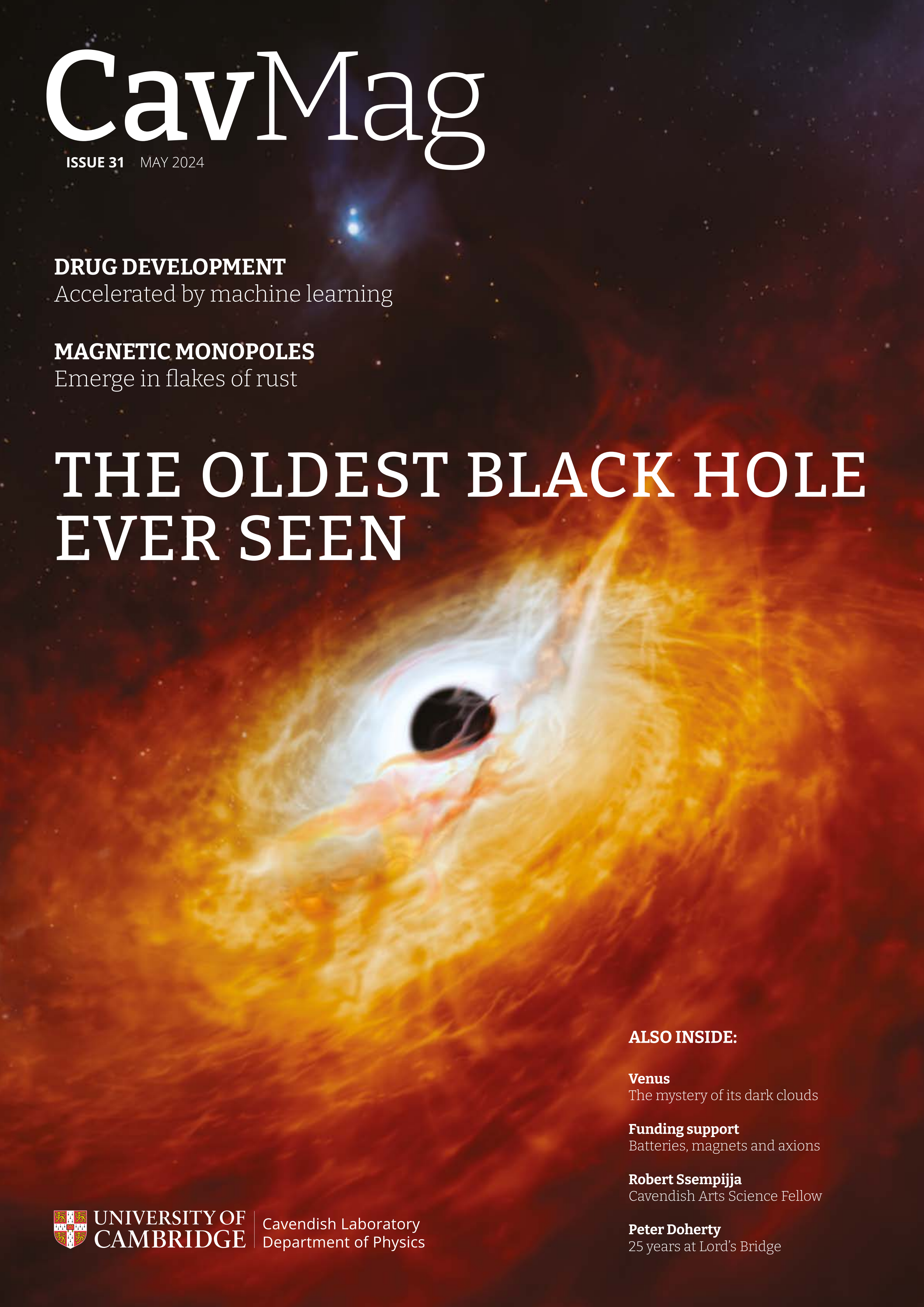

CavMag

ISSUE 31 MAY 2024

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Accelerated by machine learning

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Cavendish Arts Science Fellow

Peter Doherty
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UNIVERSITY OF CAMBRIDGE
Cavendish Laboratory
Department of Physics

Welcome
to CavMag 31

Harry Cliff

You may have noticed a slightly different look and feel to this latest edition of CavMag. Malcolm Longair founded this magazine in 2009 and remained at the helm for fifteen wonderful years, publishing 30 editions. It is a great privilege, and somewhat daunting, to be stepping into his substantial shoes as CavMag editor. To mark the start of this new era, the team have refreshed the design of the magazine, including what I think is a rather elegant new cover layout produced by CavMag's long-serving graphic designer Matt Bilton of Pageworks. We've also switched to a different recycled paper, giving the magazine more of the feel of a popular science magazine that you might find in your local newsagents. Alongside the new print edition is a new digital home for CavMag at cavmag.phy.cam.ac.uk, where you can find all the same articles, in a format that looks great whether you're browsing on a computer, tablet or smartphone.

However, while the look of CavMag may have changed, you'll still find the same stories of scientific research within its pages, along with recent developments and news from the Cavendish. After spending the past few weeks editing the articles that make up this 31st edition, I'm struck by the sheer breadth and quality of the research that the Cavendish Laboratory produces. Within these pages you'll find stories of the oldest black hole ever seen, new materials that may one day transform computer processing and energy storage, and novel phenomena that have emerged as Cavendish scientists probe complex atomic systems.

Another duty that I've inherited from Malcolm is the role of curator of the Cavendish Collection of historic scientific instruments. During the seven years when I spent half my time moonlighting from the High Energy Physics group as a curator of exhibitions at the Science Museum in London, I came to appreciate just how historically significant this collection is, including items – from JJ Thomson's original cathode ray tube to Crick and Watson's DNA model – that any science museum around the world would give an arm and a leg for. I'm delighted that the collection continues to grow with the recent arrival of objects from the life and work of Ray Dolby, which will soon go on display in the near-completed Ray Dolby Centre. You'll find an account of these recent acquisitions within these pages.

We are keen to hear your thoughts on the evolving design and content of CavMag, so if you have feedback or requests for content that we don't currently cover, please do get in touch at cavmag@phy.cam.ac.uk. I'd like to finish by thanking the Cavendish staff who contributed to this edition, particularly to Vanessa Bismuth for her crucial role in shaping this latest issue and the new digital edition, and to Malcolm for his guidance and long service as the founding editor of CavMag.

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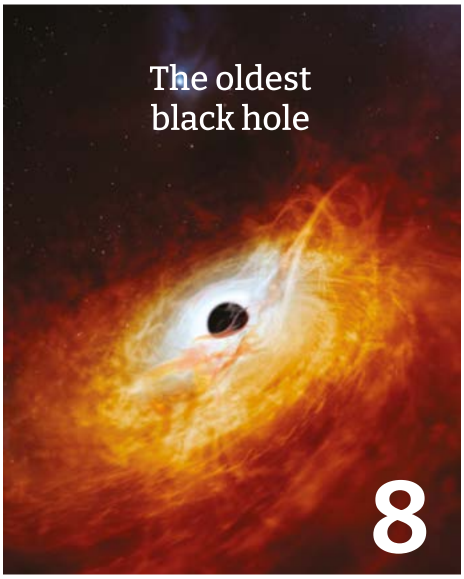

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CavMag is the free magazine produced by the Cavendish Laboratory for its Alumni community. It is published twice a year.
Editor Harry Cliff
Contributor/Managing Editor Vanessa Bismuth
Photography Chris Brock (unless credited otherwise)
Design Matt Bilton / Pageworks

Colossal caverns ready for Deep Underground Neutrino Experiment

LEFT: The two largest caverns are more than 500 feet long and about seven stories tall. Credit: Matthew Kapust, Sanford Underground Research Facility

The Deep Underground Neutrino Experiment (DUNE) marked a major milestone in February with the completion of three enormous subterranean caverns that will host the experiment's far detector. Located a mile underground at the former Homestake gold mine in Lead, South Dakota, the caverns are the core of a research facility that spans an underground area about the size of eight football fields. Workers spent almost two years blasting through 800,000 tons of rock to create the caverns.

DUNE will study an intense neutrino beam that will be produced at Fermilab near Chicago and fired 810 miles through the Earth to reach the far detector, which will be comprised of four huge liquid argon time projection chambers, each weighing 10,000 tons. When a neutrino interacts in the detector, the resulting charged particles will ionise the liquid argon, allowing DUNE to create incredibly detailed three-dimensional images of the neutrino interaction. With the caverns excavated, work can now begin on preparing them for installation of the detectors later this year.

The Cambridge DUNE group at the Cavendish Laboratory has been a core member of the international project since its beginning, contributing to the experiment's hardware and software. "We are very excited to have reached this milestone," said Dr Melissa Uchida, leader of the Cambridge DUNE group and Associate Professor of High Energy Physics. "This momentous moment paves the way for our scientists to begin to answer some of the most fundamental questions of the Universe, for example to determine if neutrinos are partly responsible for the existence of our matter dominated Universe."

DUNE's physics goals include determining whether neutrinos violate charge-parity symmetry, which relates matter to antimatter, figuring out the ordering of the three different neutrino mass states, as well as studying how supernovae explosions create neutron stars and black holes through the intense bursts of neutrinos that they emit. DUNE faces stiff competition from other neutrino experiments around the world, in particular the Hyper Kamiokande experiment currently under construction in Japan. In the race to be the first to unravel the many mysteries around some of nature's most elusive particles, the completion of the experiment's new home marks a significant step toward forward. DUNE's scientists are now itching to begin installation of their vast new detectors.

REACH for cosmic dawn

BELOW: Rainbow over the newly built REACH instrument in the Karoo desert in South Africa. Credit: Dominic Anstey, Cavendish Laboratory

In December, astronomers from the Cavendish Laboratory and the Kavli Institute for Cosmology celebrated the start of operations of a new radio telescope, over five years in the making. REACH (the Radio Experiment for the Analysis of Cosmic Hydrogen), is now beginning to probe the times in the early universe known as cosmic dawn and the epoch of re-ionisation, when the first stars awoke and ended the long dark ages that followed the Big Bang.

REACH is located in the Karoo, a semi-desert area of South Africa ideally suited for radio astronomy thanks to its remarkably low levels of radio interreference from human activity. The REACH instrument itself, built through a collaboration between the University of Cambridge and Stellenbosch University, is an antenna radiometer that studies the sky at frequencies between 50 and 200 MHz. REACH's target is the 21-cm atomic transition in neutral hydrogen atoms, an electromagnetic signature that allows astronomers to probe the period immediately after the Big Bang, from when the first atoms formed, filling the dark universe with neutral hydrogen and helium, up to the formation of the first stars and galaxies.

This relatively uncharted period is crucial for understanding how the first structures formed in the cosmos but is difficult to observe at shorter wavelengths as light from the first stars is blocked by the hydrogen clouds that surrounded them. Instead, astronomers look for the signatures left as those first luminous sources heated and re-ionised the surrounding hydrogen gas, leading to characteristic 21-cm microwave emissions, which have subsequently been redshifted to radio wavelengths of a few metres by the expansion of space.

However, this faint primordial 21-cm signal is extremely hard to detect due to huge backgrounds from human activity such as television transmitters, and radiation from the ionosphere, which are 100,000 times brighter than the sought after signal. While the upcoming giant radio telescope, the Square Kilometre Array (part of which is also being built in the Karoo) will ultimately produce a detailed map of the 21-cm line out to the edge of the observable universe, REACH is aiming for a simpler method of detection by averaging the signal across the sky. The REACH team are employing advanced Bayesian statistical techniques and physics models of their instrument, the signal and the backgrounds to filter the precious cosmic information from the ocean of noise. An exciting and challenging journey of discovery has now begun.

Advancing battery research for real-world impact

Akshay Rao is the only researcher at the University of Cambridge to be awarded an ERC Proof of Concept Grant to turn his ground-breaking battery research into tangible innovations.

Rao, Harding Lecturer in Physics at the Cavendish Laboratory, is one of the 102 successful frontier researchers to receive the prestigious European Research Council (ERC) funding in the third and final competition round of 2023.

Worth €150,000, the recent ERC grant will help Rao and his group bridge the gap between the results of their pioneering research on battery material development and the early phases of its commercialisation.

The Proof of Concept Grants are designed to enable researchers to take an idea from the lab into the world of business and to transform ground-breaking research into tangible innovations. The grant scheme is part of the EU's research and innovation programme, Horizon Europe.

One of the keys to creating a cleaner and more sustainable energy system is improved battery storage. Scientists worldwide are working hard to improve batteries so they can store more energy, charge faster, and last longer. To do this, Rao's group is exploring how batteries charge and discharge, and what makes them age and wear out.

The project called OptoBAT, which will be supported with this grant, will develop a new microscopy platform to help accelerate this research for both industry and academia.

OptoBAT uses charge photometry to rapidly identify which materials have the right properties to reduce the effects of aging and capacity loss in batteries.

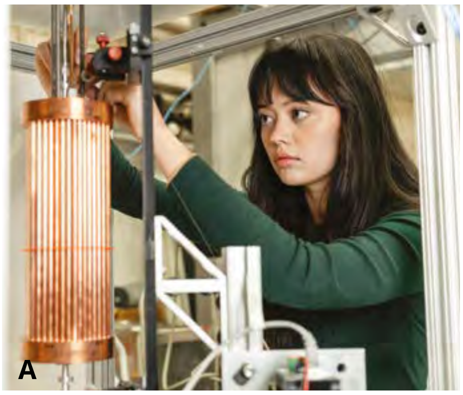
Rao's group specialises in studying a variety of materials, such as those used in solar cells, batteries, and LEDs, to gain insights into their behaviour at the nanoscale and to radically improve energy technology.

With OptoBat, Rao and his team are hoping to make charge photometry an indispensable part of battery research and an accelerant for the development of new battery technologies for a greener future.

Rao is the co-founder of two companies: Cambridge Photon Technology, which is developing next-generation materials designed to increase the performance of existing silicon solar panels, and Illumion, which develops high-throughput optical tools to accelerate battery material development.

Find out more about Akshay Rao's research at **rao.oe.phy.cam.ac.uk**.

Cambridge team joins ALPHA hunt for dark matter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A team of Cambridge University scientists working with colleagues from around the world were recently awarded a $3.7 million grant to build an experiment to search for the axion, a promising candidate for dark matter.

