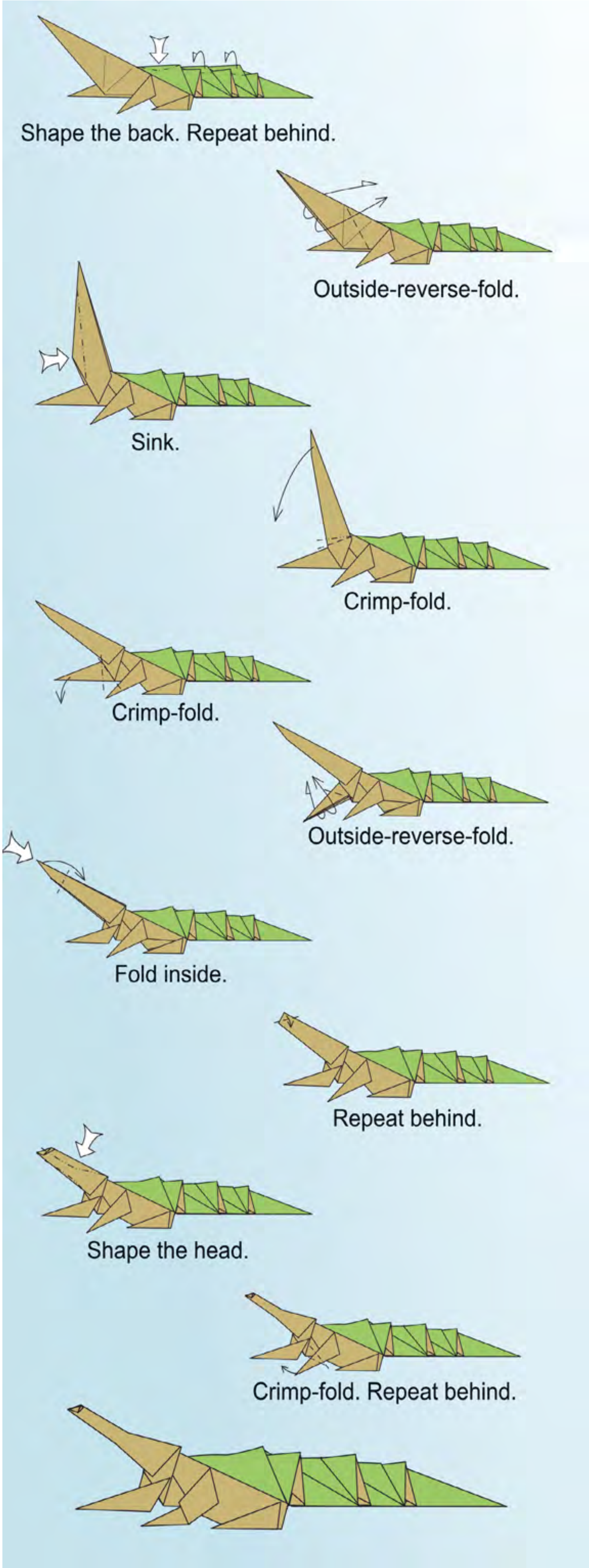
Repeat behind.



Fold inside three times. Repeat behind.

Pull out three times. Repeat behind.

Crimp-fold.



Kapitsa's Crocodile

Piotr Kapitsa joined the Cavendish Laboratory as a mature graduate student from the Soviet Union in 1921. He quickly established his reputation as a brilliant and ebullient experimental physicist, very much to the liking of Ernest Rutherford who praised his work. Kapitsa was delighted by Rutherford's commendation of his work. As he wrote to his mother,

> 'Today the Crocodile summoned me twice about my manuscript . . . It will be published in the Proceedings of the Royal Society, which is the greatest honour a piece of research can receive here . . .Only now have I really entered the Crocodile's school . . .which is certainly the most advanced in the world and Rutherford is the greatest physicist and organiser.'

This is an early appearance of Kapitsa's nickname 'Crocodile' for Rutherford. As he explained in an interview with Ritchie Calder,

> 'In Russia, the crocodile is the symbol for the father of the family and is also regarded with awe and admiration because it has a stiff neck and cannot turn back. It just goes straight forward with gaping jaws – like science, like Rutherford.'

A more fanciful version of the origin of the nickname 'Crocodile' relates to the crocodile in J. M. Barrie's play *Peter Pan* which had swallowed an alarm clock and thus gave warning of his approach. Rutherford's heavy tread and loud voice, including his rendition of the hymn 'Onward Christian soldiers', gave Kapitsa early warning of the Crocodile's approach.

