UNIVERSITY OF CAMBRIDGE

SEPTEMBER 2018

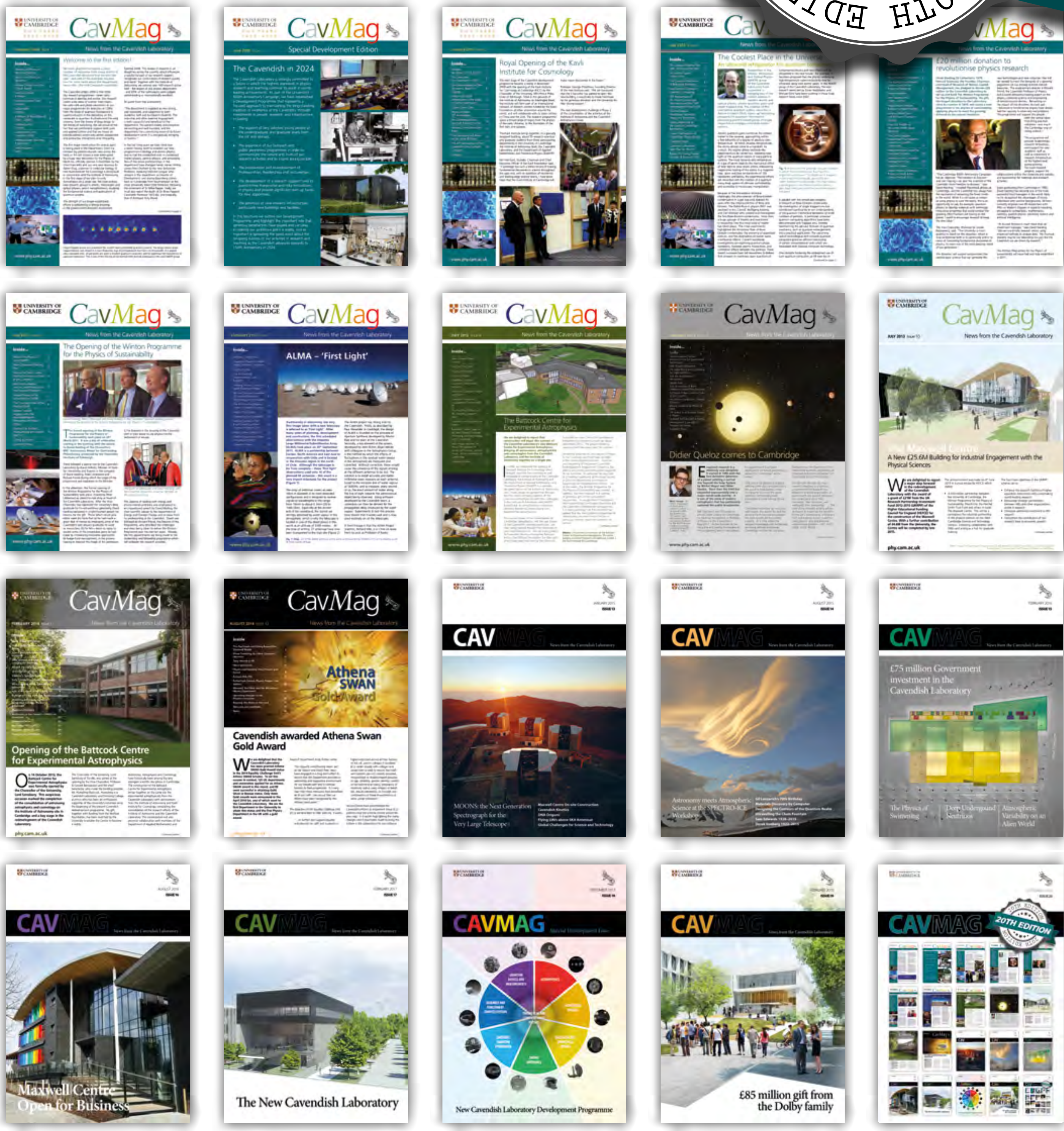
**ISSUE 20**

# CAVMAG

20TH EDITION

20TH EDITION

20TH EDITION



# Ten Years of CavMag and its 20th Edition

## A Personal Perspective

**It seems scarcely credible that this is the tenth year of CavMag and its 20th edition. It is timely to reflect on what has been achieved since we began this adventure. It is gratifying that many of our aspirations have been fulfilled in what must have seemed an outrageously ambitious project in 2008, let alone 2002 when the first tentative steps were taken.**

### INSIDE



### The Pre-CavMag Years

I was appointed Head of the Cavendish Laboratory in October 1997 in succession to Archie Howie. I was eight years in that role and it proved to be a demanding but exciting time. It soon became apparent that, whilst the Laboratory had done very well on the West Cambridge site since the move from central Cambridge was completed in 1974, the buildings were showing their age and were not at all adapted to environmental concerns. Brian Pippard had designed a Laboratory which maximised the floor space for a given amount of money, £3.8M, which had to be spent in a single quinquennium. The heat loss was enormous, there was an insidious asbestos problem throughout the Laboratory, the flat roofs were a continuous source of water leakage and the space was overcrowded. Virtually all laboratory areas had been redeveloped at least three times and the buildings were beyond their design lifetime.

After much discussion, I asked the University for permission to begin the process of designing a new Laboratory which would eliminate all the problems and create a state-of-the art Laboratory which would enable us to attract the very best physicists from around the world to Cambridge. In 2002, the University approved this proposal and asked me to go ahead and develop plans for a new Laboratory, supported by David Peat, the Administrative Secretary of the Laboratory. They also asked me to go out and raise the funds for this venture.

We invited the architects BDP (Building Design Partnership) to come up with outline concepts for how the Laboratory could be rebuilt on the same site which at that time we regarded as the location of choice. They developed a splendid plan which involved a phased construction so that the scientific programmes could continue while the existing buildings were pulled down and replaced. The concept was to maximise cross-fertilisation between the different types of physics being carried out in the Laboratory. Fig. 1 shows the imaginative solution proposed by BDP, but it was a seriously expensive project. The new Laboratory would be constructed in four phases to smooth the large capital cost of the redevelopment and to preserve the continuity of the research programme.

At the same time, we made new appointments to support the Physics of Biology and this led to further discussions, stimulated by the arrival of Chris Dobson in Cambridge, to create a multi-disciplinary approach to the interaction between physics, chemistry, biochemistry and clinical medicine. Keith Peters, then Professor of Physic in the Medical School, was particularly enthusiastic about developing a collaboration with the Cavendish in the Physics of Medicine. Over the next few years, he and I developed the concept of a Physics of Medicine Building as one of the first stages in the implementation of BDP's concept of a phased development for the rebuilding of the Laboratory. With the support of the Wolfson Foundation and the enthusiastic support of

**FIG. 1. An early concept for the phased redevelopment of the Laboratory by BDP.**

Alison Richard, then Vice-Chancellor of the University, the plans for the Physics of Medicine building were approved, but the resources only allowed the first phase of that project to be completed (Fig. 2). At this point, I reached the end of my spell as Head of Department and Peter Littlewood took over in 2005 – I went on two years' sabbatical.

## CavMag and the Implementation of the Development Programme

When I returned from my sabbatical, Peter asked me, in my last year of service as Jacksonian Professor, to take on the role of Director of Development and Outreach. We needed to reconnect with all our alumni and this resulted in the creation of the alumnus magazine CavMag and an invitation to all alumni to visit us. We worked with our colleagues in what was then CUDO, the Cambridge University Development Office, in taking forward this department-led initiative. Special mention must be made of the efforts of Lorraine Headen and our excellent graphic designer Matt Bilton, who has designed all 20 editions of CavMag.

First, we had the opening of the Physics of Medicine Building in 2008 and then George Efstathiou of the Institute of Astronomy led the initiatives to create a Kalvi Institute for Cosmology, bringing together the cosmologists and extragalactic astrophysicists in the Cavendish Laboratory, the Institute and the Department of Applied Mathematics and Theoretical Physics. Again, Alison Richard was very strongly supportive of the project to bring a Kavli Institute to Cambridge and it has proved to be a great success (Fig. 3).