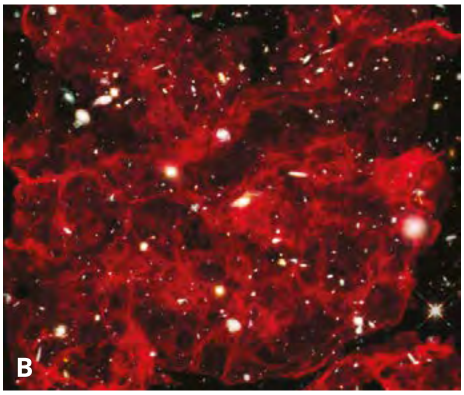
The Axion Longitudinal Plasma Haloscope (ALPHA) is an international project that will use a powerful superconducting magnet to search for axions, particles that may account for the invisible dark matter that makes up 85% of the matter in the universe. Their project recently received $3.7 million in funding from the Gordon and Betty Moore Foundation, the Simons Foundation, the Alfred P. Sloan Foundation and the John Templeton Foundation, which have partnered to support innovative 'tabletop' experiments small enough to be housed in a university lab, yet explore realms of physics typically probed by large-scale facilities.

ALPHA, which will be sited at Yale University in the United States, uses a metamaterial resonator placed inside an existing 16-Tesla magnet.

"This ambitious experiment aims at expanding our understanding of the fundamental structure of the universe while still fitting into a typical room-sized university physics research lab," said Hiranya Peiris, who recently joined Cambridge as Professor of Astrophysics (1909) at the Institute of Astronomy and is a founding member of the ALPHA collaboration.

The search for axions, which sits at the intersection of particle physics and astrophysics, has initiated a new connection between the Cavendish Laboratory and Cambridge's Institute of Astronomy. Scientists from both institutions will support the project by providing R&D and testing for the superconducting resonator components.

Siddharth Saxena, superconductivity specialist at the Cavendish Laboratory, said: "Our Cambridge team will support the design and development of the detection systems to make this table-top experiment cutting edge in its resolution and efficiency."



"By pooling their resources and expertise, the foundations have boosted the impact of their support and are able to collectively fund more tabletop projects that could push the frontiers of fundamental physics," said Mete Atatüre, Head of the Cavendish Laboratory.

"This development is very timely for Cambridge, given the current interest in boosting dark matter science in the UK."

ALPHA is a collaboration between 12 institutions: Yale University (which is hosting the experiment); Arizona State University; the University of California, Berkeley; the University of Cambridge; the University of Colorado at Boulder; the University of Iceland; ITMO University; Johns Hopkins University; MIT; Oak Ridge National Laboratory; Stockholm University, and Wellesley College.

European funding for new thin magnet research

Chiara Ciccarelli has been awarded a Consolidator Grant from the European Research Council (ERC) to support her career as she researches ultra-energy-efficient data storage solutions.

Magnets remain the best way that we know of to store digital data for long periods of time and so Ciccarelli's research focuses on ways to write and read their magnetic state as fast and energy-efficiently as possible

Her project, PICaSSO, has been awarded €2.1 million to explore new ways to write the magnetic state of thin magnets at low temperatures and ultra-fast speeds by interfacing them with superconductors.

"Although we are still at an early stage, this would allow developing ultra-energy-efficient cryogenic data storage solutions," said Ciccarelli, a Professor of Physics at the Cavendish Laboratory and a Royal Society University Research Fellow. "This is a necessary requirement for the realistic scaling and flourishing of quantum computers."

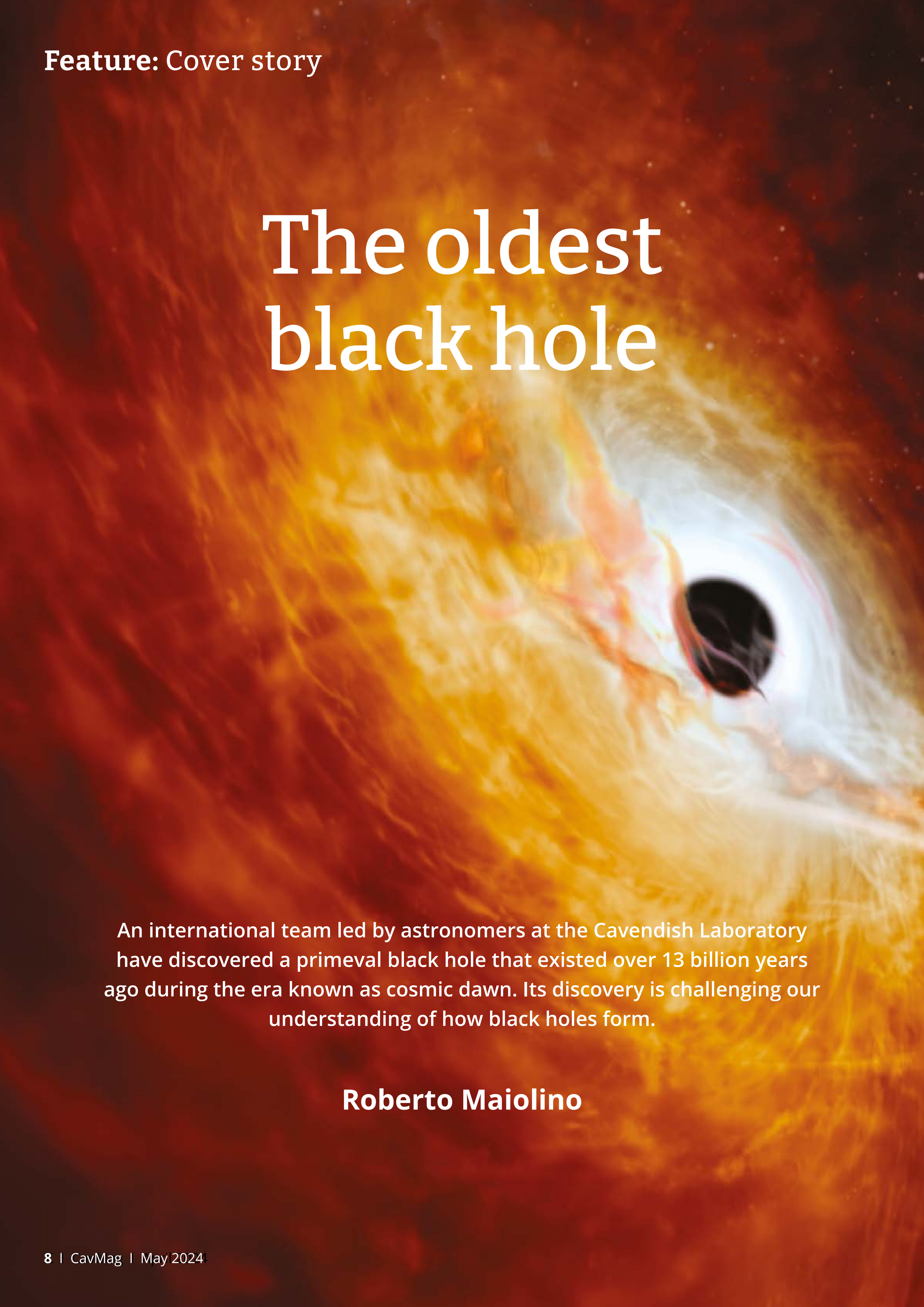
"I am absolutely delighted to have been awarded a Consolidator Grant. It is an amazing opportunity to do great and new science and an important recognition of the work of my amazing team" said Ciccarelli.

She is one of the 308 researchers selected by ERC for this year's Consolidator Grants. Worth in total €627 million, the grants are part of the European Union's Horizon Europe programme. The ERC, set up by the EU in 2007, is the premier European funding organisation for excellent frontier research.

Announcing the awards, Iliana Ivanova, European Commissioner for Innovation, Research, Culture, Education and Youth, noted the encouraging increase in the number of female winners for the third year in a row, demonstrating progress towards a more inclusive and diverse scientific community.

A: University of California, Berkeley graduate student Heather Jackson performs research on metamaterial resonators to be used in the plasma haloscope search for dark matter axions. Credit: AJ Gubser, UC Berkeley

B: Image illustrating how measurements made by Euclid can be used to infer the way that dark matter is distributed throughout the Universe. Work performed by ATG under contract for ESA. Credit: ESA



The oldest black hole

An international team led by astronomers at the Cavendish Laboratory have discovered a primeval black hole that existed over 13 billion years ago during the era known as cosmic dawn. Its discovery is challenging our understanding of how black holes form.

Roberto Maiolino

Revolutionary. This is one of the most frequently used adjectives in the plethora of papers that have been published with data from the James Webb Space Telescope so far. This is no overstatement. Webb is truly revolutionising many areas of astrophysics. With its 6.6-metre mirror making it the largest telescope in space, Webb's sensitivity in some infrared bands is up to a thousand times better than any previous instrument. Such an enormous leap in sensitivity has only been achieved a handful of times in the history of astronomy, or indeed in the whole of science. To give a sense of the magnitude of the improvement, it's equivalent to instantaneously upgrading Galileo's four-centimetre telescope to modern ten-metre telescope! It is therefore not surprising that Webb is opening spectacular new vistas on the cosmos. The exploration of infant black holes in the early universe is one area whose horizon is drastically expanding thanks to the advent of Webb.

We know that most galaxies in the local universe have supermassive black holes at their centres. These giants have masses ranging from millions to billions of times that of the Sun, and account for between 0.1% to 0.5% of the total mass of their host galaxy. At the centre of our own Milky Way is a black hole with a mass of four million suns, whose discovery was rewarded with Nobel prizes for Andrea Ghez and Reinhard Genzel in 2020.

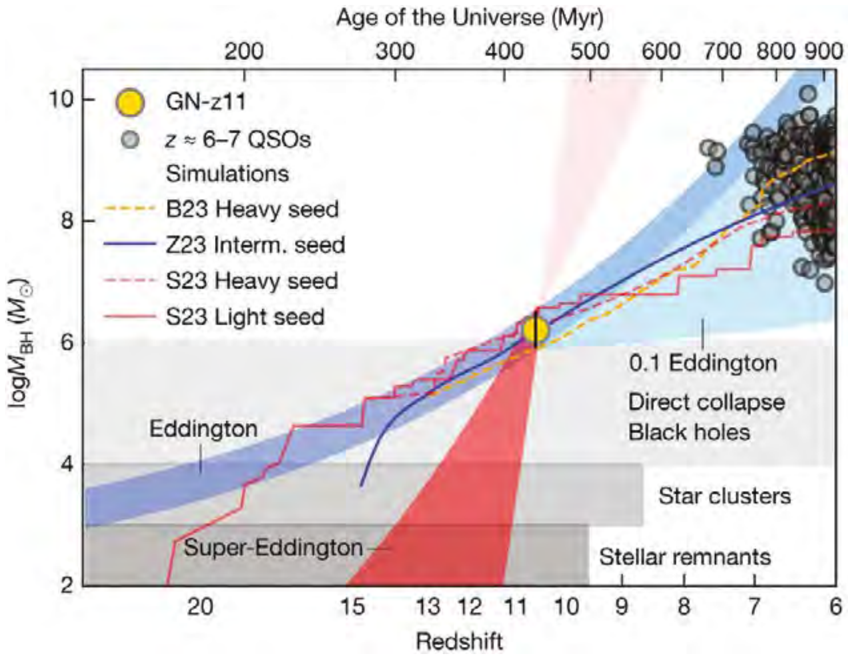
How these supermassive black holes came to be is one of the most intriguing questions in astrophysics. The standard scenario is that their first seeds were the remnants of massive stars that died in supernova explosions, leaving black holes with masses of a few tens, or possibly a few hundred suns. By accreting matter from the surrounding environment these black holes then grew to much larger sizes.

However, there is a theoretical maximum rate at which black holes can grow. Black holes typically consume gas from a so-called 'accretion disc', which becomes extremely hot (around 100,000 degrees) and radiates intense ultraviolet light. If the accretion rate is too high, then the pressure of this radiation on infalling matter overcomes the black hole's gravitational pull and prevents it from growing any faster. This is the so-called 'Eddington limit'.

To test this theory, we need to look back in time to observe the first phases of black hole formation and growth in the early universe. Webb can act as just such a time machine. Its unprecedented sensitivity allows it to spy extremely distant (and hence faint) galaxies that, due to the finite speed of light, are seen as they were in the remote past, up to several billion years ago.

Webb has discovered dozens of new black holes in their accretion phase, dating back more than 10 billion years. My own team at the Cavendish recently discovered the most distant ever of these black holes using NIRSpec, the primary spectrometer aboard Webb. We found the black hole in the core of a galaxy known as GN-z11, which dates back more than 13 billion years to when the universe was a mere 440 million years old, young in cosmic terms. This early epoch is known as 'cosmic dawn', the time when the first stars burst into light.

The black hole was identified through multiple signatures in the electromagnetic spectrum produced by its host galaxy. Specifically, it was possible to unambiguously identify the presence of extremely dense gas, tell-tale atomic transitions, and powerful winds of ionised gas with speeds of around one thousand kilometres per second, all typical of accreting supermassive black holes.



ABOVE: Black hole mass as a function of age of the universe and redshift.

This primeval black hole is estimated to weigh in at around 2 million solar masses, making it relatively small compared to the gargantuan black holes found in later epochs, many of which have masses of over a billion suns. However, the black hole in GN-z11 is nonetheless surprisingly large given the relative youth of the universe during that epoch. In fact, there should not have been enough time so early in the universe for the black hole to grow to such a vast size through the standard mechanisms that we know of in astrophysics.

This is illustrated in the figure above showing the black hole mass (on the vertical axis) as a function of age of the universe (upper horizontal axis). The lower horizontal axis shows how the age of the universe translates into 'redshift', a measure of how much the wavelength of light is stretched while travelling to us due to the universe's expansion. The golden circle shows the mass of the black hole in GN-z11 and the blue shaded region shows its mass projected back in time assuming that it was accreting steadily at the Eddington limit. Crucially, this shows that even if the black hole had grown as fast as theoretically possible, to reach its observed size it would have needed to have had a mass of over a thousand suns just 100 million years after the Big Bang. Even assuming that it formed within the first few tens million years after the Big Bang (which is extremely unlikely since few stars are thought to have formed that early) it is extremely challenging to explain the black hole in GN-z11 as a stellar remnant uninterruptedly accreting at the Eddington limit.