In 1930, Kapitsa persuaded Rutherford to seek funds for a dedicated laboratory within which to house his high magnetic field equipment and cryogenic facilities. Rutherford obtained £15,000 from the Royal Society Mond fund. It was opened by the Chancellor of the University, Stanley Baldwin, in February 1933. In secret, Kapitsa organised the carving of a full-size crocodile on the external entrance wall of the new Laboratory and a carving of Rutherford himself, both by the distinguished sculptor Eric Gill. We have continued to use Kapitsa's crocodile as an unofficial logo for the Cavendish. ■

DIY Physics with Advanced Sensors

ANDREW FERGUSON AND ANDREAS BETZ

When you think of DIY, what is the first thing that springs to your mind - painting and decorating, fixing your bike or car, making furniture …? How about microcontrollers, 3D printing and robots? In fact, these are today at the forefront of a new type of DIY, the enthusiasts meeting in 'fablabs' and at 'Maker Faires'. Attendees at the well-attended Maker Faire events are difficult to characterise but conspicuously include 3-d printer enthusiasts and robot makers. A chance discussion in the Cavendish common room prompted us to propose a talk at the Maker Faire in Rome, where we could apply our common hobby in programming microcontrollers to communicate physics to a technically literate audience and inspire others to (re-)discover science.

Some late-night 'making' by Andrew led to the 'apple-drop' experiment. This aimed to turn Isaac Newton's famous story, about his theory of gravity being inspired by a falling apple, into a fun data-acquiring experiment. In our experiment a papier mache apple, beautifully made by James Haigh at the Hitachi Cambridge Laboratory, is dropped to the floor (Fig. 1, top). The apple core holds an ARM based microcontroller which acquires data from a MEMS accelerometer chip. The microcontroller also wirelessly transmits the acceleration data to a laptop. The MATLAB scientific programming language, which was controlling the experiment, then plots acceleration against time (Fig. 1, bottom).

The apple-drop worked well. As experimental physicists we were delighted to see unexpected facets to the data, for example we could see that air-resistance produces a small retarding force proportional to velocity squared. Also, the data confronts the nature of gravity. Why does the accelerometer say it is accelerating when it is resting, and vice-versa?

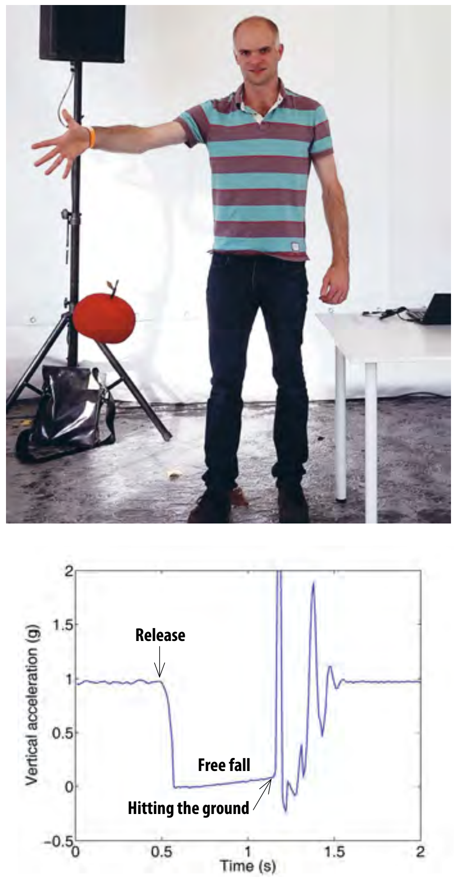


FIG 1.

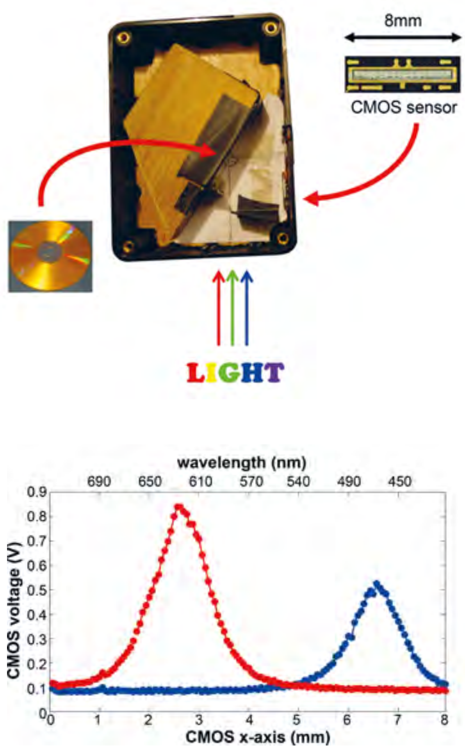


FIG 2.