**FIG. 2. The Physics of Medicine Building, opened December 2008.**

With the support of Lorraine Headen, we next held a breakfast meeting sponsored by Cavendish Alumnus Humphrey Battcock with a number of potential benefactors. Humphrey himself planned to be a benefactor and encouraged the others to get on board. The remarkable result of this breakfast event was that David Harding was strongly attracted by our proposal for a Physics of Sustainability programme which he supported with a magnificent gift of £20M. This programme was then led by Richard Friend and the results have featured regularly in CavMag and in the annual Winton Lecture series. This gift had enormous impact upon the research directions of the Laboratory and continues to produce science and trained scientists of the highest quality for academe and industry.

With this success, we felt confident that we could go ahead with the next phases of rebuilding of the Laboratory. Peter Littlewood handed over the reins as Head to Department in 2011 to James Stirling until he was lured away to become Dean of Imperial College, London in 2013. At that point Andy Parker took over as Head of Department and threw himself vigorously into the redevelopment programme.

A key goal was to relocate the remaining Cavendish experimental astrophysicists to the Institute of Astronomy site next to the Kavli Institute. Humphrey Battcock's generosity enabled us to build the Battcock Centre for Experimental Astrophysics and this was supplemented by a generous grant from the Wolfson Foundation.

For the first time all the astronomers in the Institute of Astronomy and the Cavendish were brought together on a single site (Fig. 4). At the same time, space was released in the Rutherford Building which was soon occupied by the Cavendish Bio-Medical physicists.

With the major gift from David Harding, we were next able to secure the resources from the UK Research Partnership Investment Fund (UKRPIF) to build the Maxwell Centre (Fig.5). The focus of this project was the interaction between basic physics and the needs of industry and society, matching the aspirations of the Physics of Sustainability agenda. We were able to move rapidly since this was considered to be part two of the Physics of Medicine (POM) project, for which planning permissions had already been granted. A significant part of that planning was that the building should be located to the west, rather than the east, of the POM building and that the Paddocks site on the opposite side of JJ Thomson Avenue should be considered for the

FIG. 3. The Kavli Institute for Cosmology, opened November 2009.
FIG. 4. The Battcock Centre for Experimental Astrophysics, opened Autumn 2013.

FIG. 5. The Maxwell Centre for the interaction between the Physical Sciences and Industry, opened Spring 2016.

redevelopment of the rest of the Laboratory. This proposal had great advantages since it allowed us to build first and decant 'at leisure', but required the capital investment up front. Again fortune was on our side.

## The New Cavendish Laboratory

With about £80M raised for these four buildings, the University made the reconstruction of the rest of the Laboratory its highest priority. The strong support of the Vice-Chancellor at the time, Leszek Borysiewicz, was crucial in securing government funding in 2016 from the Treasury to the tune of £75M. This was matched by a magnificent gift from the Dolby Foundation and also by the University, altogether providing 75% of the total cost of the New Cavendish Laboratory project. Ray Dolby, the inventor of the Dolby noise-reduction technology, had been an outstanding graduate student in the Laboratory and made this extraordinary bequest to the Laboratory. In recognition of the Dolby gift, the Building will be named the 'Ray Dolby Centre'. We were given the green light to go ahead with the detailed planning for the construction phase and, as reported elsewhere in this issue, that is about to begin.

CavMag has kept Alumni, our supporters and members of the Laboratory fully informed of these developments and has acted as a historical record of the evolution of our ideas and concepts over the last ten-year period. It reflects not only the changing perspectives on the rebuilding of the Laboratory, but also many of the scientific highlights over the same period.

Let me record our heartfelt gratitude to all Alumni for their interest and support of what we have been seeking to achieve over the last ten years.
But the job is not finished. Our vision was set out in CavMag18 and now we need to deliver that new approach to the future physics programme, in collaboration with our national and international partners. The development and fund-raising activities must continue to ensure that the Laboratory remains one of the world's leading physics departments.
The nature of the research may change, but the inspiration of the achievements of our predecessors will stimulate the continuation of our efforts to produce world-leading research. And CavMag will be with us into the foreseeable future.

**MALCOLM LONGAIR**

# Full Speed Ahead on the New Cavendish Laboratory Project

**Since the announcement of the Dolby gift in December 2017, the project has moved ahead at a great speed. We report on progress and how the project will be monitored and evaluated through the next three years of construction on site. This is a very large and challenging project. We intend keeping readers up to date with progress, recalling that this type of development can only be expected to take place once a century.**

## Detailed Design

A great deal of preparatory work has been carried out by the architects Jestico and Whiles in collaboration with the University's Estates Management and the Laboratory's in-house team, led by Richard Phillips (Fig.1). The result was the completion of the architect's design and RIBA Phase 3 report in early 2018. To clear the way for construction, full planning permission for the New Cavendish Laboratory was received from the Cambridge City Council in early February 2018.

The construction firm Bouygues was appointed for the detailed design phase for RIBA Phase 3 of the project. There followed a very large effort on the detailed examination by the University's Estates Management team of the commercial details of the proposals made by Bouygues. These included a number of suggestions for improvement of the efficiency of how the design intent is implemented.

The most important of these have been discussed in detail by the Laboratory's Logistics Committee which represents the interests of the future users of the Laboratory.

To give some idea of the scale of the work carried out by the Estates Team, well over one thousand individual points have been raised for detailed scrutiny. The result of this activity was an agreed plan described in detail in four major architectural, planning and financial documents. This process was completed in early June 2018 and culminated a week or so later in a report by Beverley Weston, Head of Estate Projects, University of Cambridge, to the Pro-Vice Chancellor for Planning and Resources. The proposals have been approved at a project cost of £303 M. The final step in the legal process was the signing of the contract with Bouygues in August 2018. Once signed, the project entered RIBA Phase 4, the formal start date of the construction phase beginning in January 2019 with handover of the completed building starting in February 2022.

Meanwhile, Bouygues carried out preparatory tests on site through the construction of two large concrete slabs to evaluate in situ their proposals for guaranteeing the vibrational stability of this platform for the most sensitive experiments. It is planned that part of this construction will evolve into the bicycle park area under the entrance to the new Laboratory (Fig. 2). The tests gave the contractors the opportunity to verify the nature of the ground, the performance of local concrete suppliers and the vibrational properties of the site.

## Management of the Project

The project will be managed in accordance with the University's established procedures for capital projects. Many customers have to be satisfied that the project is carried out with all due diligence and it is interesting to describe what this involves. Without going into the detail of the roles of the various layers of management, these committees are:

- *Planning and Resources Committee* of the University, chaired by the Pro-Vice-Chancellor for Planning and Resources.
- *Buildings Committee,* responsible for providing advice on technical aspects of the project and value for money.
- The *West and North-West Cambridge Estates Academic Board*, responsible for the overall direction and co-ordination of academic capital projects on the University's West and North-West sites.
- The *New Cavendish Project Board*, responsible for delivering the project within the agreed funding with the Planning and Resources Committee and the West and North-West Cambridge Estates Academic Board.
- The *Cavendish Logistics Committee,* coordinating and prioritising user requirements, both internal and external, at Departmental level.

This Committee structure has now been set up and is in operation.

## The Facilities Steering Committee

One of the new features of the programme is that the Laboratory will take on the role of a National Facility, providing services and facilities to the UK Physics community as a whole. The Facilities Steering Committee is responsible for providing strategic direction and oversight of the national facility aspects of the project to ensure that the commitment to widening access to the whole UK community of the Laboratory's facilities is delivered. This committee reports through the Engineering and Physical Science Research Council (EPSRC) to government and has now been set up with wide representation of the Laboratory and the national community of physicists. Besides Cambridge representation, the Committee includes senior representatives of the University community, the EPSRC and the National Physical Laboratory. We are delighted that Andy Parker has been re-appointed Head of the Cavendish Laboratory until 2022, following his exemplary leadership of this huge project (Fig.1).