This result has prompted astrophysicists to explore new scenarios. Some have proposed that the seeds of early black holes were born 'big' with masses of a few hundred thousand times the mass of the Sun (known as 'heavy seeds'), via the direct gravitational collapse of massive, pristine clouds of gas. Others have suggested that dense clusters of black holes and stars may have undergone a runaway merging process that rapidly produced intermediate mass black holes, with masses of tens of thousands times the mass of the Sun ('intermediate mass seeds'), which then accreted matter to reach the mass seen in GN-z11. Yet another possibility is that the black hole seeds are stellar remnants ('light seeds'), but they manage to gobble matter very voraciously, above the Eddington limit, even if only in short bursts.

As illustrated in the figure, all these scenarios can reproduce the large black hole mass observed in GN-z11. However, it is particularly intriguing that the black hole itself is found to be accreting at five times the Eddington limit. This supports the idea that the super-Eddington scenario is actually a realistic possibility. Subsequent work by my team, in particular by Cavendish PhD student and P.C. Ho Scholar Ignas Juodžbalis, produced additional evidence that this is a likely route for the early

> **“This slew of exciting discoveries is just a first glimpse of the results that will inevitably flow from the James Webb Space Telescope”**

formation and growth of black holes.

One possible explanation for this extremely rapid rate of accretion is that the infalling matter is self-shielding from the strong radiation pressure. However, it is expected that such phases of extremely vigorous accretion cannot be sustained for long periods and must be short lived. In between these voracious meals most of these infant black holes must spend much of their early life in a dormant state.

Another interesting feature of the black hole in GN-z11 and many other infant black holes recently discovered by Webb, is that they are ‘overmassive’ relative to their host galaxies. In contrast to local, mature black holes, their infant counterparts in the distant universe can have masses that are comparable to their host galaxies! While nature appears to have facilitated the rapid growth of black holes, the formation of stars in their host galaxies lagged behind, perhaps inhibited by the large quantities of energy released by their matter-guzzling black holes.

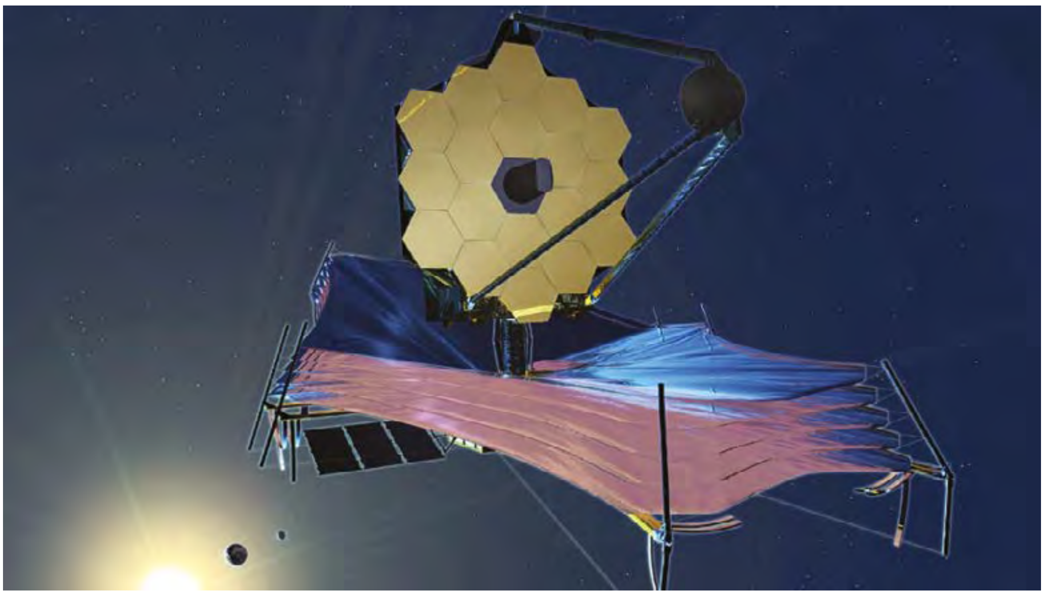
Yet another exciting result that we obtained from Webb is the discovery of a growing number of supermassive black hole pairs in the early universe. The most distant and spectacular of these was found by Newton-Kavli Junior Fellow Hannah Übler in a galaxy that existed 750 million years after the Big Bang. These results add yet another unexpected dimension to the problem and suggest that supermassive black hole mergers are another important route for their rapid growth in the early universe. These violent collisions would have produced gravitational waves that will be detectable by the next generation of gravitational wave observatories, such as the LISA space mission recently approved by the European Space Agency.

This slew of exciting discoveries is just a first glimpse of the results that will inevitably flow from the James Webb Space Telescope, coming from just its first year of operation. This revolutionary instrument is expected to operate for another twenty years. The most exciting discoveries are undoubtedly yet to come! ■

Roberto Maiolino is Professor of Experimental Astrophysics at the Cavendish Laboratory and the Kavli Institute for Cosmology, Cambridge.

R. Maiolino et al., Nature, 627, 59 (2024).

BELOW: Artist’s impression of the James Webb Space Telescope in orbit.



Accelerating drug development with machine learning

Researchers at the Cavendish have found that machine learning and artificial intelligence can significantly improve predictions of how therapeutic molecules will behave in the lab and in living things. Their results open a promising route to dramatically speed up the discovery and development of pharmaceuticals.

Emma King-Smith

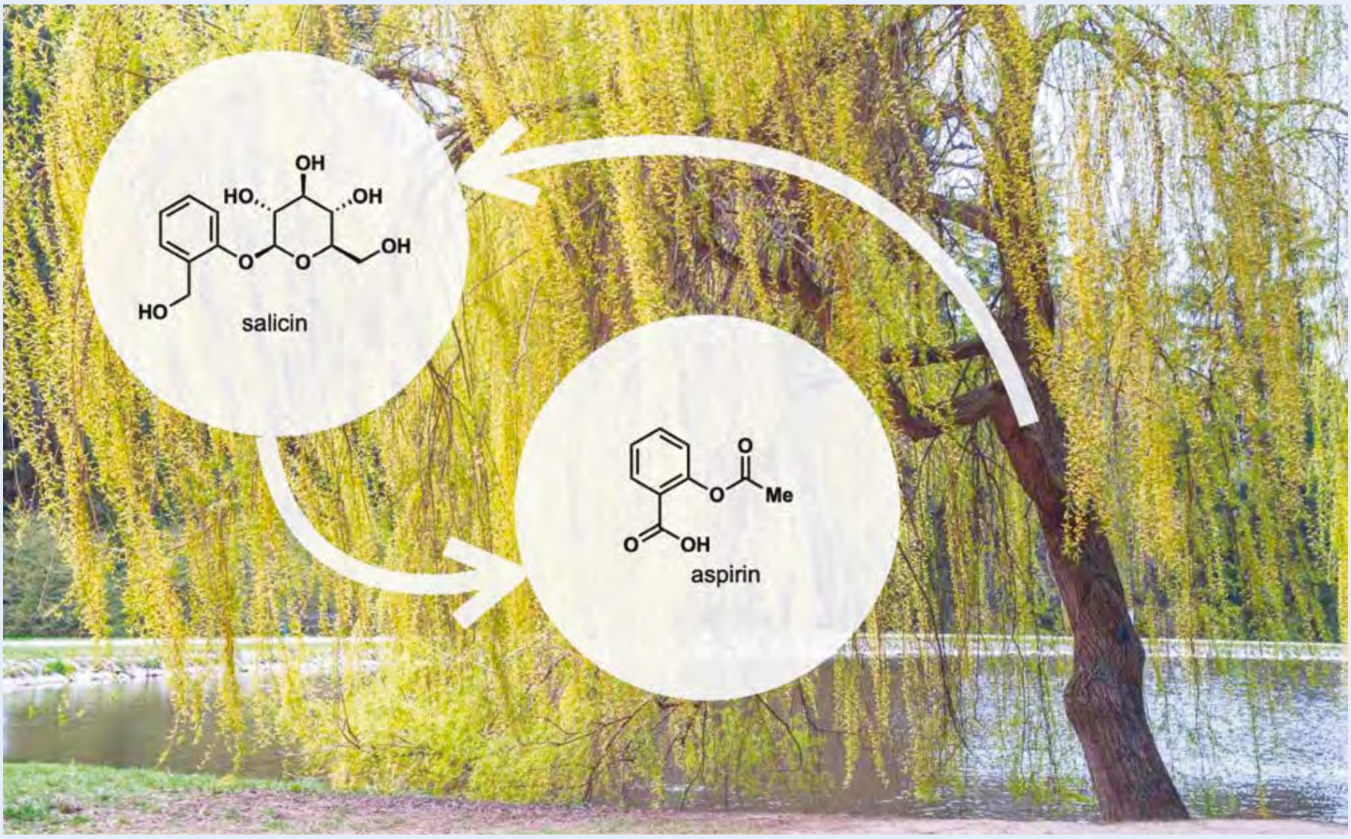
We have come a long way from chewing on willow bark to relieve fevers, but despite shiny new machines and billions of pounds poured into the development of new pharmaceuticals, safety testing, and chemical research, we still have a distinctly trial-and-error approach towards finding new drugs. Even though we've made immense progress in understanding the human body's biological pathways, we still struggle to predict how a foreign agent like a therapeutic will react in a complex biological system. In fact, we are often unsure how molecules will interact with each other even within a controlled laboratory system like a test tube. These limitations have big consequences for how we approach drug design: we don't know ahead of time what the best molecule is to treat a given aliment, and even if we did, we don't necessarily know how to make it in a reliable, let alone commercially viable way.

Understanding molecules in the test tube

A fundamental challenge is determining how molecules react with one another *outside* the human body. This is a crucial hurdle that must be crossed if we are to understand the intrinsic properties of the molecules we have already discovered and ultimately build new molecules with therapeutic applications. To that end, our team struck up a collaboration with Pfizer to investigate how molecules behave

The historical discovery pipeline for therapeutics

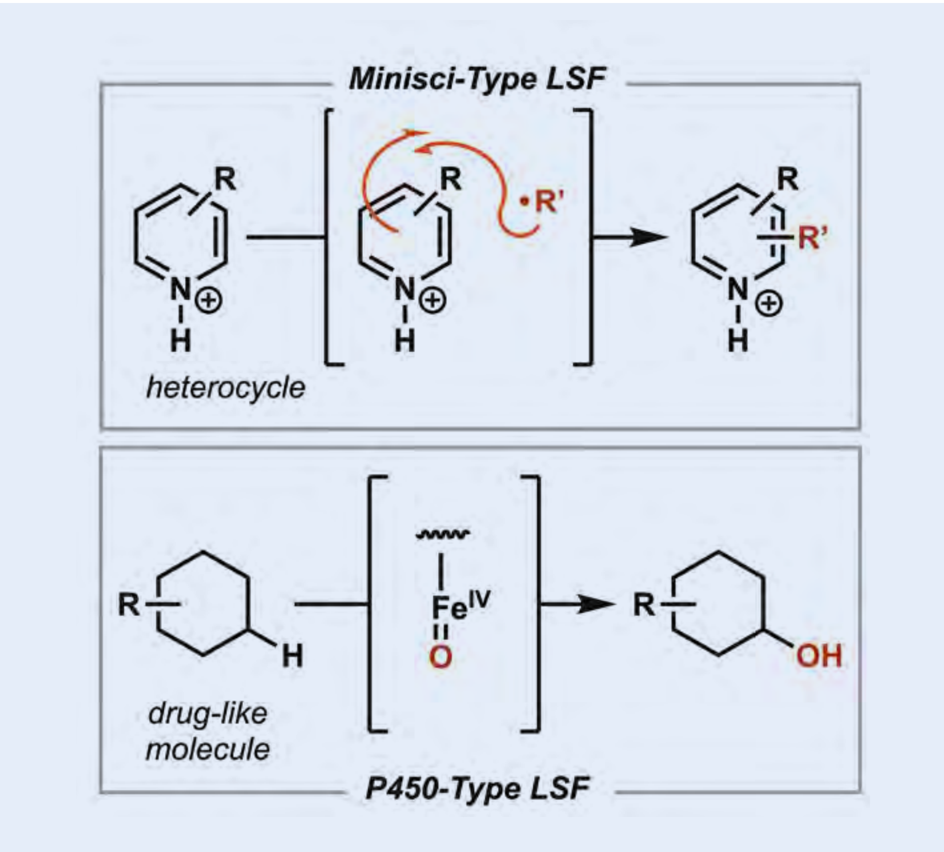
Aspirin, one of the world's most used drugs, was itself a modification of salicin, a natural component of white willow bark (Salix alba). Salicin was used as far back as 3,500 years ago as an antipyretic by the ancient Sumerians and Egyptians. To this day, drawing heavy inspiration from naturally produced molecules is still a common practice in drug discovery.



when exposed to specific types of reaction conditions. In particular, we focused on the 'Minisci' and 'P450' reactions – two chemistries with well-established utility in pharmaceutical research. Minisci reactions use radicals (molecules or atoms with an unpaired electron) to form new bonds with ring-shaped molecules, which appear commonly in nature and pharmaceuticals. P450 reactions also use radicals, and play a central role in drug metabolism and drug-drug interactions.

Given the recent breakthroughs in machine learning and artificial intelligence (AI) in biological research, such as AlphaFold's ability to predict the structures of folded proteins, we suspected a machine-learning-powered framework could be the key to unlock new chemical insights. However, data-driven chemical research is plagued by a dearth of real-world experimental data. While biology has embraced a spirit of open-source, readily-accessible big data, data from chemistry is fragmented and more laborious to generate. Unfortunately, machine learning's requirement for large data volumes is non-negotiable. Given the limited chemical dataset of around just 2000 reactions, we faced a daunting task.

A technique known as 'transfer learning' offered a possible solution. Here, a model previously trained for a different task is repurposed, reducing the demand for a large training dataset. Our approach leveraged the fact that the original and new training tasks do not need to be very similar, just tangentially related for the model to perform well. Our model was first trained on abundant chemical information from one of the few open-source chemistry databases. Then it was re-trained on the much smaller Minisci and P450 reaction datasets to predict where on a molecule a new bond was likely to form during the reaction. To our delight, this tactic proved successful and highly accurate, outperforming the current gold standard (Fukui reactivity indices) as well as other machine learning based platforms.