Meanwhile Andreas was busy making a spectrometer using a DVD as a diffraction grating. There are many designs available (see spectralworkbench.org) and we designed an instrument that placed the emphasis on data instead of images. We employed a CMOS linear array to detect the spectrum made by the diffraction pattern (Fig. 2, top). A microcontroller then reads the data from the sensor and sends it to the laptop, where it is plotted.

The spectrometer really had the ability to fascinate. The audience loved the simplicity of the instrument as well as seeing the spectra produced by different coloured LEDs (Fig. 2, bottom). They had fun working backwards to find out a colour from a measured spectrum. Finally, there was a lot of head-scratching when they were asked to find the colour magneta in a rainbow.

It was great fun and we learned a lot about gravity, optics and outreach. We underestimated the amount of work it would take to make the experiments robust, the fascination that people have with physics, and the difficulty in getting a home-made spectrometer through airport security! We'll be back next year to show new, improved experiments and to listen to music played by that amazing robot band. ■

FIG.1. (top) Andrew dropping an apple. **(bottom)** Acceleration versus time as the apple is dropped from ceiling height (2.3 m). Between the release (0.5 s) and collision with floor (1.2 s) the apple is in almost in free-fall but air resistance causes the acceleration to depart slightly from zero.

FIG. 2. (top) A home-made spectrometer. Light enters through a slit (two razor blades) and hits a diffraction grating made from a piece of a DVD. The spectral components are then recorded by a linear array of CMOS sensors connected to a micro-controller. **(bottom)** Spectra of red and blue light emitting diodes obtained with the spectrometer. The sensor's voltage output corresponds to the light intensity at each pixel.

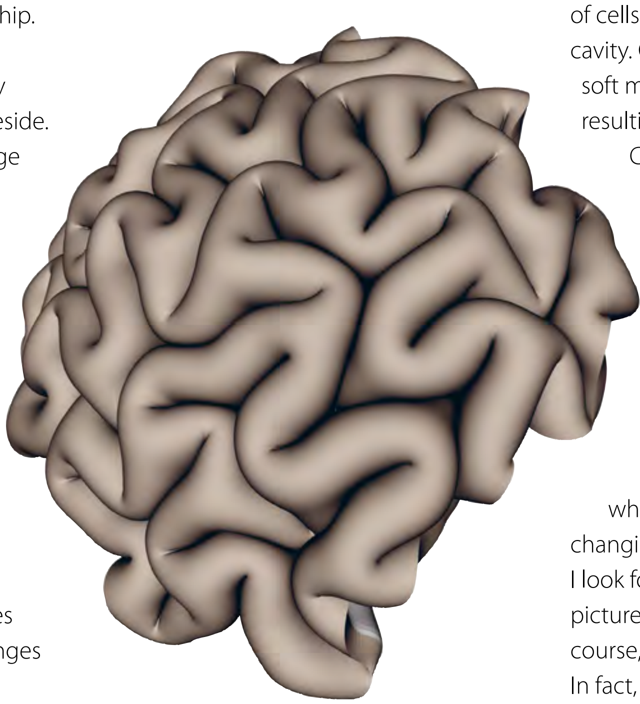
We are delighted to welcome John Biggins, Aglaé Kellerer, Eileen Nugent and Liam O'Brien as the first generation of three-year physics lecturers. They describe their fields of interest and a little of their careers to date.

John Biggins

It was as a second year undergraduate here at the Cavendish, while grappling with Maxwell's equations and statistical mechanics, that I fell irrecoverably for theoretical physics. At the end of the year, I realised that, just maybe, I was good enough to make a living at it. A Cavendish PhD followed, investigating the curious properties of rubbers containing liquid crystal order under the superb supervision of Mark Warner. I then moved to Harvard on an 1851 Royal Commission fellowship. There I first became interested in the interface between elasticity, geometry and biology, where my interests still reside. After two years I returned to Cambridge UK as a research fellow at Trinity Hall and now, exactly a decade after first grappling with Maxwell's equations, I relish the opportunity of joining the Cavendish teaching team as an Early Career Lecturer.