## Operating model for the Cavendish Laboratory as a National facility

A draft document describing how the laboratory will operate during the operational phase starting in 2021-2022 has been prepared in consultation with the University, the Laboratory and the EPSRC.

A key role will be played by the ***Facilities Steering Committee*** in ensuring that the Laboratory delivers its commitments to government in supporting the UK science community in a fair and open manner. This committee will be supported by the Laboratory's ***Science Service Unit*** which will ensure that external users are provided with the expected level of service in obtaining their science products and being able to reduce and interpret their data effectively.

## Outlook

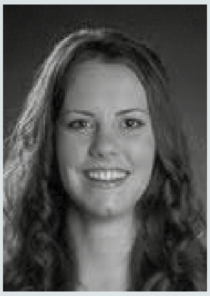
Needless to say, we are delighted that we are in such a strong position in going forward to the next phase of the Laboratory's role in the support of pure and applied physics research. Our plan is to keep readers up-to-date with the progress of the project, which is undoubtedly one of the most important and exciting many of us have ever been involved in.

**MALCOLM LONGAIR**

**FIG. 1 (opposite). Andy Parker (right) and Richard Phillips (left) looking in the direction of what will become the new entrance to the laboratory, with the steel reinforcement of the 1 metre thick slab in the background. Richard has been leading the Cavendish Laboratory's management of the construction project very effectively, while Andy, as Head of the Laboratory, has overall responsibility for all aspects of the Laboratory's involvement in its construction and operational phases.**

**FIG. 2 (above). The reinforcement in the area which will ultimately be part of the bicycle park underneath the entrance plaza right outside the entrance to the new building.**

# 'Mind the Nano Gap' at the Royal Society



**From 2nd - 8th July 2018 researchers from the University of Cambridge EPSRC Centre for Doctoral Training in Nanoscience and Nanotechnology (NanoDTC) presented the *Mind the Nano Gap* exhibit at the 2018 Royal Society Summer Science Exhibition in London, the most prestigious UK science festival. Giuliana Di Martino and Nikki Weckman describe a remarkable week of Nanoscience adventures.**

*Mind the Nano Gap* was one of 22 exhibits selected for the week-long festival celebrating the very best of UK science. Over 30 Cambridge NanoDTC students and associates were involved in putting the exhibition together, and had the chance to showcase their exciting research to the public during daily free sessions, as well as to Fellows of the Royal Society and invited guests during two evening black-tie Soirees (Fig.1).

One of us (Giuliana Di Martino), recently appointed to a Winton Advanced Research Fellowship and lead organiser of the event, was quoted as saying:

*"The exhibition was an incredible interdisciplinary showcase, a great success which attracted more than 15,000 people, capturing the attention of media and politicians, being reported by the press - The Times, The Sunday Mail, Business weekly - as well as being aired on radio and television with the BBC and London Live (Fig.2 (top))."*

*Mind the Nano Gap* introduced visitors to the biosensors of the future that use nanoscale techniques to detect molecules in extremely small quantities. In healthcare, it is critical to be able to measure traces of molecules with great accuracy. Many interesting and important biological molecules like DNA and proteins, however, are very small and we are constantly improving our ability to observe and measure them. But to make real progress, we need to measure the millions of times rarer signalling molecules that manage our health, and this needs vastly improved but affordable detection technologies. By pulling molecules of interest into the small space, or nanogap, between our tiny sensor components, they can now become visible to our instruments.

Various techniques exist to achieve this using nanopores, atomically thin membranes, or tiny gaps between nanostructures that are just billionths of a metre across.

**FIG 1. Volunteers in front of the Mind the Nano Gap Stand (top) during one of the sessions open to the public and (bottom) at one of the Soirees hosted for Fellows of the Royal Society and their guests.**

The *Mind the Nano Gap* exhibition took visitors on a tour of the exciting biosensing research being carried out at the NanoDTC through a number of hands-on activities and demonstrations. An experiment with plasma balls was presented to help understand nanogap sensing with lasers, an air tower was used to mimic the sensing of molecules through a nanopore, and visitors could hear (literally) how scientists sense molecules through mass and charge with an active nano-membrane (Fig. 2 (bottom)).

For instance, an exhibit showed how illuminating molecules with a laser can stimulate them to vibrate. Each molecule vibrates in a different way. Capturing the vibrational (Raman) signals allows us to see what molecule we are detecting. Placing these molecules in

**FIG. 2. (top) Giuliana Di Martino, event organizer, showcasing the exhibit to the media. (bottom) Nikki Weckman playing with the graphene membrane with young people visiting the exhibition.**

the gap between two gold nanoparticles increases the detected vibrational signals. The extremely intense light in the nano-gap vigorously shakes the bonds of molecules in their vicinity causing them to emit different colours. This allows us to see the chemical structure of the biomolecules inside the nano-gap.

Another activity aimed to describe how we can force biological molecules to pass through nanopores, tiny holes with diameters only tens of nanometres in size. As the molecules pass through the pore, they change the number of ions from the solution going through the pore at the same time. These changes in current differ depending on the type of molecule that passes through the nanopore. Therefore, by analysing the number and shape of the changes in the current, we can see which molecules are present and how many there are in a solution. We are thus able to detect many different molecules in one measurement, including those that are indicators of health.

The young people also fell in love with a colourful vibrating membrane. Very thin membranes made of graphene, for example, are very sensitive to molecules sticking on their surfaces by changing the way they vibrate, or their electrical properties. By studying these changes in the membrane, we can "see what's there" and exploit it for sensing applications. Membranes made of graphene are particularly interesting because of their thickness, a sheet of graphene being made from a single layer of carbon atoms. This thin graphene surface is therefore extremely sensitive to anything touching it.

This latest NanoScience research carried out at the University of Cambridge could be used to recognise traces of molecules in urine, for example. This would allow easy, real-time health monitoring or drug testing in hospitals and even has applications in your own home, such as the 'intelligent toilet', on show during the exhibition.

Jeremy Baumberg, Director of the Cambridge NanoDTC, said:

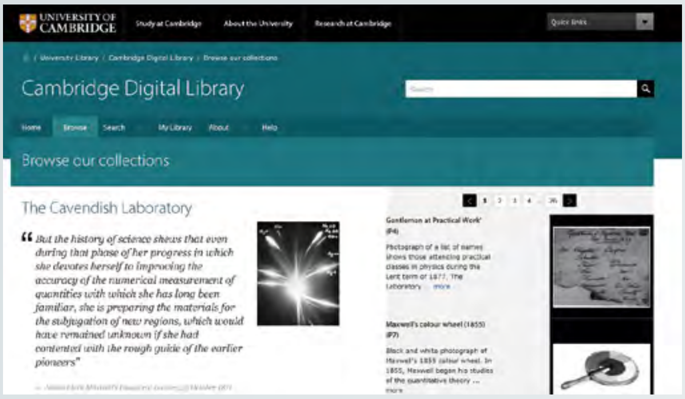
*"We have very little idea how well our body is doing on the inside – and particularly whether our brain is out of whack or our hormones unsettled. Personalised medicine offers the vision to track our health individually, but is generally limited to simple things that can be collected using wearable devices, like heart rate or sleep patterns. What we really need is access to some of the important molecules circulating inside us, but so far this is too expensive to do in the home. Our intelligent toilet exhibit showcased a new way we could access this by checking crucial molecules of interest that flow out in our urine. One current application for the system is towards better treatment of patients who suffer from depression, as no method exists to determine accurately the dosage of medication required. However, this could also be extended to other disorders and, possibly, drug testing."*

Ethical issues surrounding these technologies were also discussed and visitors to the intelligent toilet exhibition were invited to become actively part of the research by expressing how they felt about the privacy of the biomedical information produced from this intriguing technology through completing a short ethical survey.