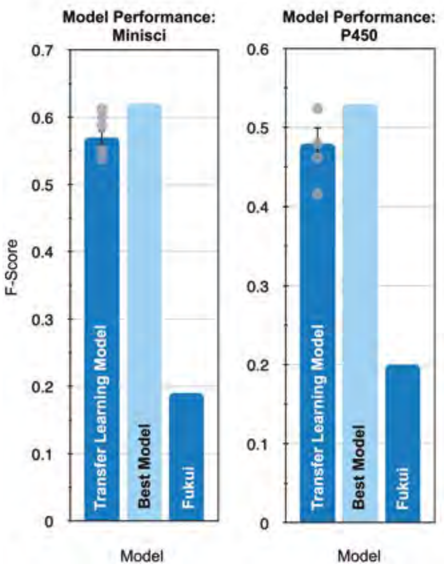


ABOVE: An overview of the Minisci and P450 reactions.

Excitingly, it was then possible to apply this style of transfer learning much more broadly. By taking atomic position information from crystal structures supplied from the Cambridge Crystallography Data Centre, a foundational chemistry model was constructed. This model achieved state-of-the-art performance across a variety of important, unrelated chemistry tasks including predicting the yield of common chemical transformations, the lethal dosage of compounds (acute LD_{50}), and even what a compound will smell like.

Understanding molecules in living things

However, the bigger challenge is understanding how these complex chemical systems will function in a living organism. Here, too, we have made some important strides. During the drug discovery process, each potential therapeutic drug is screened against a biological target of interest. Over the decades, the screenings have become more efficient, more automated, and faster. The overall workflow is to make the compounds, purify the compounds, give the compounds to



ABOVE: Model performance of our machine learning approach versus Fukui reactivity indices. The grey dots indicate actual values for five repeated neural network initialisations, while 'Best Model' refers to the highest performing of these five.

the biological systems, and finally see what happens. Purification is often time consuming, and so researchers have devised a new process called 'direct-to-biology', which omits purification, going directly from compound synthesis to biological evaluation. Typically, this would lead to a muddy and confusing biological readout, but for select reactions that have been carefully optimised, it is a viable strategy.

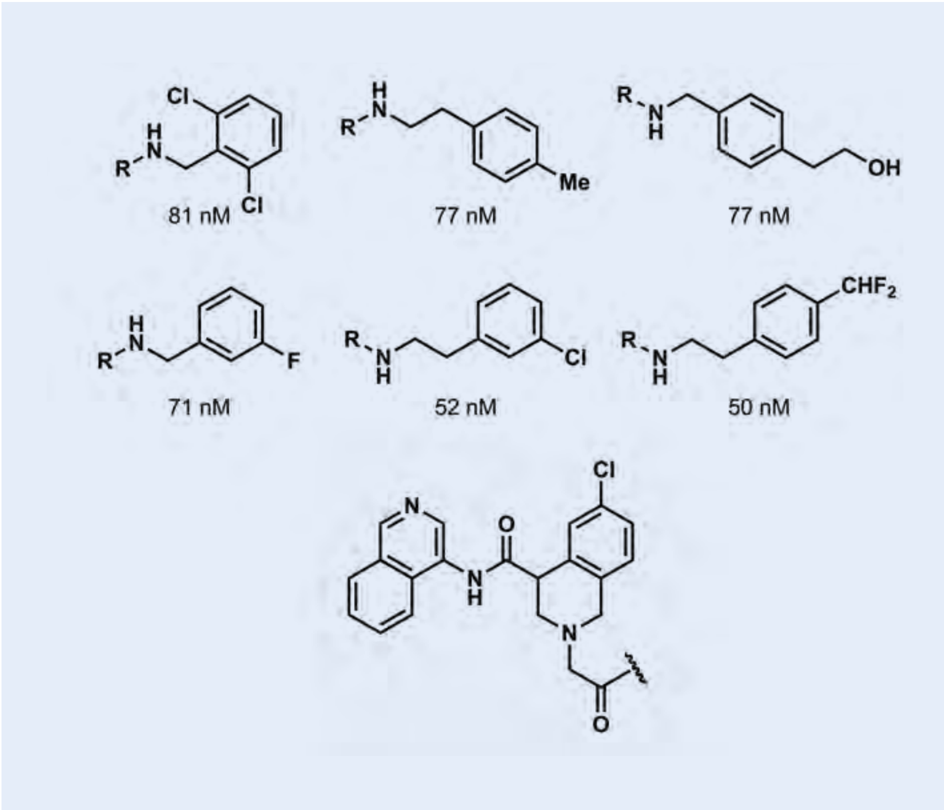
Given the relative modernity of direct-to-biology, its scope of applicability is still narrow, but we suspected that a machine-learning-based approach could expand the reach of this powerful technique, effectively using our platform as a 'de-confounder' to allow chemical reactions deemed too noisy for direct-to-biology application to be included in the workflow. As a proof-of-concept, our team collaborated with members from the London Group at the Weizmann Institute of Science. We used our machine learning platform in combination with direct-to-biology screens to identify several promising molecules for the treatment of acute SARS-CoV-2 infection that would have been missed otherwise.

We still face many open challenges in the field of drug manufacture. Our research is part of a body of work that shows the value of machine learning as a tool for chemistry-centric research, allowing us to peel back the curtain on complex chemical and biological systems. As we look to the future of AI, exemplified today with the uncanny abilities of large language models such as ChatGPT, Claude and ERNIE Bot, one can only imagine where this marriage of machine intelligence and chemical modelling will take us. ■

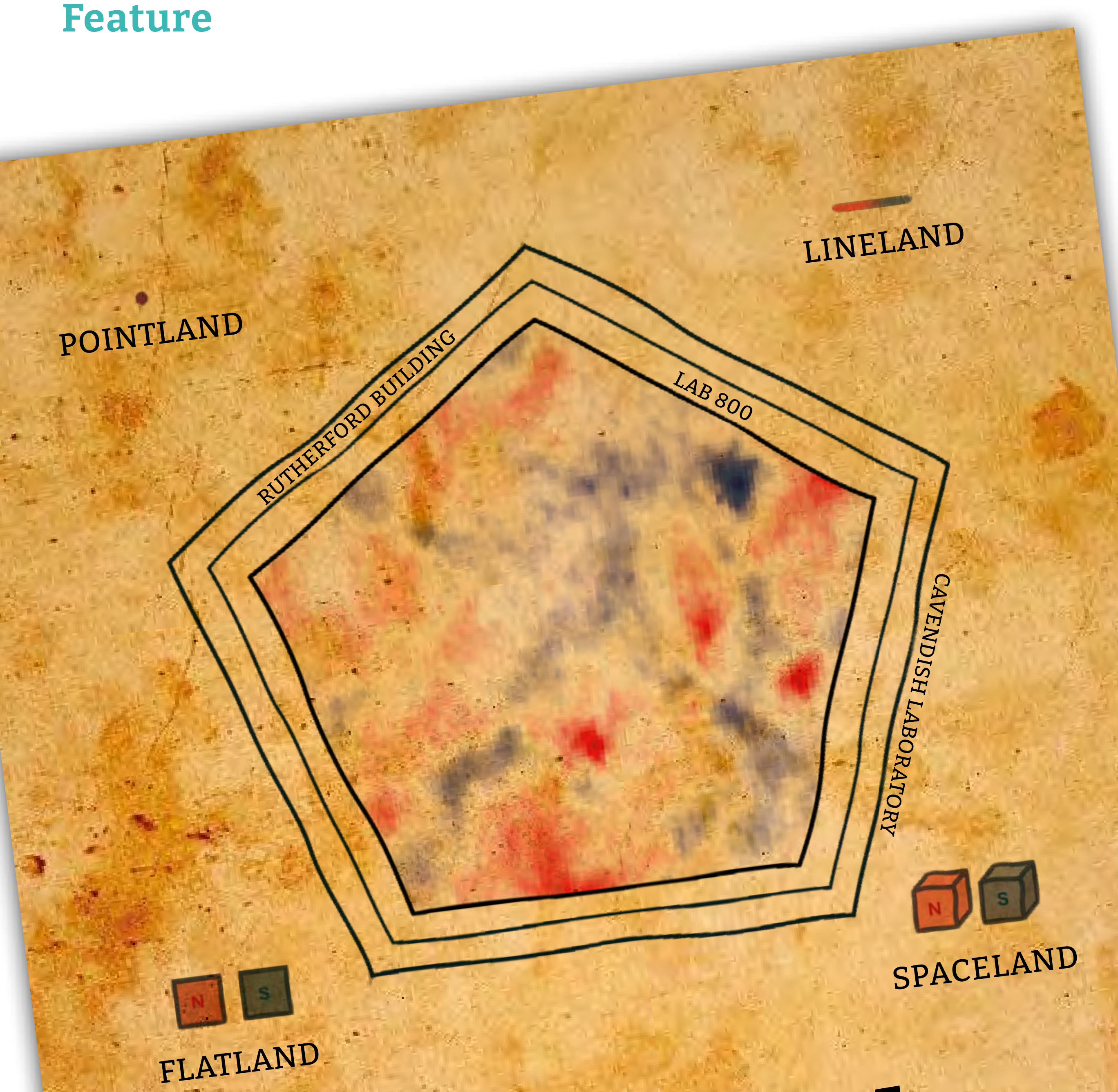
"the bigger challenge is understanding how these complex chemical systems will function in a living organism"

Emma King-Smith is a synthetic chemist turned data scientist working at the intersection of machine learning and organic chemistry.

E. King-Smith et al., Nature Communications, 15, 426 (2024).
E. King-Smith, Chemical Science, 15, 5143 (2024).
W. McCorkindale et al., RSC Medicinal Chemistry, 15, 1015 (2024).



ABOVE: Promising molecules for treating SARS-CoV-2 infection uncovered using our machine learning platform. SARS-CoV-2 main protease inhibition IC_{50} values shown below each compound.



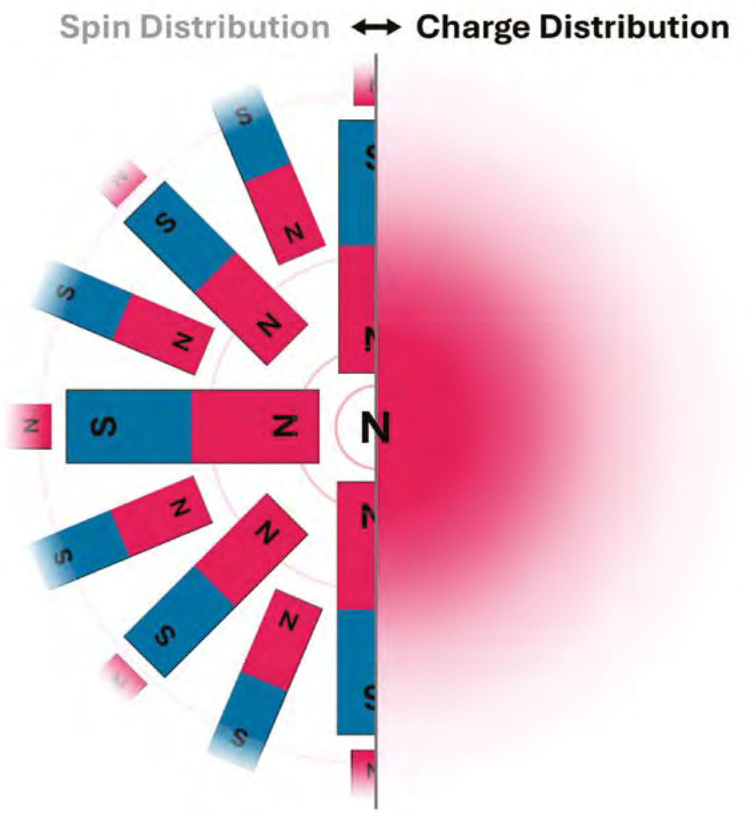
Rustland

A Tale of Flat Magnetism

Anthony K.C. Tan, Michael Hörgen, Lucio Stefan and Mete Atatüre

While fundamental magnetic monopoles remain elusive, Cavendish scientists have managed to create emergent magnetic monopoles in flakes of rust, with potential applications for faster and greener computing.

It is common knowledge that a magnet comes with two poles, north and south. Cut the magnet in half, and you get two smaller magnets, each still with two poles. This is a widely held notion taught to us in school, yet there is no reason why a magnet with a single pole, known as a *monopole*, could not exist. Theoretical speculation about monopoles began with Paul Dirac's quantum theory of magnetic charges in 1931, in which he showed that if at least one magnetic monopole exists in the universe, then electric charge must come in discrete lumps – in other words, electric charge must be quantised. Well, electric charge is indeed quantised, hinting that monopoles may actually exist. But despite extensive searches, including at particle physics experiments like the Large Hadron Collider, we have yet to find conclusive evidence of magnetic monopoles as fundamental particles in our universe.



ABOVE: The arrangement of spins in a 2D plane that give rise to an emergent monopole.

Monopoles as emergent quasi-particles

Instead of searching for a single elusive fundamental particle, our team in Cambridge pursued the intriguing concept of monopoles as a collective phenomenon in a system composed of many atomic magnets. In the study published in *Nature Materials,* these tiny magnets, also known as spins, arranged in a particular pattern on a plane shown in the illustration to the right, can exhibit characteristics akin to a magnetic monopole. This is a fascinating example of 'emergence', a concept popularised by Philip Anderson in his seminal essay *More is different*. Emergence suggests that the collective behaviour of a system can give rise to entirely new properties that are more than the sum of its individual parts. In this case, the spins collectively form what can be described as a quasi-particle resembling a monopole. Indeed, with different spin distributions, we can obtain a zoo of exotic magnetic quasi-particles, including one resembling an anti-monopole.