My research centers on soft solids, materials with the ability to sustain large shape changes when forces are applied, but then bounce back to their original shape when the forces are released. Examples abound, including rubber bands, sponges and skin. Sometimes, when we apply simple forces, these solids undergo large but simple shape changes. For example, if you pull on a rubber band it simply gets longer. However, simple compression, rather than producing shortening, often leads to wrinkling, buckling, bending, twisting, and a whole host of more exotic shape changes. Understanding these shape changes can shed light on subjects as disparate as geology and developmental biology. I am particularly interested in the latter: has evolution harnessed these mechanical forces to sculpt organs during development?

For example, I have recently been particularly interested in a compressive shape change unique to soft-solids. Whenever the surface of a soft solid is sufficiently compressed it changes from being flat to being dramatically furrowed.



These furrows bear a striking resemblance to the pattern of folds on the surface of the human brain. This leads to a remarkably simple hypothesis: does the exterior of the brain simply grow more than the interior, enter mechanical compression, and then fold into its iconic shape through an elastic instability akin to buckling? Our recent work strongly suggests this is exactly what happens.

Looking forwards, I have a multitude of ideas to explore. Within developmental biology, there are many other examples of complex shapes emerging from simple ones, which are prime candidates for a mechanical treatment. I am particular excited by the first shape transition seen in early embryos from a solid ball of cells, to a ball with a large central cavity. Cancer is another context where soft material undergoes rapid growth, resulting in mechanical compression. Can I use the theory of soft solids to help understand the shape and spread of tumors? Finally, and at something of a tangent, a new form of liquid-crystalline rubber, known as blue-phase-rubber, has recently been synthesised for the first time in Cambridge. Blue phase rubber has many exotic optical properties that change when it is stretched, including its colour changing from bright blue to bright red. I look forward to building a theoretical picture of this exciting new material. And, of course, I look forward to starting lecturing. In fact, I have started early, lecturing a first year course on oscillations this term. I hope my comparatively recent memory of being on the receiving end of lecturing will help make my lectures comprehensible and help encourage the next set of bright young physicists into physics careers. ■

Aglaé Kellerer

When I first entered the new Battcock Centre for Experimental Astrophysics, one of the first things I noted were the photographs of the Würzburg antennae. These had been built in Germany during the Second World War, but were later used for radio astronomical observations by the Cavendish Laboratory (see Box). I noticed the photographs, because – much like the antennae – I was born in Würzburg and am now working on astronomy in Cambridge. Luckily however, my resemblance to a Würzburg antenna ends there.

I develop instruments – notably adaptive optical (AO) correction systems – for telescopes that observe at visible to near-infrared wavelengths. AO systems compensate for the effects of the Earth's atmosphere on astronomical observations. Rapid fluctuations in the optical refractive index of the air above the telescope distort the incoming wavefronts and thereby degrade the angular resolution of telescopes. AO systems correct for these wavefront distortions in real time. As the telescope size increases, the corrections become ever more complex. In 1989, the first astronomical prototype had 19 correction-elements and a 150 Hz sampling-rate. Current systems have several thousand correction-elements and sampling-rates greater than 1000 Hz, and this is far from the end of the line.

Ideally, an AO system restores the diffraction-limited resolution performance of the telescope. While this is normally considered to be the fundamental limit to the resolution of a telescope, this year's Nobel Prize in Chemistry reminds us that we can be even more ambitious; the diffraction limit can be overcome and this routinely takes place in microscopy. Consider a photon emitted by an

Würzburg Telescopes in War and Peace

Radar was at the heart of air defence and guidance for aircraft and rockets during the Second World War. The German radar telescopes, transmitters and receivers were of outstanding technical quality. The photographs show how they could be transported by rail to any location and quickly assembled as a radar transmitting station. Immediately after the War, there was scarcely any money for equipment for radio astronomy in the UK, but Martin Ryle and his colleagues acquired large amounts of high quality German radar equipment which had been requisitioned after the War. They took away five truckloads of surplus equipment from the Royal Aircraft Establishment (RAE) at Farnborough, including several 3m and two 7.5m steerable Würzburg radio antennae, as well as a large amount of high quality German coaxial cable.

In 1951, Graham Smith, working at the Rifle Range site of the recently formed Cambridge Radio Astronomy Group, used the pair of Würzburg antennae as an interferometer to measure the positions of the four brightest radio sources in the northern sky with an accuracy of about 1 arcmin. The observations of Cygnus A and Cassiopeia A led to their optical identification by Walter Baade and Rudolph Minkowski, who made their observations with the Palomar 200-inch telescope. Cassiopeia A was associated with a young supernova remnant in our own Galaxy, while Cygnus A was associated with a faint, distant galaxy with a redshift $z = 0.0561$. When this result was communicated to Ryle, he quickly changed his view on the nature of the radio sources. Fainter extragalactic radio sources such as Cygnus A must lie even further away and so could be used for cosmological investigations. This was the motivation for the great series of radio telescopes which Ryle constructed over the next twenty years and for which he received the Nobel Prize in Physics.