**GIULIANA DI MARTINO AND NIKKI WECKMAN**

For more information about the event, see
**http://Nanogap.nanodtc.cam.ac.uk**

# Cavendish Laboratory Digital PhotoArchive goes live




**The Laboratory has a very rich history of discovery and innovation in Physics and its cognate disciplines. Fortunately, many of the important instruments, pieces of apparatus, events and the personalities involved have been preserved photographically. These photographs provide a vivid picture of the development of physics and bring to life the genius and ingenuity of past members of the Laboratory from the Maxwell era onwards.**

The present collection of photographs is the legacy of generations of photographers who recorded equipment, buildings and events for posterity. The core of the photographic collection is a sequence of over 1800 glass plates, film negatives and prints compiled in the 1970s by the Laboratory Photographer at the time Keith Papworth (hence the P numbers). In addition, there are thousands of photographs from the later period. The preservation of the most important of these in an accessible digital Photographic Archive has been a priority as we begin a new phase in the history of the Laboratory with the rebuilding of the whole Laboratory to be completed in 2022. We wish this historical material to be made widely available to all interested parties.

In this first release, we have selected a sample of 202 images of historical importance from the Papworth catalogue, mostly from the early history of the Laboratory up to about the 1970s. These include a number of images from the Cavendish Snapshot Albums which were initiated by Eryl Wynn-Williams in 1927. These much more informal images give a striking picture of life in the Laboratory, including hockey and cricket matches, which complement the more formal images taken by professional photographers. All the black and white plates and negative films as well as the colour images have been professionally scanned at very high resolution.

Of the 202 images, 163 are in black and white and 39 in colour.

We will be adding to the collection with the aim of providing as comprehensive a Photo Archive of the History of the Laboratory as is feasible. The archive went live this summer and can be accessed at:

**https://cudl.lib.cam.ac.uk/collections/cavendish**

When you enter the website, you will be presented with the home screen shown on the left.

By clicking on the desired image in the right-hand column of the screen, you will find an enlarged image with brief historical details of what is shown, as well as technical details about the image itself. The example below shows a wonderful photograph of Francis Aston with his third mass spectogtraph (P42). The images can be greatly enlarged on screen to show their remarkable quality.

For permission to use and reproduce any of these images, we follow the procedures established by the University Library's Cambridge Digital Library. Once you have selected the image of interest, please click on boxes on the right-hand side to find out how the material can be used and if fees are payable – the latter is generally only for material to be used for commercial purposes. We ask all users of this material to go through the procedure of registering their use so that we can keep a track of how it is being used.

We are about to enter the next phase of the project which will be to continue to preserve digitally the next batch of historic images. We can assure you that there are lots of treasures in store.

**ISOBEL FALCONER AND MALCOLM LONGAIR**

# Isobel Houghton one of the Top 50 Women in Engineering 2018

**We are delighted to report that Isobel Houghton, a former Cavendish undergraduate and postgraduate student, has been chosen as one of the Top 50 Women in Engineering 2018, an initiative sponsored jointly by the Women's Engineering Society (WES) and the *Telegraph* to raise the profile of women in engineering.**

Isobel, then Isobel Piper, read Experimental and Theoretical Physics at Clare, obtaining a first class degree, and then completed a PhD in the Atomic, Mesoscopic and Optical Physics Group under the supervision of Richard Phillips. During her PhD, she developed experimental techniques to control single electrons in semiconductors. Throughout her studies at the University of Cambridge she was involved in public engagement, organising and participating in fortnight-long roadshows and school visits with Cambridge Hands-On Science (CHaOS).

In 2013, she then joined Atkins where she is now a Senior Engineer working as a consultant to the energy industry. She leads a programme of seismic assessment of UK power stations, supporting the operation of approximately 20% of the UK's generating capacity.

As Atkins' representative to the Women in Nuclear Western group, she shares best practice with other organisations, for example as an invited speaker at the 2017 Nuclear South West conference and at the Department for International Trade. She has worked with the Institute of Physics, sharing her experiences of maternity career breaks and part-time working at the 2018 Women Physicists in the Nuclear Industry event.

Design, experiment, analysis and computational modelling have been key themes throughout Isobel's career. She has demonstrated the transferability of these skills, all essential for a successful and fulfilling career in engineering. She actively encourages other women to choose careers in engineering and challenges employers to change their policies to ensure engineering is an attractive career for everyone.

We are very proud of Isobel's achievements. She is an excellent role-model for how training in the physical sciences can lead to a very successful career in physics-based industries.

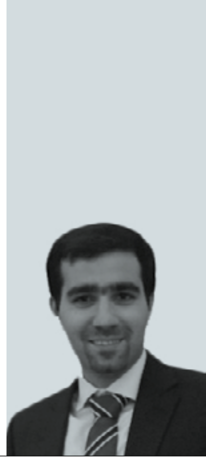
# Roberto Maiolino knighted

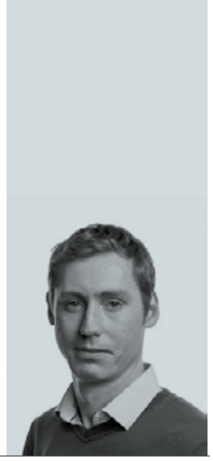
**We congratulate Roberto Maiolino, Professor of Experimental Astrophysics in the Cavendish Laboratory and Director of the Kavli Institute for Cosmology, on being made a knight of the Order of the Star of Italy (OSI). The decoration was presented to him by the Italian ambassador to the UK, Raffaele Trombetta, on behalf of the Italian president, in recognition of Roberto's work in promoting British-Italian relations in the field of science through his teaching work at universities and his research.**

Roberto obtained his degree in physics and his doctorate in research from the University of Florence. In the course of his subsequent work abroad, he has maintained close links with Italy. In addition to holding the post of associate astronomer at the Rome Astronomical Observatory until 2012, he is a member of the Scientific Council coordinated by the Embassy of Italy in London, a body that advises the embassy's Science Office on its activities and selects recipients for awards and scholarships that are offered to young Italians in the UK.

Roberto has made a huge impact upon experimental astrophysics in Cambridge since his appointment as Professor of Experimental Astrophysics. He brought a completely new vision of how the Cavendish Astrophysics Group contributes to contemporary astrophysics and cosmology, an example being the article in this edition of CavMag by Renske Smit.

In the photograph, Roberto, his family, members of the Kavli Institute and other colleagues joined the celebrations at the Italian Embassy in London with Ambassador Trombetta and his wife (front centre).





# Perovskite-based solar cells become even more competitive

**MOJTABA ABDI-JALEBI, SAM STRANKS and their colleagues have discovered that the addition of potassium iodide boosts the performance of perovskite-based solar cells by 'healing' defects and immobilising ion movement, which to date have limited the efficiency of cheap perovskite solar cells.**

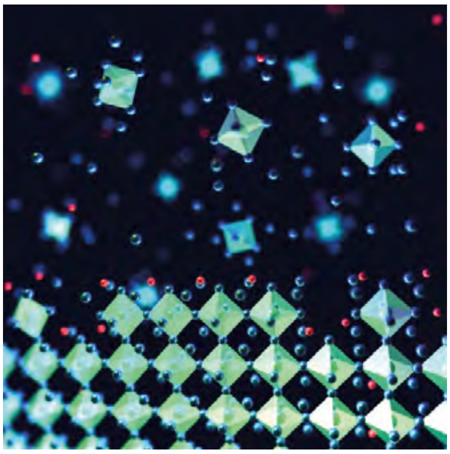


**FIG. 1. Artistic visualisation of an atomic scale view of perovskite crystal formation in the presence of potassium cations (red spheres).**

In a recent publication in *Nature*, further developments in the effectiveness of solar cells based on metal halide perovskites have been reported. These materials constitute a promising group of ionic semiconductor materials that, in just a few short years of development, now rival commercial thin film photovoltaic technologies in terms of their efficiency in converting sunlight into electricity. Perovskites are cheap and easy to produce at low temperatures, which makes them attractive for next-generation solar cells and lighting.