Flat magnetism

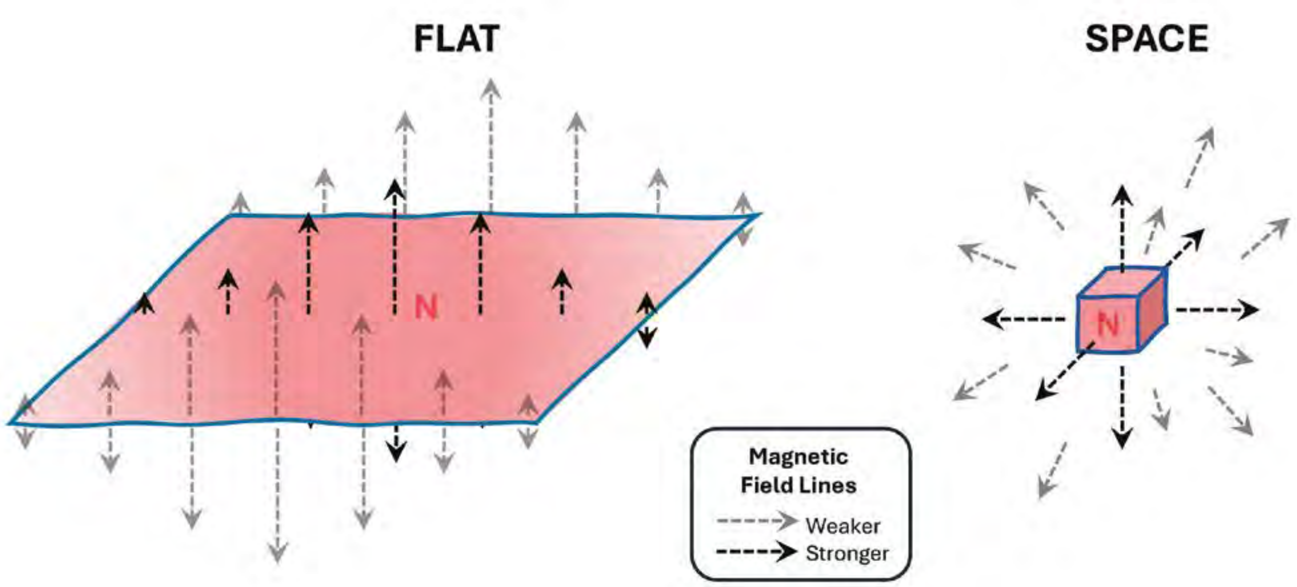
An interesting consequence of the physical picture above, is that the emergent magnetic charges are two-dimensional – or flat. One can visualise this using the magnetic field generated by the charges. For a *true* monopole in isolation, the magnetic field lines extend outwards from the particle in all directions. For emergent monopole charges, the field lines extend only in directions perpendicular to the plane hosting them. The emergent magnetic charges are therefore restricted to a two-dimensional plane and exhibit two-dimensional magnetic character.

Direct visualisation via quantum sensing

Despite their intriguing nature, such monopole-like quasi-particles are difficult to observe directly due to their extremely weak magnetic field signature. In the new study, our team employed a new cutting-edge imaging technique, harnessing the extremely high magnetic field sensitivity of a single, isolated spin embedded within a sharp diamond tip. This approach involves scanning the diamond tip across a magnetic sample of interest, allowing researchers to reconstruct the underlying magnetic properties. This is equivalent to using a tiny bar magnet to sense a large distribution of bar magnets.

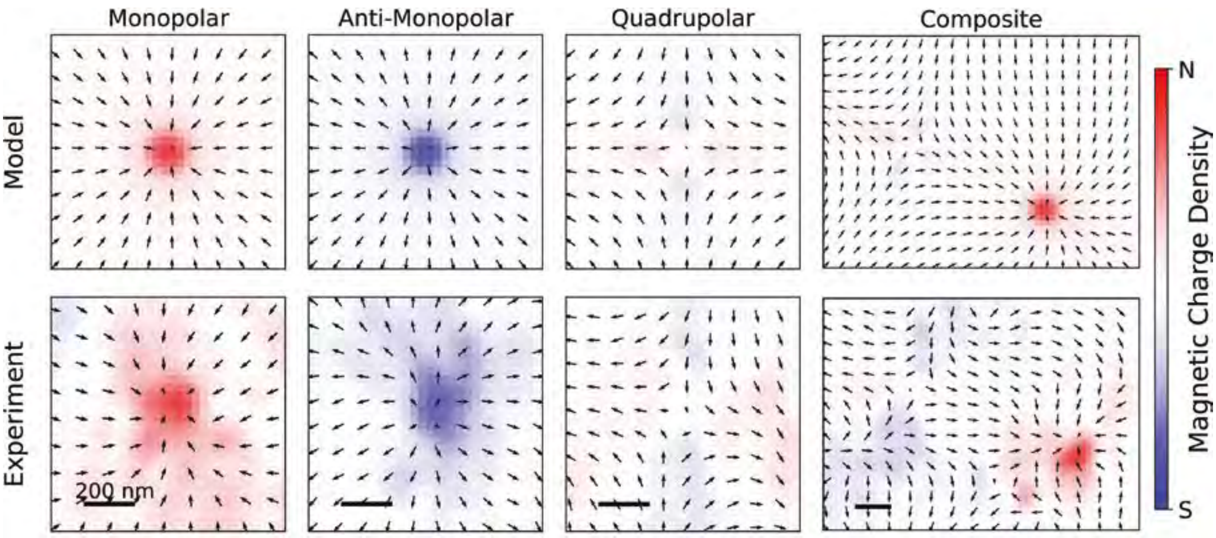
Fertile rustland

While using this diamond quantum sensor to study a tiny crystal flake of hematite, a reddish rust compound commonly found in rocks and soil, we were surprised to detect a monopole field signature amongst the other predicted quasi-particles. We found that these magnetic charge patterns, arising from the intricate interplay of whirling spins, are remarkably stable even in the ambient conditions of the lab. They were spontaneously created as the hematite sample was warmed up from just under minus three degrees Celsius to room



ABOVE: For a 2D monopole, the magnetic field lines only extend perpendicular to the plane (left), whereas they would extend in all directions for a fundamental monopole (right).

“we were surprised to detect a monopole field signature amongst the other predicted quasi-particles”



ABOVE: Comparison between the theoretically predicted and experimentally measured spin and magnetic charge distributions.

temperature. The experimentally obtained spin and magnetic charge distribution are shown alongside their theoretical models in the figure above.

Opening doors to new paradigms

It has been suggested that magnetic charge (or spin) quasi-particles can glide across the material surface to easily encode and process information. This breakthrough study therefore marks a significant step towards greener and faster computing, as the visualisation of magnetic monopole quasi-particles not only makes them easier to study, but also opens exciting avenues for their precise control and manipulation. Fundamentally, the monopolar and other charge patterns observed in hematite are two-dimensional – like a pancake of magnetic charges – and are very unlike the point-like nature of a true magnetic monopole living in a three-dimensional space. They are, in fact, constituents of a complex charge ensemble, interacting with each other on a two-dimensional charge canvas, and could provide invaluable insights into monopole-like properties in a controlled physical dimension that is dissimilar to ours. True monopoles might still be elusive, but in the meantime, we can have fun studying their 2D equivalent, much alike going to a gallery to stand in front of an exotic landscape, that for now at least, exists only as a painted canvas. ■

Athony K. C. Tan completed his PhD at the Cavendish in 2022, supervised by Mete Atatüre and has now taken up a postdoctoral position at Imperial College London.

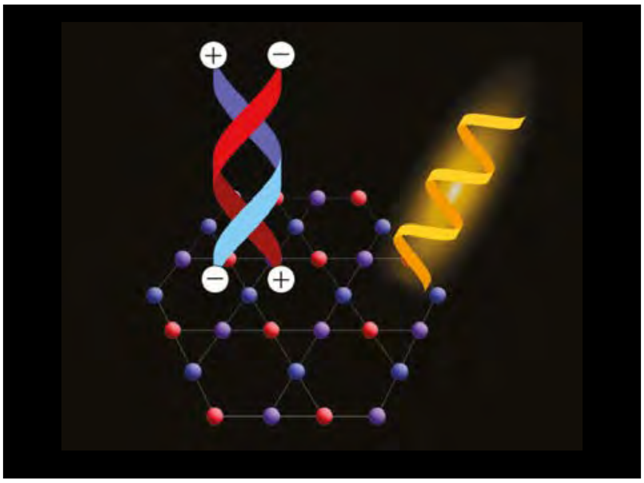
Electrons dance themselves in knots

Researchers at the Cavendish have discovered new realm of 'topological phases' with tangled, knot-like properties, which hold promise for new forms of robust memory storage and processing.

Robert-Jan Slager

"More is different". This is how Philip Anderson, former head of the theory group at the Cavendish, summarised the intrigue of condensed matter physics, the study of phenomena that emerge when a large number of particles are brought together. Unexpected behaviours often appear in complex systems that were not predicted ahead of time based on the properties of the constituents alone. Perhaps the most famous example is superconductivity, where a material conducts electricity without loss of energy.

A powerful mathematical tool for understanding condensed matter systems is the concept of topology: the study of the properties of a system that remain unchanged by smooth transformations like bending, stretching or twisting. The number holes in an object, for example, makes a donut and a coffee cup with a handle identical from a topological point of view, even if trying to drink your coffee from a donut is a bad idea. We can make this exact from an algebraic viewpoint by integrating so-called 'surface curvatures' over objects to give 'topological numbers' that relate to the number of holes.



ABOVE: Illustration of changing topological charges via braiding upon periodic driving by light.

While topology is an active field of mathematics, these concepts come to life in the electron systems that we explore in the laboratory. In such topological systems, the electronic wave functions weave together to form knots that cannot be smoothly disentangled or deformed into each other. These 'topological phases' have distinct and extremely robust physical properties controlled by these topological numbers, such as novel quantum excitations and electromagnetic couplings. What's more they hold promise for applications ranging from advanced electronics to quantum computing, representing a holy grail in modern physics.

Specific mathematical rules have been developed that lay out the types of knots and associated topological patterns that can emerge in a crystalline material, but the past few years have seen the discovery of new topological phases that follow novel rules. In these systems, electrons perform a precise dance to create emergent particles that can be moved around each other, or 'braided', storing topological information in a distinctive manner.

We discovered that these phenomena come into their full glory when the system undergoes a change. By suddenly altering the parameters and then releasing the system, we can induce specific knotted patterns that can then be measured. Most recently, we fired periodic laser pulses at the electronic phases and found that we could not only induce braiding, but also produce anomalous phases, characterised by topological numbers that can't exist in static settings.

Perhaps most excitingly, we found that these phases are highly resilient against external perturbations, making them promising candidates for robust information storage and processing. They are now actively being investigated by the quantum simulation groups here at the Cavendish and in labs around the world, making it an interesting time for this nascent field.

R.-J. Slager, A. Bouhon, F.N. Ünal, Nature Communications 15, 1144 (2024)

Venus's dark clouds

A team from the Cavendish and the Department of Earth Sciences may have finally solved a hundred-year-old mystery over dark streaks in the atmosphere of Venus.

Paul B Rimmer

© JAXA/ISAS/DARTS/Damia Bouic

In optical light, Venus is a bright pale-yellow orb, a featureless pearl suspended in the blackness of space. The planet owes its colour to the scattering of light by its cloud tops, which are made mostly of sulfuric acid droplets, with some water, chlorine, and iron. But look at the planet in ultraviolet and you discover a series of strange dark streaks and patches that astronomers have, so far, been unable to explain.

These dark patches are collectively referred to as the 'unknown ultraviolet absorber'. After Soviet and American probes found evidence of iron in the clouds of Venus, Vasilii Moroz, one of the planetary scientists who helped design the Soviet probes, suggested that iron and sulfur might explain the ultraviolet absorber. But until recently, this hypothesis had not been investigated experimentally.

What compounds does iron form when mixed with sulfuric acid and small, but varying amounts of water? This is the question I started to explore with Clancy Jiang and Nicholas Tosca of Cambridge's Department of Earth Sciences. When we first discussed iron-sulfur mineralogy in the clouds of Venus, Jiang and Tosca thought the closest analogy was sulfuric acid drainage in mines here on Earth. Based on minerals found in these mines, we hypothesised that Venus's clouds may contain a mixture of the iron-sulfur minerals copiapite and rhomboclase, along with acid ferric sulfate.

Reproducing the acidic conditions of Venus's clouds in the lab, Jiang found that the Venusian atmosphere is far too harsh an environment for copiapite. However, rhomboclase and acid ferric sulfate could form, and Jiang went on to synthesise them.

Taking some of Jiang's samples, I studied their spectra using an ultraviolet-visible light spectrometer that I built with Samantha Thompson at the Cavendish. I found that the ultraviolet absorption of a combination of rhomboclase and acid ferric sulfate looked a lot like the 350-400 nanometre ultraviolet absorber in the clouds of Venus!

However, the dark patches on Venus also absorb ultraviolet between 250 and 350 nanometres, so what might explain that? Gabriella Lozano, Corinna Kufner and Dimitar Sasselov of Harvard University's Centre for Astrophysics found that dissolved iron might be the culprit.

So, are we right? Are the clouds of Venus really peppered with rhomboclase and acid ferric sulfate? Do these compounds finally answer a nearly century-old mystery?

It's too soon to say. To really know for sure, new probes will have to go to Venus that have the ability to detect minerals in its atmosphere. Our first chance to learn more will come from NASA's DAVINCI mission, scheduled for launch in 2029, which will study Venus in ultraviolet from orbit while a lander will sample the atmosphere during its descent to the surface.

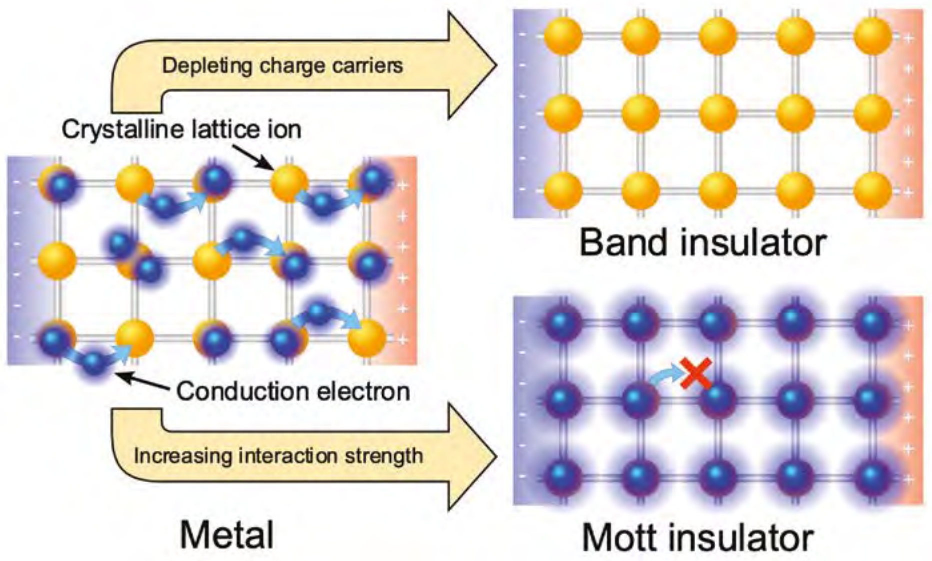
C. Z. Jiang et al., Sci. Adv. 10, 8826 (2024).