TOP: A Würzburg 7.5m radar antenna being prepared for railway transportation. This mobile configuration allowed the deployment of a complete Würzburg radar station at any railway site.

MIDDLE: An assembled Würzburg radar antenna, still on its goods wagon. (Photographs: reproduced courtesy of the Foundation Centre for German Communication and related Technology, the Netherlands. See www.cdvandt.org)

BOTTOM: The two Würzburg antennae at the rifle range site in Cambridge used as an interferometer. Francis Graham Smith is seen in the foreground.

astronomical target. Before it is detected, it is part of an immense spherical wave centred on the astronomical target and extending all the way to the telescope. But once it is registered by the detector, its virtual pathway is narrowed down to the telescope aperture. According to Heisenberg's uncertainty principle, there is then a corresponding uncertainty in the photon's momentum, that is, its incoming direction, which determines the diffraction limit on the detector.

The diffraction limit is thus built into the foundations of quantum mechanics. Crucially, however, it applies only to independent photons – for sets of coherent or entangled photons the limit can be considerably smaller. Sub-diffraction limited microscopy is based on non-linear processes, such as stimulated emission. Could we use similar processes to overcome the diffraction limit in astronomy? If so, what kinds of quantum leaps in optics might empower tomorrow's astronomy?

There will be a number of ways, such as photon entanglement. But one radical breakthrough might be the possibility of detecting photons without destroying them through so-called 'quantum non-destructive measurements'. When photons arrive at a detector, for example, the retina or a CCD chip, they interact with atoms, the energy of the photon is transmitted to the atom and the photon is thereby destroyed. In a non-destructive measurement, the photon is detected, but not destroyed. This is an active field of research, notably in the context of quantum computers, where photons are to be used as information carriers, or flying qbits, between quantum gates.

Most of our knowledge about the Universe comes from photons that have been collected with telescopes. These photons travel for thousands of millions of light-years, but once detected, they are instantaneously destroyed. No astronomical photon has ever been detected twice. The non-destructive detection of astronomical photons would result in a change of paradigm for astronomy. And the most interesting applications will be those that we have not yet thought of. ■

Eileen Nugent

I grew up in rural Ireland where I went to a co-ed convent school. I enjoyed every subject with a mathematics component and found solving mathematically formulated problems very satisfying. We mainly had non-specialist substitute physics teachers so it wasn't an inspiring first contact with the subject but physics opened up for me while studying natural sciences at University College Dublin. A combination of flexible open-ended practicals and some excellent courses in condensed matter physics left me with a desire to be an experimentalist and with an interest in ultra-cold quantum phase transitions.

To gain a better theoretical understanding of these systems I embarked upon a Masters in computational physics at Queen's University Belfast/University of Bergen. My main interest was collective excitations of Bose-Einstein Condensates particularly in toroidal geometries. Theoretically these weakly-interacting systems are tractable and placing them in a toroidal geometry created the ideal system to investigate persistent currents. Constricting the torus at one location during persistent flow is predicted to produce the sonic analogue of a black hole. During my DPhil in Oxford I realized a toroidal Bose-Einstein Condensate in the laboratory by combining optical and radio-frequency dressed-state magnetic potentials. By controlling the properties of the radio frequency field simultaneous confinement and stirring could be achieved to initiate persistent currents. During my postdoc in Oxford we extended this work by time averaging these magnetic potentials to produce a fully magnetic toroidal geometry.

At that time I also began demonstrating on a biophysics practical course, which investigated the physics of bacterial nanomotors. This experience completely changed my view of living systems and the role of physics in a complete description of life. Biological physics seemed to be an open field with a demand for new experimental approaches and many unanswered questions, both factors in my switching fields. The biophysics group in the Cavendish Laboratory underwent a rapid expansion at that point and seemed like an exciting place to be. I was fortunate to obtain a postdoc in Pietro Cicuta's Group. I began working on microfluidic devices to investigate how cells can dynamically control the physical structure of their DNA molecules and whether this plays a role in controlling gene expression and hence cellular response to environmental changes[1,2].