Despite the potential of perovskites, there have been limitations which have hampered their efficiency and consistency. Tiny defects in the crystalline structure of perovskites, called traps, can cause electrons to get 'stuck' before their energy can be harnessed. The easier the electrons can move about in a solar cell material, the more efficient that material becomes in converting photons, particles of light, into electricity. A further issue is that ions can move about in the solar cell when it is illuminated, which can cause a change in the bandgap and consequently the colour of light the material absorbs. The challenge the team faced was to make these materials stable with the bandgap needed, and so they tried to immobilise the ion movement by tweaking the chemical composition of the perovskite layers. If successful, this would enable perovskites to be used as versatile solar cells or as coloured LEDs, which are essentially solar cells run in reverse.

In the study, the chemical composition of the perovskite layers was changed by adding potassium iodide to perovskite inks, which then self-assemble into thin films (Figs. 1 and 2). The technique is compatible with roll-to-roll processes, which means that it is scalable and inexpensive. The potassium iodide formed a 'decorative' layer on top of the perovskite which had the effect of 'healing' the traps so that the electrons could move more freely, as well as immobilising the ion movement, which makes the material more stable with the desired bandgap.

We have demonstrated promising performance with perovskite bandgaps ideal for layering on top of a silicon solar cell or with another perovskite layer, the so-called tandem solar cells. Silicon tandem solar cells are the most likely first widespread application of perovskites. By adding a perovskite layer, light can be more efficiently harvested from a wider region of the solar spectrum.

Potassium stabilises the perovskite bandgaps needed for tandem solar cells and makes them more luminescent, which means more efficient solar cells. It almost entirely manages the ions and defects in perovskites (Fig. 3).

The perovskites turn out to be very tolerant of additives – you can add new components and they'll perform better. Unlike other photovoltaic technologies, we don't need to add an additional layer to improve performance – the additive is simply mixed in with the perovskite ink.

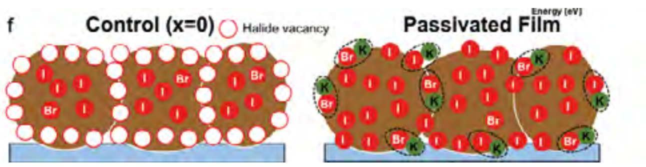
The perovskite and potassium devices showed good stability in tests, and were 21.5% efficient in converting light into electricity, which is similar to the best perovskite-based solar cells and not far below the practical efficiency limit of silicon-based solar cells, which is 29% (Fig. 4). Tandem cells made of two perovskite layers with ideal bandgaps have a theoretical efficiency limit of 45% and a practical limit of 35% - both of these are higher than the current practical efficiency limits for silicon. You get more power for your money.

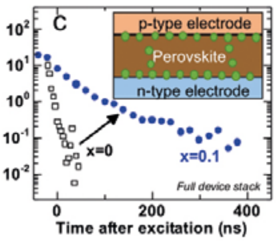
These next-generation solar cells could be used as an efficiency-boosting layer on top of existing silicon-based solar cells, or be made into stand-alone solar cells or coloured LEDs.

The research has been supported in part by the Royal Society and the Engineering and Physical Sciences Research Council. The international team included researchers from Cambridge, Sheffield University, Uppsala University in Sweden and Delft University of Technology in the Netherlands. Sam Stranks is leader of the group in Optoelectronics and holds a Royal Society University Research Fellowship. The research is also supported by the European Research Council Award HYPERION.

**Reference:**

Mojtaba Abdi-Jalebi, *et al.* 'Maximizing and stabilizing luminescence from halide perovskites with potassium passivation', *Nature*, 555, 497–501, 2018.



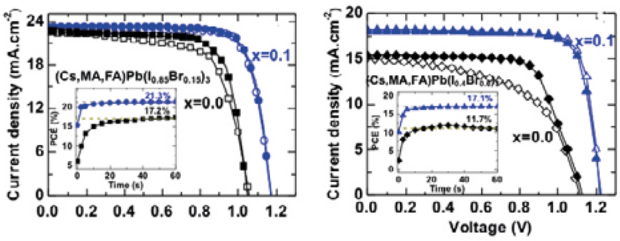




**FIG. 2. (top). Cross-section of a film showing halide-vacancy management in cases of excess halide, in which the surplus halide is immobilized through complexing with potassium into benign compounds at the grain boundaries and surfaces.**

**FIG. 3 (middle). Luminescence properties. Time-resolved photoluminescence decays of encapsulated perovskite films without (x = 0) and with potassium (x = 1) passivation with excitation at 400 nm and a pulse fluence equivalent to about that of the sun, when the perovskite is interfaced with both electrodes in a full device stack.**

**FIG. 4 (bottom). Enhanced solar power conversion efficiency. (a) Forward (open symbols) and reverse (closed symbols) J–V curves of the best-performing solar cells with perovskite absorbers without and with passivation under full simulated solar illumination conditions. Inset, stabilized power output under the same conditions. (b), J–V curves of the best-performing solar cells for perovskite absorbers without (x = 0) and with (x = 0.1) potassium passivation.**

## Helen Megaw and Perovskites

When Laurence Bragg reconstructed the physics programme of the Laboratory after the Second World War, the programme of X-ray crystallography expanded greatly with Will Taylor as Reader in Crystallography and Head of the Crystallography Group. Among those who joined the group was Helen Megaw who had been trained in X-ray crystallography by Desmond Bernal during her PhD studies in the Laboratory in the early 1930s.

After seven years of school teaching, she joined Philips Lamps Ltd in Mitcham in 1943 where she worked on the crystal structure of barium titanate, an important industrial mineral. This material crystallises into the class of minerals known as perovskites and has the property of being ferroelectric. It was during this period at Philips Lamps that Helen first determined the crystal structure of perovskites using her expertise in X-ray crystallography. As Michael Glazer has written,

**'She had a particularly interesting gift: a rare ability to be able to visualise in three dimensions, so that she could take a crystal structure and turn it around in her mind and then sketch it from any perspective. In the days before computer graphics, this was a very useful trick, especially for a crystallographer, who must somehow always be able to appreciate three-dimensional architecture.'**

She became a Fellow and Director of Studies in Physics at Girton College in 1946 and became only the second woman tenured member of the Academic staff of the Laboratory in 1949. She was a memorable and demanding teacher, particularly of experimental physics at which she excelled. She retired to her native Northern Ireland in 1972. In 1989 she became the first woman to receive the prestigious Roebling medal of the Mineralogical Society of America and in 2000 was awarded an honorary degree of Queen's University Belfast.

The perovskite story thus comes full circle with Helen's pioneering research supporting the study of these important materials in so many applications.

**Reference:**


A.M. Glazer, 2008. *Megaw, Helen Dick (1907-2002)*, Oxford Dictionary of National Biography, Oxford University Press. https://doi.org/10.1093/ref:odnb/76773

# Order in the Chaos of the early Universe

**We are delighted to report that RENSKE SMIT has been awarded the 2018 MERAC Prize of the European Astronomical Society for the Best Doctoral Thesis in Observational Astrophysics. She is currently a postdoctoral fellow in the Laboratory, supported by a NWO Rubicon grant. In the autumn of 2018 she will take up a Newton-Kavli fellowship at the Kavli Institute for Cosmology in Cambridge. Here she describes the remarkable results of her thesis and recent observations.**

Ever since Edwin Hubble uncovered the nature of spiral galaxies, astronomers have been fascinated by the organised spiral structure and disk rotation of these 'Island Universes'. Looking at Messier 101 (Fig. 1 (left)) one cannot help but wonder how such galaxies were formed and whether all star-forming galaxies in the history of the Universe have had similar appearances at some stage.