Resolving electronic gridlock in a Mott insulator

Scientists from the Cavendish's Quantum Matter group have studied how a material known as a Mott insulator transforms into a metal under extreme pressures, giving insights into how their electrons go from gridlock to freedom.

Malte Grosche

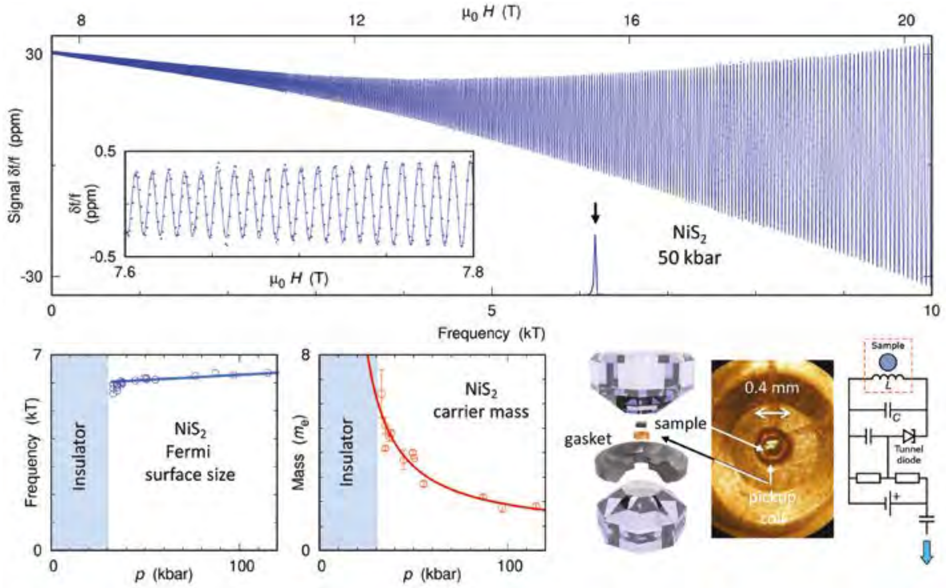
Mott insulators do not lack conduction electrons as is the case in a conventional insulator or semiconductor. Instead, electrons are locked into position by their mutual interaction. Tuning a Mott insulator by varying the distance between the atoms in the lattice under applied pressure shifts the balance between repulsive interaction and the tendency of electrons to spread out. This makes it possible to turn a Mott insulator into a metal and study the correlated metallic state, in which the grid-locked electrons have been set free.



ABOVE: Comparison between a conventional band insulator and an interaction-induced Mott insulator.

Foremost among the scientific questions surrounding this 'Mott metal' state on the threshold of 'Mott localisation' (the point at which conduction electrons become locked in place) is the velocity distribution of the conduction electrons: because the electrons are always in motion, we do not determine their position but rather examine the relationship between their momentum and energy by observing the electronic Fermi surface and effective mass. The Fermi surface separates filled from unfilled electronic states in momentum space at low temperatures. Without the lattice atoms, it would be spherical, but in real materials it can have a more intricate shape. The electronic effective mass can in a real material be orders of magnitude different from the mass of free electrons in vacuum. It is strongly affected both by the interaction with lattice atoms and by interactions between the electrons themselves. The effective mass tells us how fast the electrons in momentum states near the Fermi surface are moving.

Observing quantum oscillatory phenomena in high magnetic fields and at low temperatures provides direct access to these key properties, using a set of techniques that was pioneered at the Cavendish by David Shoenberg. To measure the mass of electrons in vacuum, JJ Thomson observed the deflection of the electrons' trajectories in a moderate applied magnetic field. A similar phenomenon, the Hall effect, exists for electrons moving in a metal, but it does not allow precise measurements of the effective electron mass. Quantum oscillations, by contrast, are associated with the closed cyclotron orbits of conduction electrons in very high magnetic fields, when the electrons spiral around the magnetic field lines. Only certain orbits are



ABOVE: Quantum oscillations observed in the pressure-metallised Mott insulator NiS² (top panel) indicate little change in the Fermi surface size with pressure (bottom left), whereas the effective mass of the electron charge carriers rises rapidly, as the insulating state is approached (bottom centre). Measurements employed a radio-frequency tank circuit technique with pickup coil inside the high-pressure sample space (bottom right).

allowed by quantum mechanics, and this quantisation depends on the strength of the applied field. Many material properties oscillate with applied field, as subsequent orbits in momentum space pass through key sections of the electronic Fermi surface. At the time of Shoenberg, quantum oscillations could rarely be observed in anything but the cleanest elemental metals. The far higher magnetic fields available today have dramatically widened the applicability of this method, which my Quantum Matter group colleagues have recently applied to resolve the electronic structure of the novel superconductor UTe_2.

High precision measurements under extreme hydrostatic pressures generated in miniature gemstone anvil pressure cells are required in order to record quantum oscillations in a pressure-metallised Mott insulator. We have overcome this challenge by tracking changes at the part-per-10-million level of the resonance frequency of a tank circuit oscillator, which probes sample properties via the effect they have on the self-inductance of a small inductor placed within the high-pressure sample volume. Using this novel technique, Quantum Matter group scientists and colleagues at high field facilities in the USA and the Netherlands have resolved the electronic structure in high-purity samples of the Mott insulator NiS_2 at sub-Kelvin temperatures, applied magnetic fields of up to 35 T and at pressures reaching beyond 100,000 atmospheres.

Our results show that as the threshold of Mott localisation is approached from the metallic side by reducing the pressure, the electrons appear to grow heavy and they slow down dramatically, but their concentration hardly changes. In a 'Mott metal', interactions boost the effective electron mass – a phenomenon that generalises to more complex systems such as cuprate, organic and iron-based superconductors, Moiré superlattice systems and Kondo lattice materials. These materials display numerous collective phenomena of current interest, such as various distinct types of superconductivity and magnetism as well as other, more subtle forms of order. Our understanding and, ultimately, the ability to manipulate these phenomena depend on resolving the nature of the underlying correlated metallic states from which they arise. Our high-pressure study in NiS_2 shows how this may be achieved.

A. G. Eaton et al., Nature Communications, 15, 223 (2024).
K. Semeniuk et al., Proc. Natl. Acad. Sci. 120, e2301456120 (2023).

Peter Doherty: twenty-five years of innovation

Peter Doherty defines himself both as an instrument maker and a people person. A fan of science fiction, a Star Trek reference is never far from his lips. We sat down to discuss his twenty-five years of service as the Astrophysics Group's Chief Mechanical Workshop Technician.

Vanessa Bismuth

You started in the Astrophysics Workshop in 1998 after an already long and fruitful career in industry. Tell us how you found your way to the Cavendish.

I did an apprenticeship as an instrument maker before emigrating to Canada, where I worked for the aircraft industry and on nuclear power stations. When I returned to the UK, I joined PYE Telecoms where I spent 12 years before they closed the factory and I had to look for a new job. I came across the job advert almost by accident! After a rigorous interview process (nine hours in three different rounds), I was hired to join the Radio Astronomy Group's workshop as a technician. I started on a three-year contract to work on a project called the Heterodyne Array Receiver Project or HARP. I was made permanent after that.

As a technician, I go from fixing a 120 tonnes telescope to machining components with precision up to two microns. No one day is ever the same as many colleagues often approach me with questions and challenges to solve. This is a very rich and diverse environment to work in.

Did you have any prior interest in radio astronomy or astrophysics before joining the team, or were you simply driven by curiosity?

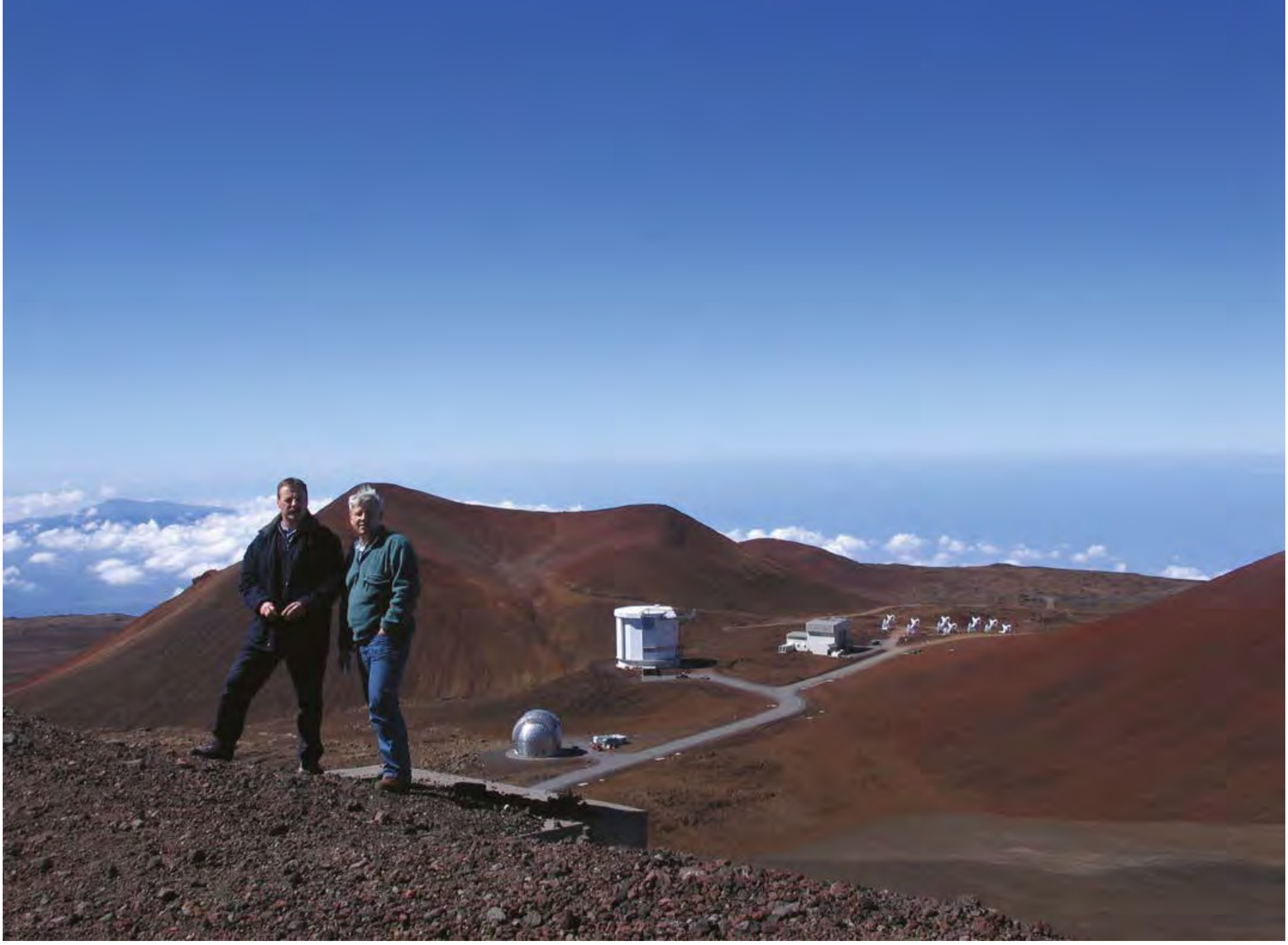
No, I knew nothing at all about radio astronomy! I remember stumbling upon the Mullard Observatory site when I was 15 and making a joke about aliens. About a year before I started in the role, they had an open day and my wife and I were debating about going in to have a look. We finally decided that we would go another time. That other time turned out to be the following year when I was already working there, and I was the one welcoming people in!

Tell us about the Mullard Observatory at Lord's Bridge. How was the site when you started and how has it evolved with time?

Originally Lord's Bridge was just farmland, but since 1957 it's been the home of huge telescopes. This includes the Ryle of course, with its eight massive 50-ton telescopes, as well as the Cambridge Optical Aperture Synthesis Telescope (COAST) and the Very Small Array. In more recent years, we have also added the Arcminute MicroKelvin Imager (AMI). AMI is comprised of a small array of ten 3.7-metre telescopes, and a large array of eight 13-metre dishes of the Ryle Telescope, rearranged in a new configuration.

Nowadays, telescopes tend to be built by international collaborations and we don't do this on our own anymore. However, we continue to build prototypes for bigger projects in other parts of the world, SKA and HERA for example.

The history of the site is so rich, I have made a bit of my speciality to give tours to all kinds of groups, including primary and secondary school children, radio and optical astronomy enthusiasts, and even Cambridge astronomy students. In 15 years, I must have done about 80 tours for more than 1,000 people. This is not officially part of my role, but I have been a happy volunteer ever since my first tour.



LEFT: Peter Doherty in the AMI enclosure at Lord's Bridge.
ABOVE: Peter and HARP's project manager Harry Smith at the James Clark Maxwell Telescope in Hawaii in 2005.

Over the last 25 years, what would you say has been the most rewarding moment?

One project that fills me with immense pride is the HARP project. The goal was to create a 350 gigahertz, 16-element receiver for the James Clark Maxwell telescope in Hawaii, with unparalleled accuracy, down to plus or minus two thousandths of a millimetre. It was a daunting challenge as the machines we had were not originally designed for such precision. What made it even more remarkable is that the blocks were never machined that way again.

The process involved assembling circular horns and corrugations to ensure the beam patterns exceeded expectations. After six years of hard work, we successfully assembled the receiver and took it to the telescope in Hawaii. To my delight, it worked flawlessly and to this day, it is still in use and functioning perfectly.