In 2012 I began a research fellowship at Lucy Cavendish college, expanding my work to cover topics as diverse as cell-size control[3], algae-bacteria symbiosis and infectious diseases[4]. During the current lectureship I am planning to expand on this work to build a "brain on a chip" microfluidic platform for characterising neuronal connectivity between neurons derived from cells of patients with severe neurodegenerative diseases. The measurement and modeling of neuronal connectivity present significant biophysical challenges to the growing need for quantitative, *in-vitro* models of these diseases. Microfluidic platforms with integrated electro-physiology measurements would enable a better understanding of the underlying causes of such diseases and pave the way for new treatments. The platform itself could also serve as an intermediate testing ground for new drug candidates. ■

[1] Microfluidic chemostat for measuring single cell dynamics in bacteria. Long *et al.* Lab Chip, **13**, 947 (2013).

[2] Short timescale micro-dynamics of Bacterial Chromosomal Loci, Javer Godinez *et al.* Nature Communications, **4**, 3003 (2013).

[3] Concerted control of Escheria coli cell division, Osella *et al.* PNAS Advance Issue (2014).

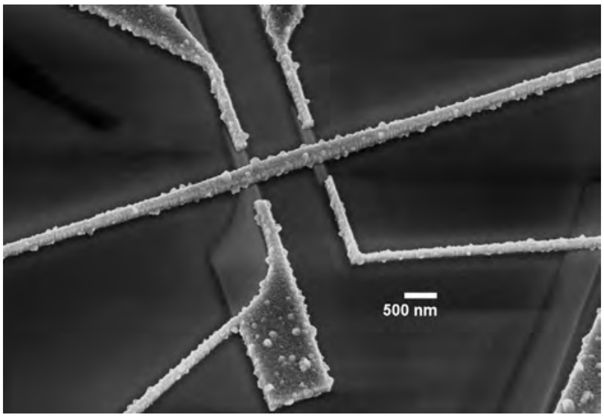
[4] Inflammasome activation causes dual recruitment of NLRC4 and NLRP3 to the same macro-molecular complex. Man *et al.* PNAS Advance Issue (2014).

Liam O'Brien

After gaining a Masters in Physics at St. Hugh's College, Oxford, in 2006, I moved to Imperial College to undertake a PhD with the Experimental Solid State Physics group under the supervision of Russell Cowburn. I received a Corrigan Scholarship for research in advanced nanotechnology. Following my PhD, in 2010, I joined the Thin Film Magnetism group at the Cavendish where I was awarded a Marie Curie Research Fellowship. As part of this fellowship I was able to spend three years working as a visiting researcher at the University of Minnesota, USA, hosted by Chris Leighton at the Department of Chemical Engineering and Materials Science, before returning to Cambridge in late 2014.

My research to date has predominantly focussed on nanoscale magnetic devices and their interaction with spin polarised electrical currents, studies that fall within a field broadly termed 'spintronics'. Within spintronics researchers attempt to manipulate the spin of an electron, much in the same way traditional electronic devices manipulate charge, with technological applications from field sensors and RF signal generation, to logic and data storage. My early research focussed on a particular class of nanomagnetic data storage and logic devices, which use magnetic domain walls in nanoscale ferromagnetic wires to propagate data. I complemented this with investigations into the fundamental mechanisms limiting spin transport in all-metallic nanoscale devices; although the processes which cause a spin polarised current to relax in bulk metals are reasonably well understood, there is much still to learn about the transportation of spin at the nanoscale, including the influence of patterning and interfaces, in particular.

I was delighted to take up a Cavendish Early Career Lectureship, and look forward to continuing such research. During this time I intend to focus my efforts on the use of the non-local spin valve, a device that can physically separate spin- from charge-currents, and the information it can provide on spin relaxation, particularly in novel metallic devices (Fig. 1). This has the promise of providing fascinating insight into the influence of, for example, virtual bound states, like dilute magnetic or highly spin-orbit-coupled impurities, on dephasing a spin accumulation. This work will capitalise on the expertise within the TFM group in thin film deposition, characterisation and manipulation of ferromagnetism at the nanoscale. Ultimately, when paired with further nanomagnetic and thin film research, this may provide new logic and storage technologies with superior performance to current generation devices. ■



Scanning electron microscope image of a non-local spin valve device with Fe electrodes and an Al channel. The device is fabricated using electron beam evaporation, under ultra-high-vacuum, without the need to break vacuum between evaporation steps.