With the continuous improvement of astronomical instrumentation, optical 8- to 10-meter class telescopes have been able to make studies of earlier generations of star-forming galaxies up to about 10 billion years back in time, spanning roughly 70% of the history of the Universe. The further we look back in time, clear changes in the appearance of these galaxies are observed. These star-forming galaxies observed billions of years ago already rotated in thick, 'puffed-up' disks but their spiral-arm morphology had not yet developed (Fig. 1(right)). The increased turbulence in the gas of these galaxy disks has suggested that the rapid inflow of gas in the dense early Universe is important in determining their structures.

These results pose many questions about the earliest generations of galaxies during the first three billion years of cosmic time. When did the first disk-like star-forming galaxies, distant cousins of our own Milky Way, appear in the history of the Universe? Does the highly turbulent environment in which galaxies form just after the Big Bang prevent the formation of ordered disk rotation? New research with the Atacama Large Millimetre Array (ALMA) carried out while I have been at the Cavendish Laboratory suggests that we are on the brink of answering some of these very fundamental questions.

In our current understanding of the early Universe, the first stars formed a few hundred million years after the Big Bang from essentially pristine hydrogen gas. The first stars are thought to be supermassive and explode as supernovae on very short timescales. The first supernovae pollute their environments with elements such as carbon and oxygen which are synthesised in these explosions and these elements enable the gas to cool rapidly to form the new populations of stars that make up the first galaxies.

With modern-day telescopes we are able to look back in time and search for galaxies that formed in the first billion years of cosmic time, often referred to as "cosmic dawn". While the light from these galaxies travels to the Earth, the expansion of the Universe stretches the wavelengths of all the emitted electromagnetic radiation. This reddening, or 'redshift' of radiation from the early Universe, has proved to be both a blessing and a curse. On the one hand, the exact determination of redshift is a remarkably effective and precise means of determining the cosmic epoch at which the light was emitted. On the other hand, the starlight from the most distant objects in the Universe that reaches our ground-based telescopes is shifted out of the optical 'window' of the Earth's atmosphere, where transmission of radiation is high, into the more challenging infrared wavelength regime.

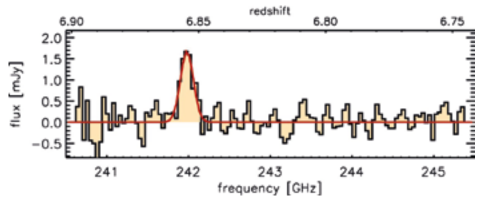
In order to determine the redshift of light, and thereby determine the distance and look-back time of the most distant galaxies, we need a sharp feature, preferably a narrow emission line, in the spectra of the objects we are studying. For galaxies close to home, we find a wealth of emission lines in the spectra of star-forming galaxies in the optical spectrum. For the most distant galaxies, however, these lines are redshifted into that part of the electromagnetic spectrum where light barely penetrates the atmosphere and out of the wavelength range of present-day space-based spectrographs. Observers of the distant Universe have therefore shifted their focus towards the long wavelength regime of the (sub)millimetre sky. At these low frequencies, at the edge of the high-transmission radio window of the atmosphere, we are now seeing the signatures of cool gas and dust of some of the most distant galaxies in the Universe.

New discoveries in this wavelength regime have grown exponentially once ALMA become fully operational in 2013 (Fig 2). ALMA is the largest sub-millimetre telescope array in the world consisting of 66 millimetre/submillimetre antennae on a high plane in the Atacama desert in Chile. It operates as an interferometer to obtain high-resolution, ultra-sensitive images and spectra of the Universe. The Cavendish Laboratory has contributed substantially to the development of this telescope by providing some of the instrumentation essential for the observations, particularly, the water vapour radiometers, and by also hosting ALMA's first Project Scientist, Richard Hills.

A team of scientists led from the Cavendish Laboratory, which I coordinated and which included Stefano Carniani and Roberto Maiolino, recently used ALMA to obtain precision measurements of the redshifts of two galaxy candidates during the first billion years of cosmic time, the first time such a measurement has been carried with a sub-millimetre telescope. These galaxies were selected from images obtained from both the Hubble and Spitzer Space Telescopes, but these telescopes did not have spectroscopic facilities to confirm their extreme distances. A short frequency 'scan' of both sources by ALMA revealed a transition of ionised carbon - typically the brightest collisional excited fine-structure line emerging from star-forming galaxies - and confirmed a look-back time of almost 12.9 billion years, 94% of the age of the Universe (Fig.3).

While the success of the redshift determinations was an important proof of concept for ALMA's role in early Universe research, the observations yielded another unexpected result. The relatively bright carbon lines were remarkably spatially extended and, despite the low-angular resolution of the observations, the velocity structure within such galaxies was revealed for the first time by mapping the variations in the Doppler shift of the lines (Fig. 4).

The smooth gradient in the velocity of the gas is highly suggestive of the rotation of disk-like galaxies, similar to those seen three billion years later in cosmic time, during the peak epoch of star-formation in the Universe. Despite the turbulent environments in which these early galaxies are located, they seem to be able to 'mature' early and settle down into relatively regular systems. Some theoretical models and cosmological numerical simulations had recently highlighted the possibility that galactic disks formed very early in the



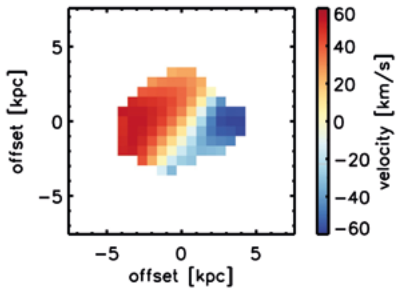




**FIG. 1 (left): Messier 101, a disk galaxy in the local Universe. right: a clumpy turbulent disk galaxy observed 3 billion years after the Big Bang.**

**FIG. 2 (below) The Atacama Large Millimetre Array (ALMA), the most powerful sub-millimetre telescope on Earth, showing some of the 66 antennae.**

**FIG. 3 (above top) Detection of a fine-structure transition of ionised carbon that determines the redshift of the galaxy (z = 6.854), corresponding to a cosmic epoch 800 million years after the Big Bang.**

**FIG. 4 (above bottom) Velocity structure measured in a galaxy 800 million years after the Big Bang.**

primeval Universe and the new ALMA observations have nicely confirmed this scenario. New observations with ALMA at higher angular resolution are underway and will provide us with even more physical insight into the kinematics of galaxies during this crucial first epoch of galaxy formation.

**References:**

Rotation in [C II]-emitting gas in two galaxies at a redshift of 6.8
Renske Smit, Rychard J. Bouwens, Stefano Carniani, Pascal A. Oesch, Ivo Labbé, Garth D. Illingworth, Paul van der Werf, Larry D. Bradley, Valentino Gonzalez, Jacqueline A. Hodge, Benne W. Holwerda, Roberto Maiolino & Wei Zheng. *Nature*, **553**, 178–181, 2018.

# On Maxwell, Reduced Momenta, Electromagnetism and Governors – the Mechanical Origins of Maxwell's Equations

I recently reviewed the route James Clerk Maxwell took to his discovery of his equations for the electromagnetic field in a paper celebrating the 350th Anniversary of the founding of the *Philosophical Transactions of the Royal Society* (Longair 2015). Maxwell's great paper of 1865 is a wonderful exposition of the theory and is not hard to follow once the notation is translated into modern usage. His reliance upon mechanical analogues was only too apparent in his earlier papers of 1856 and 1861-62. In his assessment of the significance of Maxwell's 1865 paper, Whittaker famously remarked that

*'In this, the architecture of his system was displayed, stripped of the scaffolding by aid of which it had been first erected.'*

Indeed, the vortex tubes, idler wheels and so on have disappeared and yet the mechanical roots of his insights are present in Section 2 of the 1865 paper. This section illuminates Maxwell's deep understanding of mechanics and electromagnetism and his remarkable continued use of working by analogy.