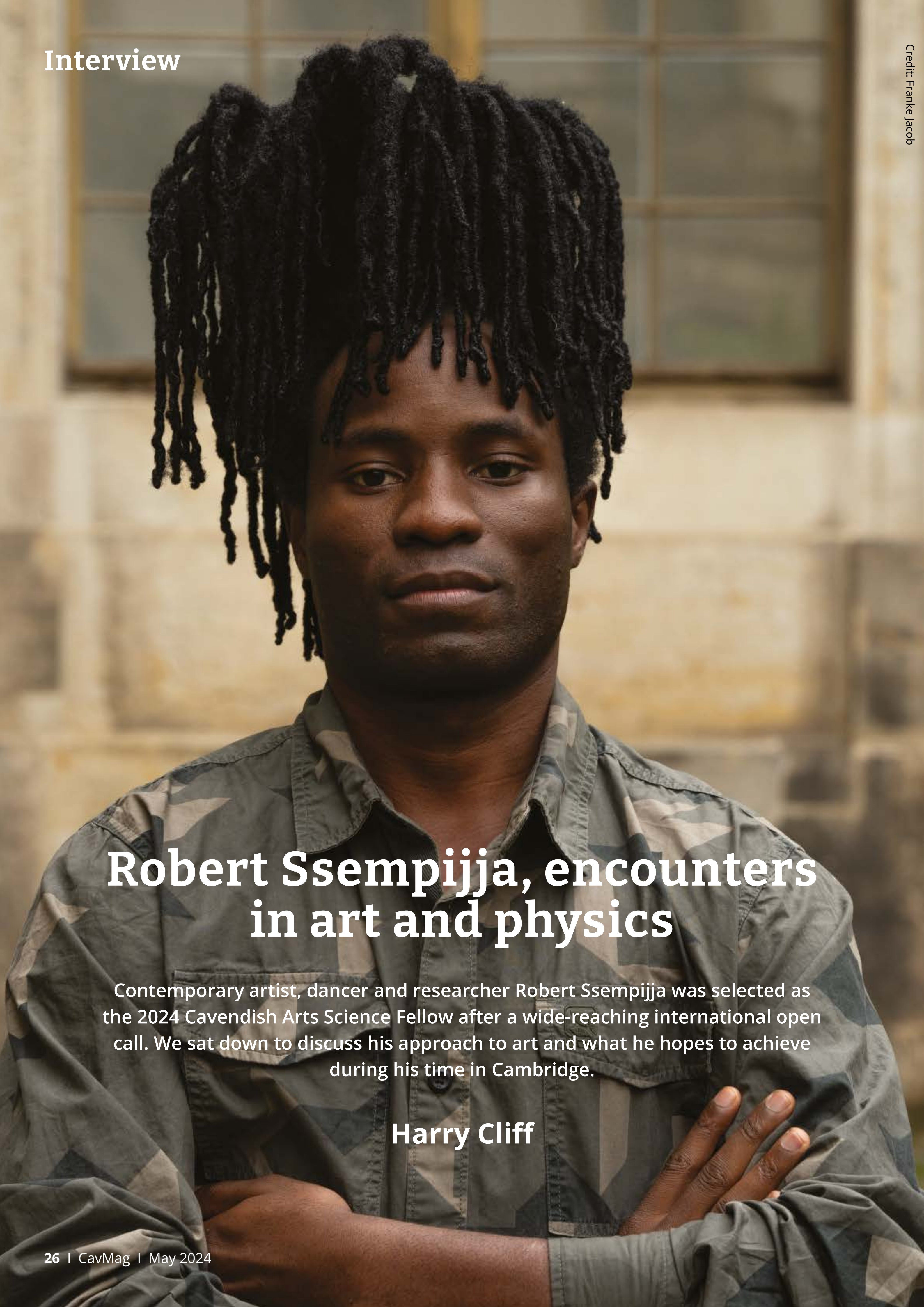
The satisfaction I felt from completing such a highly complex task was indescribable. Witnessing the beam patterns generated from the meticulously machined blocks was incredibly satisfying. All the time and effort put into crafting the blocks, knowing they couldn't be replicated, made the success even more remarkable.

I never truly doubted that it would work, but the overwhelming sense of achievement in that moment was priceless. If only I could capture that feeling and sell it, it would be a treasure beyond measure.

Did you ever think you'd spend half of your career in this role?

I have never felt the need to constantly change jobs. I value building relationships and working with great people as much as the job itself. I have found this at the Cavendish, where I have had the opportunity to excel and contribute to long-term projects from start to finish. This level of involvement and seeing a project through to completion is a dream come true for me as an engineer.

Finally, having a good reputation and being helpful to others has always been important to me. Just like Scottie in Star Trek who didn't want to become a relic, being useful is the most important thing to me. I'll definitely miss the feeling of knowing I've helped others and created things when I eventually move on from the Cavendish.



Credit: Franke Jacob

Robert Ssempijja, encounters in art and physics

Contemporary artist, dancer and researcher Robert Ssempijja was selected as the 2024 Cavendish Arts Science Fellow after a wide-reaching international open call. We sat down to discuss his approach to art and what he hopes to achieve during his time in Cambridge.

Harry Cliff

"I do not know if I found art, or art found me."

Ssempijja's dance piece Alienation explores the meaning of home and where we belong.

I met Robert Ssempijja over a cup of lemon and ginger tea on a pale spring morning in Cambridge's West Hub. Ssempijja is an artist who uses dance to express ideas that cannot easily be spoken, exploring how our thoughts and secrets are revealed by our bodies. He was born and grew up in Uganda and has been creating art for as long as he can remember. "I cannot tell how I came into art. Since I was young, when I first started understanding things, I was doing art."

Ssempijja's first exposure to art came while in the care of a Ugandan organisation that took him in after he and his mother ended up living on the streets, sleeping in parked cars. "I would pay the person who was supposed to be looking after the car park, and if I could not afford to pay, I had to watch the cars for him". The organisation had a varied art programme that covered everything from painting, screen-printing and graffiti writing to music. "As a kid you had to choose one of these activities to get involved in, and at a certain point I ended up choosing dance, because I also used to do a lot of break dancing. So, I do not know if I found art, or art found me."

For Ssempijja, his art is a way of expressing ideas that he might feel unable to say out loud. "There are some things that we want to talk about, but we are afraid to talk about. Growing up in Uganda I could not go on Facebook or in my community and say 'I don't like the President'. So how do I talk about something that I want to say but I can't say out loud? I can say it with my work." Ssempijja's developed numerous pieces tackling subjects from colonialism and decolonization to futurism and space exploration, often working with choreographers from other countries and cultures. He's performed his work all over the world, including in South Africa, Senegal, Uganda, Morocco, Germany, Sweden and the United States.

By his own admission, he had almost no knowledge or previous interest in science but applied to become the 2024 Cavendish Art Science Fellow after an advert kept cropping up on Instagram. "One thing that led me really to do this, is that when I read the application it said 'you don't need to have any background in physics' and I thought 'that is me! I have no idea about physics'. So I did it. And when I received the email saying I was shortlisted I thought 'I think they made a mistake!'" he told me with a laugh.

Since arriving in Cambridge, Ssempijja has had numerous conversations with physicists from around Cambridge. "The first one that struck me, was when I met someone who was studying the Sun. And I thought, how come though I grew up in a place where the Sun is always there, I have no idea about the Sun, and someone *here* who sees the Sun for two hours a year..." he grinned, gesturing at the grey skies above West Cambridge "...is so interested in it!" He continued, "that made me think a lot. That sometimes you can have a thing in abundance, and you don't care about it at all."

However, at first Ssempijja felt unsure if he had made the right decision coming to Cambridge, a place that felt alien and forbidding. "I thought, I'm not sure why I am here". But it was a conversation with a physicist about uncertainty that changed his mind. "He said to me, the uncertainty that you create as someone without an academic background coming to an academic space, it takes us out of our comfort zones". From then on Ssempijja has seen his time in Cambridge as an opportunity to bring new perspectives to the people he interacts with, as well as to challenge himself to explore areas where he feels uncertain. "Uncertainty is a place of unknowing, so when you are in this place you are confused, it brings a lot of chaos. So, I thought, how can I bring uncertainty to Cambridge?"

The work that will emerge from Ssempijja's time in Cambridge is still evolving, but he has tentatively given it the title of *Bound States*. In it, he hopes to explore how we can break out of the narrow lanes we travel down and explore new frontiers. "When you talk to physicists and they tell you what they are doing, you're like wow! You are amazed. But the moment you ask them something outside of their area they're like 'I don't know'. Sometimes it's very shocking, because you have to understand that people in the outside world assume an academic knows everything. He has a PhD! But talking to people, I started to think, you are so closed in to your box. Maybe you should look around and see what else you can pick up. To not always use the same methodologies as before."

"As an artist that is something that I've learnt to do" he continued. "Six years ago, I started getting bored with dance and this boredom sparked me to venture into other genres. I started doing installations, playing with materials and objects, to see if they could give me another perspective, to see what they can tell me about the present, the past. That is also something that became visible in my dance and my art. And that came because I was trying to look outside my bubble. I think physicists need something like that. Not just to be focussed on 'how do I split this atom?'" he said breaking into a laugh.

This is an approach he also wants to take back to Uganda. "One

"...the uncertainty that you create as someone without an academic background coming to an academic space, it takes us out of our comfort zones".

One of Ssempijja's pieces being performed in Kaduna, Nigeria.

thing I want to do with my work, especially for people back home, is to make people think, make people question, make people view Uganda in a different way. How do we start to imagine a country beyond our current capacity for imagination, and the future that we can bring to it." He recounts a conversation with his mother, who is deeply religious, about the existence of God. "It created chaos, she couldn't believe that I was questioning God. I said to her, 'it's not that I don't like what you taught me as a young boy, or the way you raised me, but I'm questioning what you taught me because I want to find out if we can create a new norm. Maybe we can have a different life outside of religion.'"

I ask him if Cambridge too, could benefit from re-examining some of its stranger traditions, the gowns, the Latin graces, the strange ceremonies. "Why are you creating trouble for me?" he smiles, "but yes, I've noticed that Cambridge has a lot of very old traditions that started before people came here from other backgrounds. But now we're living in a time where we have students from different backgrounds, where you have people like me who have nothing to do with academia coming here, so in order for them to feel welcome, to feel included, there are some traditions that need to change."

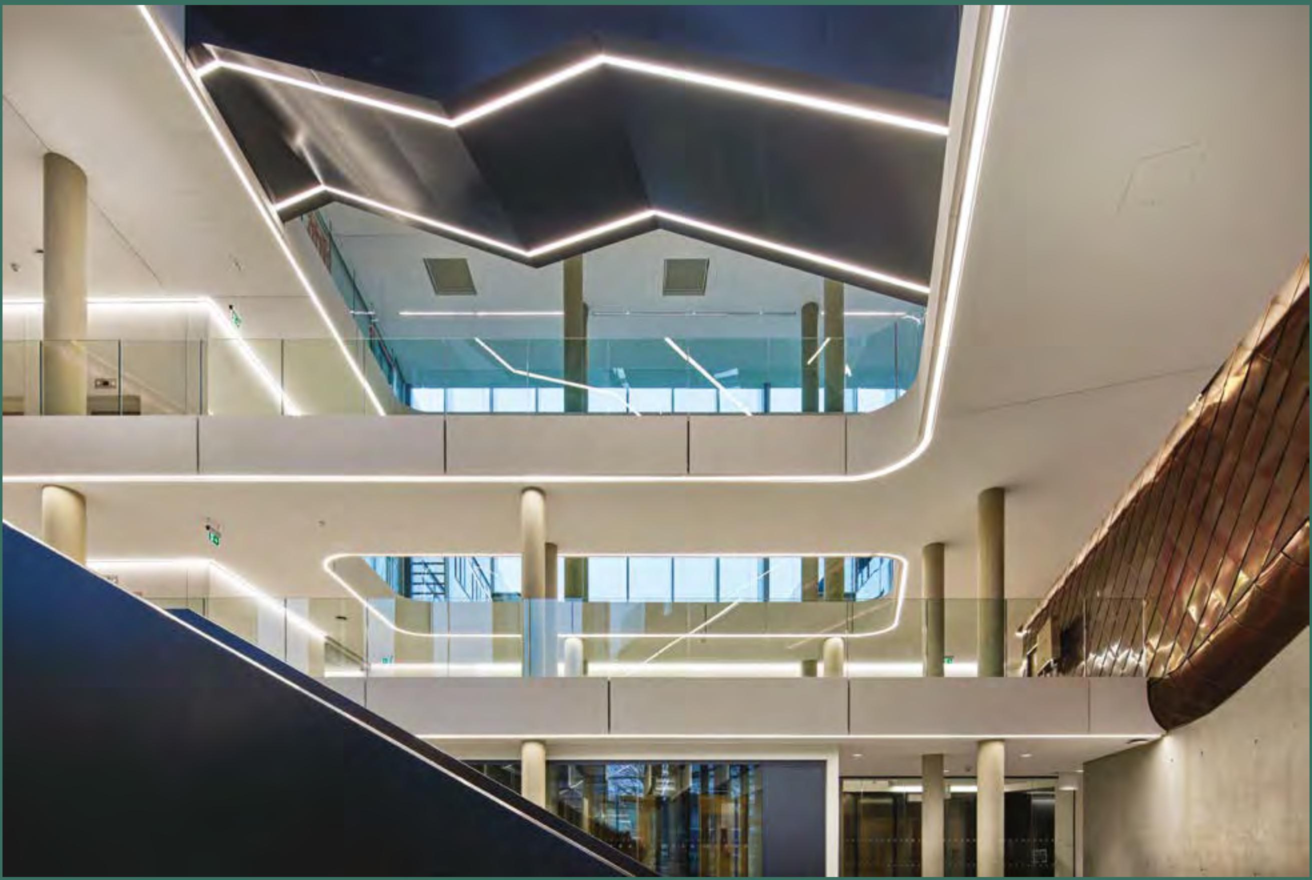
The Cavendish Arts Science Fellowship is made possible through a partnership with Girton College and with the generous support of Dr Una Ryan. For more information on Ssempijja and the Cavendish Arts Science programme, please visit **www.robertssempijja.com and www.cavendish-artscience.org.uk**.

Ray Dolby Centre: construction update

If you've passed along JJ Thomson Avenue during the evening recently, you'll have seen the illuminated entrance signage and stunningly lit public wing of the Ray Dolby Centre, revealing the gleaming copper-clad lecture theatres suspended within the atrium.

The building exterior and landscaping are now complete and await the removal of the temporary site fencing. Inside, the largest lecture theatre, named The Ray Dolby Auditorium, is operational and has already been used for training sessions for Department and Estates staff. The other lecture and seminar spaces are also almost ready for use, pending the installation of their audio-visual systems.

We look forward to the completion of this stunning new building and the process of setting up as the Department of Physics' new centre for research and teaching.



CLOCKWISE FROM TOP-LEFT:

Exterior by night.

Concrete details (column and wall) in the atrium. Image: Paul Raftery

Exterior by day.