Physics at Work, CCPE, Rutherford Physics Project and Isaac Events

We are delighted to welcome JACOB BUTLER to take the helm of the Cavendish's Outreach programme from the beginning of 2015, following Lizzie Bateman's departure to take up a physics teaching placement in the North-East. Jacob has a degree in Physics with Philosophy from York and has been working in the East Anglia region in the area of educational and training software, development and programme management.

Physics at Work 2014

The 30th anniversary of the Physics at Work exhibition was held at the Cavendish Laboratory from the 24–26 September 2014. Presenters engaged with 2100 students and their teachers during another successful and energetic three days. This year's 'School Exhibitor of the Year' was once again our own Biological and Soft System Group (Fig. 1) closely followed by new exhibitors from the Atomic Mesoscopic and Optical Physics Group. We look forward to a very closely contested competition next year!

Dates for Physics at Work 2015 are 23–25 September. **Bookings will open from our website in May/June 2015.**

Cambridge Colleges' Physics Experience (CCPE)

We are now in our third successful year of the CCPE programme and for 2014–15 we will be working with 14 of the Cambridge Colleges in this collaboration following the increase to 8 colleges last year.

Early in November we hosted 5 afternoons for Y11 (15–16 year old) students and in the following week 5 afternoons for Y9 (13–14 year old) students. Each of these weeks focussed also on the 'Girls into Physics' agenda targeting girls specifically for one day each week. The Y11 students had a brief talk on light as a wave before moving on to an experiment with geometric optics which culminated in them building a table top telescope. The afternoon finished with a presentation on how astronomers make pictures not only using visible light but all parts of the electromagnetic spectrum.

The Y9 afternoons began with a discussion session about role models in physics, why we might actually want to study physics and whether 'science is solved'. Following from there they undertook an experiment circus to build, with wooden bricks, the largest possible span bridge they could construct, a paper crane to suspend a mass as far from a table as possible and to observe and chart data on Archimedes principle. Their afternoon ended with a talk on astronomy and light, following on from its popularity in previous years with all age groups. The schools attending the 2013–14 CCPE events spanned the whole of England from the Manchester/Hull area southwards.

This programme continues in February 2015 with 2 weeks for Y12 students (9–13 & 23–27 February) and bookings will be made through schools local area link colleges. (**http://ccpe.phy.cam.ac.uk**).

A further week for Y11 students is being held from 16–20 March 2015 and for Y9 students in May 2015.

For more details of the CCPE programme, see **www-outreach.phy.cam.ac.uk/ccpe**

Rutherford Physics Project becomes Isaac Physics (isaacphysics.org)

The new-look online platform, accessible to all mobile device as well as desktop computers, was developed with the intention of enhancing the physics problem-solving skills of school students. The new platform went live in October 2014 supported by an increased programme of face-to-face student and teacher events around the country. This programme is supported by the Department for Education.

Over 4000 users have engaged with the problems presented on isaacphysics.org with 46% of users being female. Using our website analytics we are also able to determine that the site is reaching far and wide across the UK and the world. 70% are from the UK, the remainder including Italy (8%), the USA (5%), Mexico (3%) and 16 other countries.

We would be delighted if alumni would encourage young people thinking about a career in Science, Technology, Engineering and

Mathematics (STEM) to visit **isaacphysics.org** and attempt some of the physics and mathematics problems.

Further development of the platform is underway to allow students to view their progress in a variety of forms. In addition, these developments will provide teachers with the ability to set homework for their students and be able to view their classes' progress for each homework set.

Isaac Events

Teacher Continued Professional Development (CPD) events

19–20 December 2014
Møller Centre, Churchill College, Cambridge

6–7 February 2015
King's College London Mathematics School

Dates TBC in 2015:
Exeter Maths School, Kettering Buccleuch Academy, King Edward VI Five Ways School (Birmingham)

Student Workshops

16 January
Colchester VIth Form College
Please see **https://isaacphysics.org/events** for further information.

For more details about Isaac Physics, see **https://isaacphysics.org**

LEFT: Biological and soft systems exhibiton at Physics at Work 2014. The team was voted 'exhibitor of the year'.

Congratulations

Cavendish Physicists continue to receive recognition for their contributions to physics and society. We warmly congratulate them all.

Jim Scott has been selected by Thomson Reuters as a Citation Laureate. The scientists selected are 'researchers whose landmark discoveries and advances, not to mention their measurable esteem in the scientific community, place them within reach of the Nobel Prize.'

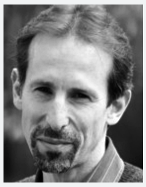
Sarah Teichman was awarded the Biophysical Society's 2014 Michael and Kate Bárány Award for Young Investigators.