His starting point is the application of two forces $F_A$ and $F_B$ to an extended rigid body at two separate 'driving points'. By working in terms of energy and changes in velocity $v$, Maxwell arrives quickly at the key result

$$\left.\begin{aligned} F_{\mathrm{A}} &= \frac{\mathrm{d}}{\mathrm{d}t}(L_{\mathrm{A}}v_{\mathrm{A}} + M_{\mathrm{AB}}v_{\mathrm{B}})\,, \\ F_{\mathrm{B}} &= \frac{\mathrm{d}}{\mathrm{d}t}(M_{\mathrm{AB}}v_{\mathrm{A}} + L_{\mathrm{B}}v_{\mathrm{B}})\,, \end{aligned}\right\}$$

**(1)**

where the terms $L_A$ and $L_B$ are the weighted masses of the extended body and $M_{AB}$ represents the coupling between the impressed forces by the rigid body. Maxwell now introduces Newton's second law $F = \mathrm{d}p/\mathrm{d}t$, where $p$ is a momentum. The quantities ($L_A v_A + M_{AB} v_B$) and ($M_{AB} v_A + L_B v_B$) are then defined as the *reduced momenta* which describe the combined action of the two forces applied at the points A and B to the extended rigid body. Although these forces are independent, they are coupled - the reduced momentum at A includes the effect of the force at B and vice versa. He then adds frictional terms of the form $R_A v_A$ and $R_B v_B$ to each of equations (1) where the $R$s are the coefficients of friction.

Maxwell then makes the following equivalences: the forces $F$ become the electromotive forces $\mathcal{E}$, the velocities $v$ become the currents $I$, the $L$s and $M$ become the self and mutual inductances respectively and $R_A$ and $R_B$ become the electrical resistances. Then, the equations of electromagnetic induction between two current-carrying conductors are

$$\mathscr{E}_{\mathrm{A}} = R_{\mathrm{A}}I_{\mathrm{A}} + \frac{\mathrm{d}}{\mathrm{d}t}(L_{\mathrm{A}}I_{\mathrm{A}} + M_{\mathrm{AB}}I_{\mathrm{B}})\,,$$

$$\mathscr{E}_{\mathrm{B}} = R_{\mathrm{B}}I_{\mathrm{B}} + \frac{\mathrm{d}}{\mathrm{d}t}(M_{\mathrm{AB}}I_{\mathrm{A}} + L_{\mathrm{B}}I_{\mathrm{B}})\,.$$

**(2)**

Mechanics has been translated by analogy directly into electromagnetism. From these, he goes on to derive the expressions for work and energy, the heat produced by the currents, the intrinsic energy of the currents and the mechanical action between conductors, and much more.

In typical Maxwellian fashion, he then designed a mechanical model which illustrates precisely the rules of electromagnetic induction in mechanical terms. Fig.1(a) shows the illustration on page 228, Volume 2 of the third (1891) edition of Maxwell's *Treatise on Electricity and Magnetism*. This edition was edited by J.J. Thomson and published 12 years after Maxwell's death. The model, built by Messrs Elliot Brothers of London in 1876, is shown in Fig.1(b). The extended rigid body C is a flywheel which consists of two long steel rods at right angles to each other to which heavy weights are attached towards the four ends of the rods, giving the flywheel a large moment of inertia. Forces are applied to the flywheel to cause it to rotate through the differential gear arrangement shown in Fig. 1(a). To make the arrangement clearer, I have redrawn the differential gearing schematically in Fig. 2(a) and (b). A and B are attached to separate axles which have bevel gears at their ends. They mesh with the horizontal bevel gear X, as shown in Fig. 2(a), which is attached to the flywheel but which is free to rotate about its own axis. The discs A and B are the origins of the forces $F_A$ and $F_B$ and their 'independent driving points' are the opposite sides of the bevel gear X.

Suppose B is stationary while A is rotated at the constant speed $v_A$. Then, the flywheel only rotates at half the speed of A. In fact, by geometry, the flywheel always rotates at the average speed of rotation of the discs A and B. I can confirm that this is indeed the case when I repeated the demonstrations with Maxwell's original apparatus, which the Whipple museum kindly allowed me to operate. Now suppose we accelerate the rotation of A. Since $F = m_A(\Delta v_A/\Delta t)$, there is a force acting on the bevel gear X. But the gear is attached to the flywheel and so there is a reaction force in the opposite sense acting on B. In other words, when the disc A is accelerated, the result is a couple acting on the bevel gear X which causes the disc B to rotate in the opposite direction. But, notice, this reaction force at B only takes place during the period when the disc A is accelerated. It is the perfect mechanical analogue for electromagnetic induction, and includes Lenz's law.

What is remarkable about this analysis is that Maxwell's electromagnetic momentum is precisely what we now call the *vector potential*, $A \equiv [A_x, A_y, A_z]$. The origin of this identification is apparent from equations (1) which are no more than $\mathcal{E} = \partial A/\partial t$. In his paper of 1865, Maxwell works entirely in terms of *A* rather than the magnetic flux density *B* which is found from the relation *B* = curl *A*. In Section 3 of the paper, Maxwell goes on to use these tools to derive the complete set of Maxwell's equations. Maxwell's development presages the four–vector notation of special relativity in which the electromagnetic four potential is $[\varphi/c, A_x, A_y, A_z]$, with the dimensions of momentum divided by electric charge.

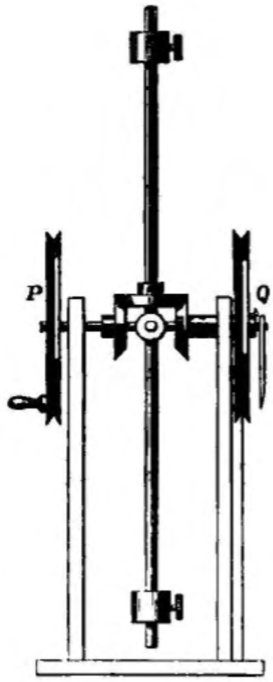
This analysis deepens our understanding of the role of the vector potential in classical physics. The general pedagogical opinion is that *A* has no real significance in classical physics beyond the fact that, when curled, it gives *B*. And yet, as soon as you tackle serious problems in electromagnetism, it is always best to start with *A*, find the distribution of *A* and then curl it. And, of course, in quantum mechanics, it is *A* which has to be quantised from the very beginning and which has real physical significance in phenomena such as the Aharonov-Bohm effect.

Remarkably, exactly the same mechanical equations (1) with the frictional terms included appear in a later paper by Maxwell *On Governors* of 1868. This paper on the stability of control systems is regarded by engineers as the pioneering paper in cybernetics.

Most text books would regard this essay as 'antiquarian' physics and yet what magic Maxwell distils from his technique of working and thinking by analogy. But the analysis involves what was at the time the controversy between Newton's action at a distance and Maxwell's model in which the force is transmitted by fields. In the initial mechanical part of the argument, 'mutual induction' takes place 'instantaneously' through the rigidity of the rigid body. In contrast, electromagnetic induction is transmitted by the influence of the electromagnetic fields. At the time, this was perceived as controversial precisely because Maxwell's field picture was not Newtonian. If nothing else, students should know that this is how the mind of a genius works.

**MALCOLM LONGAIR**

*Reference:* Longair, M.S., '. . . a paper . . . I hold to be great guns': a commentary on Maxwell (1865) 'A dynamical theory of the electromagnetic field'. *Phil. Trans. Roy. Soc.*, **A373**: 20140473 (2015).




(*a*)

(*b*)

**FIG. 1 (a) The diagram from Maxwell's Treatise on Electricity and Magnetism, 3rd edition showing the mechanical model he had built to illustrate the principles of electromagnetic induction. (b) The original model belonging to the Cavendish Laboratory and now on loan to the Whipple Museum, Cambridge University.**

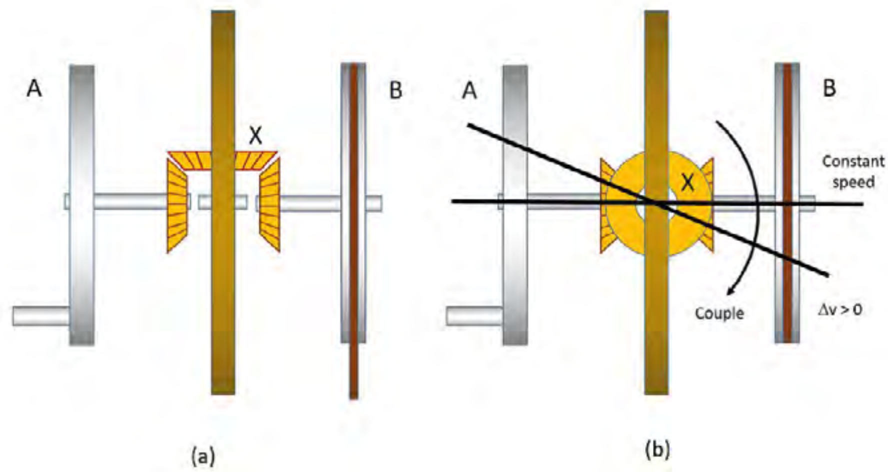



**FIG. 2 (a) A schematic diagram showing more clearly than Fig. 1 the arrangement of the bevel gears which transmit the forces to the flywheel. (b) Illustrating the origin of the couple acting on the system when the disc A is accelerated.**

Many congratulations indeed to **Catherine Clifton**, our Print Room Supervisor and reception lead, who has received a long service award from the University on completion of 35 years' service. Over the years Catherine has provided support and advice to thousands of staff, students, visitors, delivery people and contractors and this recognition for her long service is thoroughly well deserved.

## Promotions




We congratulate the following staff members on their promotions in the 2018 promotion round:
**Dr Malte Grosche** to a Professorship
**Dr Sian Dutton** to a Readership
**Dr Ulrich Schneider** to a Readership
**Dr Rachael Padman** to a Senior Lectureship

**Richard Lidstone** has been appointed HR and Events Administrator in the Kapitza Hub.

## Awards

We congratulate Winton Fellow **Rosana Collepardo** on her award of a €1.5 million ERC starting grant to develop a novel multi-scale computational method to investigate the organization of the genome with sub-nucleosome resolution.

We are delighted to congratulate **Carmen Palacios Berraquero** on her award of the Jocelyn Bell Burnell medal of the Institute of Physics for 'discovering and patenting a method to create single-photon emitting sites in atomically-thin materials, deterministically – and for using a 2-dimensional device to all-electrically induce quantum emission from these sites.'

## Advanced Fellowships

We congratulate **Giuliana Di Martino** (Page 8) and **Bartomeu Monserrat Sanchez** (left) on their appointments to Winton Advanced Research Fellowships. Giuliana describes the Nanoscience Royal Society Exhibition, in which she played the lead role, on Pages 8 –9. Bartomeu has also been awarded the prestigious Psi-k Volker Heine Young Investigator Award for his research on 'Temperature effects in spin-orbit physics from first principles'

## Arrivals

**Joshua Brett** has taken up the role of Graduate Studies Administrator in the Graduate Office. He previously worked for the Open University in a senior student support role.
**James Dean** CSC CDT Co-ordinator & Senior Teaching Associate
**Jason Hardy** Workshop Principal Technician
**Basak Yilmaz** Rutherford Hub General Administrator
**Thomas Daff** IT Team Linux System Admin/Developer
**Stephen Haws** ME Research Laboratory Technician
**David Hunt** Central Admin Project Manager (CAV III)
**Anya Howe** Safety Office Departmental Safety Technician.
**Sean Geraghty** Workshop Staff
**Egle Bunkute** Kapitza hub Staff

## Returners

**Roger Beadle** ME Temporary Senior Chief Laboratory Technician

## Books

**Jeremy Baumberg** has published a popular (social) science book, "The Secret Life of Science: How it Really Works and Why it Matters" which describes how science is now like an ecosystem, with extreme competition skewing what happens. The book has been published by Princeton University Press and is widely available.

## Ray Dolby Tribute on YouTube

This film describes the impact of innovations, discoveries and ideas that have come out of the Laboratory over the past 140 years, and the work and legacy of sound engineer Ray Dolby. He carried out his PhD at the Cavendish in X-ray microanalysis. His subsequent pioneering research led to the Dolby noise reduction system which changed the way the world listens. The Dolby family have donated £85 million to the Cavendish Laboratory to support basic physics and the construction a new Cavendish Laboratory for the 21st century.

The film can be viewed at: **https://youtu.be/Ci5VN88_jnc**

THE WINTON PROGRAMME FOR THE

Physics of Sustainability

Seventh Annual One-Day Symposium
1st November 2018
Cavendish Laboratory

# MACHINES

## From the cosmic to the nanoscale

PROFESSOR SHEILA ROWAN
Director, Institute for Gravitational Research, University of Glasgow
Gravitational wave detectors: precision measurement technologies and their applications

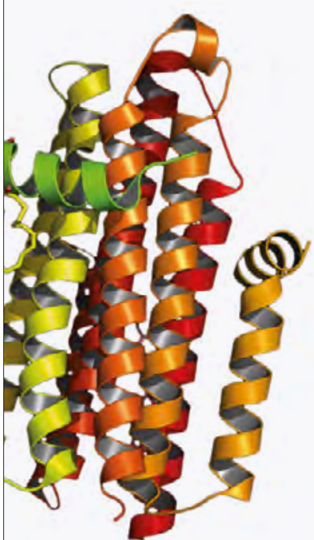
PROFESSOR ADRIAN THOMAS
Professor of Biomechanics, Zoology Department, University of Oxford, and Co-Founder and Chief Scientific Officer of Animal Dynamics Ltd
Taking inspiration from biomechanics to engineering, dragonfly drones and other bio-inspired vehicles

PROFESSOR MARK ALLEN
Alfred Fitler Moore Professor, Electrical and Systems Engineering and Mechanical Engineering and Applied Mechanics, and Director, Singh Center for Nanotechnology, University of Pennsylvania
Implantable Biomedical Microelectromechanical Systems

PROFESSOR CARLOS BUSTAMANTE
Raymond and Beverly Sackler Chair in Biophysics; Howard Hughes Medical Institute Investigator; Professor of Chemistry, Molecular and Cell Biology, and Physics
University of California, Berkeley
Power at the Nanoscale: Speed, Strength and Efficiency in Biological Motors

PROFESSOR MARK KASEVICH
Professor of Physics, Stanford University
Atom Interferometry for Geodesy and Fundamental Physics

PROFESSOR BARRIE MECROW
Professor of Electrical Power, Newcastle University
Electrical machines: from Microwatts to Gigawatts – the future challenges



UNIVERSITY OF CAMBRIDGE

For free registration, go to
**winton.phy.cam.ac.uk/machines**

# How you can contribute

**Online Giving**

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

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

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

**campaign.cam.ac.uk/giving/physics/outreach**
If you would like your gift to be applied to some other specific aspect of the Development Programme, please contact Andy Parker or Malcolm Longair. The Development portfolio is described in this edition of CavMag and is also available 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 Malcolm Longair (**msl1000@cam.ac.uk**) or Gillian Weale (**departmental.administrator@phy.cam.ac.uk**) who can provide confidential advice.

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

**CONTACT**

**The Cavendish Laboratory**
JJ Thomson Avenue, Cambridge, CB3 0HE
Tel: +44 (0)1223 337200
Email: hod@phy.cam.ac.uk
www.phy.cam.ac.uk

**Head of Department**
Professor Andy Parker
Tel: +44 (0)1223 337429
Email: hod@phy.cam.ac.uk

**Director of Development**
Professor Malcolm Longair
Tel: +44 (0)1223 765777
Email: msl1000@cam.ac.uk