The research of **Jacqui Cole** and her co-workers has been highlighted in ACS Newsletter 'Noteworthy Chemistry'.

Russell Cowburn has been elected as an IEEE Magnetics Society Distinguished Lecturer.

Sarah Bohndiek has been awarded the European Commission's 2014 MSCA 'Nurturing Research Talent' prize and the 2014 Women in Science and Engineering (WISE) Research Award.

Suchitra Sebastian was featured in 'Nature Careers 2015'. Last year, she was listed as one of thirty exceptional young scientists by the World Economic Forum.



Jeremy Baumberg was awarded the Royal Society Rumford Medal.

New Appointments

We are delighted to welcome **Gillian Weale** as Departmental Administrator. Gillian has come to the Cavendish from the English Faculty where she was the Faculty Administrator for three and a half years. Before coming to Cambridge she held positions at Loughborough University, in the Planning Office, and at the University of Exeter in the Registrar's Office. In 2014 she was seconded to the REF secretariat, supporting the work of three social science sub-panels.

We congratulate **Neil Greenham** on his appointment as Deputy Head of Department (Resources), a position which he takes over from **Richard Phillips,** whose efforts in this role we have greatly appreciated.

We are delighted to welcome four early career lectures: **John Biggins** (TCM), **Algaé Kellerer** (Astrophysics), **Eileen Nugent** (BSS) and **Liam O'Brien** (TFM). You can learn more about them and their activities on pages 18-21.

Olga Kotlyar Group Administrator, SMF/TFM
Alison Barker Group Administrator, OE
Alistair Davies Rutherford Schools Project Hub Events Manager
Heather Peck Rutherford Schools Project Hub Events Manager
Emily Boyd Administration Assistant, Graduate Students Office (maternity cover)
David Francis Chef, Cavendish Common Room
Robert Pasek Kitchen Porter, Cavendish Common Room

Continued overleaf...

Continued from overleaf...

Amalio Fernandez-Pacheco (left) (TFM) and **Akshay Rao** (second left) (OE) have been appointed to EPSRC Early Career Fellowships and Winton Advanced Research Fellowships.

Artem Bakulin (third left) (OE)**,**
Gareth Conduit (third right) (TCM)**,**
Dan Cedgington (second right) (OE) and
Andreas Nunnenkamp (right) (AMOP) have all been appointed Royal Society University Research Fellows.

We congratulate all six of them on their successes.

Leavers

We wish the following success in their future activities:

Ullrich Steiner John Humphrey Plummer Professorship of Physics of Materials
Lizzie Bateman Assistant Outreach Officer
Helen Bullen Common room
Christopher Darvill Instrument Maker
Helen Jobson Classes
Imen Litim Administration Assistant Graduate Student Office (maternity leave)
David Peet Administrative Secretary of the Department on secondment to the Human Resources Division

STOP PRESS: Theory of Condensed Matter 60th Birthday. All alumni and friends of TCM may wish to put 10/11th July 2015 in their diaries. There will be a summer party on one of those dates to celebrate the anniversary and to meet old friends. Contact Alan Clarke at ac771@cam.ac.uk.

Val Gibson, Dame Julia Higgins (Patron of the Athena Swan awards), Chris Ford and Emily Heavens-Ward at the presentation ceremony of the Athena Swan Gold Award to the Department. The Cavendish Team received the award from Dame Julia on behalf of the many members of the Cavendish Athena Swan team.

HOW YOU CAN CONTRIBUTE

» Online Giving

The University's Office for Development and Alumni Relations has made it easier to make donations online to the Department and to two of our special programmes. If you wish to make a donation to the Department, please go to:

campaign.cam.ac.uk/giving/physics

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

campaign.cam.ac.uk/giving/physics/graduate-support

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

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

If you would like your gift to be applied to some other specific aspect of the Development Programme, please contact Andy Parker or Malcolm Longair. The Development portfolio is 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: **campaign.cam.ac.uk/how-to-give** and at the bottom of the page there is a pdf file entitled **A Gift in Your Will**.

It is important that, if you wish to support the Cavendish, or some specific aspect of our development programme, your intentions should be spelled out explicitly in your will. We can suggest suitable forms of words to match your intentions. Please contact either Professor Malcolm Longair (**msl1000@cam.ac.uk**) or Mr Robert Hay (**rach2@cam.ac.uk**) who can provide confidential advice.

If you would like to discuss how you might contribute to the Cavendish's Development Programme, please contact either **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.

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