Wing 2 Level 2 General Chemistry Lab. Image: Paul Raftery

Atrium from the ground floor. Image: Paul Raftery

Physics fundamentals: extending outreach to primary schools

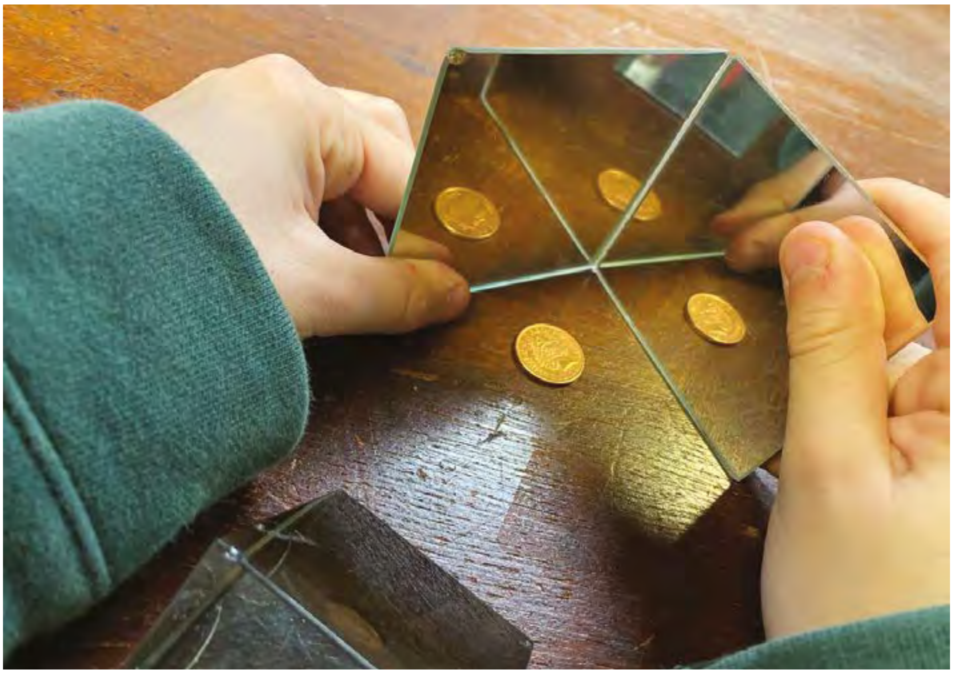
The Cavendish Outreach Team have recently expanded their physics programme for teachers to support primary students' transition to secondary school. Addressing misconceptions about physics at this crucial age is a priority.

Jacob Butler

The Cavendish Outreach Office has a long history of supporting future physicists; the 40th annual Physics at Work exhibition is taking place in September and our regular Cambridge Physics Experience (CPE) programme is now in its twelfth year. These programmes have grown over their lifetimes, responding to the changing needs of schools and developments in the wider access and participation landscape. In light of research suggesting that students' opinion of science, and physics in particular, falls sharply in their first years of secondary school, in 2018 we introduced an additional element of the CPE for years 7 and 8 (ages 11–12). This has been well received by students and their teachers, with overwhelmingly positive feedback, and is regularly oversubscribed. Building on this success, we are now developing a programme for late primary students (ages 9–10), to provide support either side of the jump to secondary school.

Challenging misconceptions

There are two main reasons for us to focus on this age group. Firstly, research indicates that opinions of science are set at a very young age, and secondly, our interactions with primary teachers highlighted the lack of high-quality physics resources at an appropriate level and a particular dearth of support for practical elements of the curriculum. Additionally, very few primary teachers have a background in maths or physics, and a packed curriculum means that fundamental concepts can be skipped over, and misconceptions left unaddressed. Together, this can make the transition to more rigorous science at secondary school particularly challenging for students. By providing teachers



Images: Local cubs taking part in Cavendish Outreach activities and a LEGO Mars rover built by students at one of our Year 7/8 events.

with support for practical sessions, we hope to provide late primary students with an introduction to physics that better positions them for positive engagement with it at secondary school and challenges misconceptions that science is a solo, uncreative enterprise in which they rarely explore their own ideas.

A new offer in tune with the primary curriculum

To do this, we have partnered with local primary schools, providing physics activities for science week events, activity days, and school clubs to better understand the practical realities of the primary curriculum. Coupled with discussions with teachers about their needs and experiences, this has helped shape the intervention we are developing. At the moment, we are sending out the first sets of apparatus to our local partners and asking for their feedback, which will be used to finalise our offering before a wider rollout in the next academic year.

You can help us make a difference

As with all our activities, this work is funded by the generous donations of our supporters. If you would like to contribute, please visit: outreach.**phy.cam.ac.uk/donations**. We are also currently looking for exhibitors to take part in this year's Physics at Work; representatives from academia and industry are welcome as the intention is to show the varied careers to which physics can lead. Please visit **outreach.phy.cam.ac.uk/paw** for more information and contact me at **jbb48@cam.ac.uk** with any expressions of interest.

Department news

2024 Cavendish Annual Thesis Prize Winners

The Cavendish Annual Thesis Prize recognises exceptional research in computational, experimental, and theoretical physics by PhD students. This year's nominations were outstanding, but three exceptional candidates stood out for their contributions - **Lena Dogra**, **Sebastian Gorgon**, and **Thomas Gessey-Jones** – and received the prestigious awards.

Award Ceremony (left to right) - Lena Dogra, Sebastian Gorgon, Thomas Gessey-Jones, and Mete Atatüre (Head of Department, Cavendish Laboratory).

They were honoured at the graduate student conference on November 30th 2023, each receiving a prize of £500. Their projects cover a wide range of topics, including determining properties of the first stars, studying new molecular semiconductors, and finding a universal equation of state for turbulent cascades.

Lena Dogra - Winner of the Abdus Salam Prize: 'Tuneable homogeneous Bose fluids close to and far from equilibrium'

Lena was a PhD student in the AMOP group at the Cavendish Laboratory working with Professor Zoran Hadzibabic. She is now a postdoc in the 'Klim-QML' project of the DLR (German Aerospace Center), where they are working on improving global climate models with quantum machine learning.

Sebastian Gorgon - Winner of the Cavendish Prize in Experimental Physics: 'Interplay of Spin and Photophysics in Luminescent Open-Shell Molecular Semiconductors'

Sebastian is a PhD student in the Optoelectronics group at the Cavendish Laboratory working with Richard Friend, the Cavendish Professor.

Thomas Gessey-Jones - Winner of the Cavendish Prize in Theoretical Physics: 'Probing The First Stars With The 21-cm Signal: Theory, Methods, and Forecasts'

Thomas is a PhD student in the Astrophysics group at the Cavendish Laboratory working with **Eloy de Lera Acedo**.

Celebrating Cavendish Women

March's Women's History Month and International Women's Day were the perfect opportunity to celebrate our current women staff and alumnae.

PhD student and Cavendish Ambassador **Tara Murphy** conducted interviews with various women for her blog series, asking for their advice for young women considering a career in science. The videos of these interviews, filmed and edited by **Charlotte Simmonds** (also a Cavendish Ambassador) and featuring **Hannah Stern**, **Siân Dutton**, **Chiara Ciccarelli** and **Emily Roe**, can be found on the Cavendish's Instagram, TikTok, and YouTube channels. You can also read the full interviews on Tara's blogs on the Cavendish's website: phy.cam.ac.uk/blogs.

In addition, the March episode of the People Doing Physics podcast featured a panel discussion with four Cavendish alumnae: **Aswathy Girija** - Commissioning Editor at Institute of Physics Publishing, **Kerstin Göpfrich** - Professor and Group Leader at Max Planck Institute for Medical Research, **Joanne Baker** - Chief Opinion Editor at Nature and author of four popular science books and

Emma Williams - Professional Development Coach and Businessowner.

They told host **Simone Eizagirre Barker** about what they learnt at the Cavendish, their natural sciences and physics background, as well as how their doctoral research in physics shaped their careers.

This episode can be found on various podcast platforms or on the People Doing Physics website: people-doing-physics.captivate.fm.

Farewell to Val Gibson

In January we said farewell to **Val Gibson**, who retired as Professor of High Energy Physics and Head of the High Energy Physics Research Group at the end of 2023.

Val joined the Cavendish in 1989 and was appointed as University Lecturer and Fellow of Trinity College in 1994, Reader in 2006 and became a Professor in 2009. She has worked on the LHCb experiment since the first beam of particles were injected into the Large Hadron Collider in 2008. Val was awarded an OBE in The Queen's 2021 New Years Honours List 'For services to Science, Women in Science and to Public Engagement'.

She has spent her career championing women in science and spearheaded the Cavendish Laboratory's success at achieving an Athena SWAN Gold award in 2014. We are immensely grateful for her successful efforts and commitment to the advancement and retention of women in science at the Cavendish and across the sector.

We send our heartfelt thanks to Val and wish her every success in her future endeavours.

Peter Norman stepping down

We also announced that **Peter Norman** had stepped down as our Head of Cavendish Estates, as he prepares for retirement. Peter joined the Department in November 2008 with extensive experience in the engineering industry. Over his 16 years in the Department, first as Head of the Mechanical Workshop, then Department Superintendent and finally in his current role, Peter has made a huge impact through a sustained and sensitive campaign of development of both staffing and infrastructure. He has worked tirelessly to improve opportunities for our technical staff, pioneering a new technical programme and fostering grassroots talent. During this period, his leadership in large-scale construction projects, notably the Maxwell Centre, showcased his exceptional project management skills.

We are fortunate that Peter has agreed to delay his well-earned retirement and remains dedicated to Cambridge Physics, redirecting his focus to oversee the completion of the Ray Dolby Centre and ensuring a seamless transition for research activities and staff.

Peter is being succeeded by **Karen King** who joined the Department in February as our new Head of Cavendish Estates. Karen has an extensive background in Facility Management in Public and Private sectors as well as Education. Most recently she was Senior Regional Facilities Manager for the Competition and Markets Authority in Canary Wharf, London, where she was also managing buildings in Belfast, Cardiff and Edinburgh. She brings her passion for sustainability and dedication to agile working and collaboration to her role and we are delighted to have her on board.

Department news

New Academic Appointments


We are delighted to welcome **Anton Souslov** and **Dorian Gangloff** to the Department, as our two newest academic appointments.

Dorian Gangloff is the new Associate Professor of Quantum Technologies and Head of the Quantum Engineering Group. A Royal Society University Research Fellow, Dorian and his team are studying information scientist studying experimental and theoretical aspects of solid-state spins and photons.

Anton Souslov is our new Associate Professor of Theoretical Statistical Physics. His group is interested in modelling the mechanics of soft materials and designing new states of matter.

Both have already been hard at work since their arrival, securing fundings for two major projects:

Anton Souslov will be the Cambridge lead for the new UK wide Metamaterials NetworkPlus to help develop the UK's capabilities in developing game-changing metamaterials breakthroughs.

Dorian Gangloff has secured funding to boost quantum networking through the MEEDGARD project, short for 'Memory Enhanced Entanglement Distribution with Gallium ARsenide quantum Dots'. This ambitious project aims to revolutionise quantum communication networks by developing an optical interface to a long-lived quantum memory in semiconductor nanostructures, specifically quantum dots (QD). With a substantial budget of €2.1 million over three years, MEEDGARD is set to make significant strides in quantum network development.

Mark Thomson to be the UK candidate for CERN Director-General

The UK government has announced its support for Cavendish particle physicist **Mark Thomson**, to be the next Director-General of CERN, the European Organisation for Nuclear Research.

Mark is a renowned Professor of Experimental Particle Physics at the Cavendish Laboratory and a Fellow at Emmanuel College. Since 2018, he is the Executive Chair of STFC, the UK Research Council that provides funding for particle physics, astrophysics, space science and nuclear physics.

Commenting on the news, Head of the Cavendish Laboratory **Mete Atatüre** said:

"Mark Thomson's candidacy for CERN's lead role is incredibly exciting. We are truly confident in the transformative impact his leadership will have on this crucial area of research, tackling some of the most foundational scientific questions of modern times."

Jeremy Baumberg newly appointed member of EPSRC Council

Congratulations to **Jeremy Baumberg** who has been recently appointed member of the Engineering and Physical Sciences Research Council (EPSRC) Council.

Jeremy is the Harold Aspden Professor of Fundamental Physics at the Cavendish and is a world-recognised leader in nanoscience and nanotechnology, crossing interdisciplinary boundaries within physical sciences and engineering.

Council members advise and help EPSRC to make decisions on scientific, research and innovation matters. It is fantastic to see our academics taking on such roles that help define approaches to and policies for scientific research.

National award for Oliwia Zawadzka

Many congratulations to our apprentice **Oliwia Zawadzka** for her recent win at the CSR Community award 2023. She received this national award in recognition of her outstanding contribution to the community by raising awareness of apprenticeships and inspiring others, through her talks at the last Physics at Work event in September. The award came with an iPad and a certificate of appreciation. Well done, Oliwia!

Tyler Colenbrander wins 2024 Cambridge Climate Challenge with team 'Benign'

Tyler Colenbrander, a physics MPhil student, was part of the team 'Benign', which won the 2024 Cambridge Climate Challenge. Their innovative business model revolves around an enzyme derived from brain cancer DNA, aiming to drastically cut greenhouse gas emissions in nylon production. The team's idea stems from a decade of cancer research published in Nature's Communications Biology. Their aim is to drastically reduce the environmental impact of producing nylon for everything from stockings to swimwear. By leveraging scientific breakthroughs for environmental betterment, Benign endeavours to bridge research and business for a greener future.

Jesús Arjona Martínez amongst Forbes 30 Under 30

Jesús Arjona Martínez, a PhD student in **Mete Atatüre's** research group, has been recognised as one of the 'Forbes 30 Under 30 Europe 2024' for his current research on quantum communication. The Forbes 30 Under 30 Europe 2024 list highlights rising stars in various industries from music and media to sport and science.

Physics PhD students rowing to victory in the 2024 Boat Race!

Many congratulations to our two PhD students, **Thomas Marsh** and **Noam Mouelle**, and the rest of the Cambridge men's blue boat team for winning the Boat Race against Oxford. Noam, who is doing his PhD in the AMOP group, was returning after his first victory last year. Thomas, a PhD in the Sirringhaus group, was also returning after taking part in the reserve boat race (Goldie) in 2023.

New Appointments to the Professional Staff

New RDC Laboratory Manager

Emily Hogg has joined the Cavendish Laboratory as the new RDC Laboratory Manager. She will be part of the Laboratories Services team and will play a vital role in supporting research groups with their move into the new Ray Dolby Centre (RDC).

Emily brings a wealth of experience to the team, having previously worked in the Biopharma Industry as a Lab Manager and most recently as Laboratory Support Team Leader for Avantor, who provided laboratory support for AstraZeneca. In this role, she was instrumental in setting up a brand-new laboratory building on the Cambridge Biomedical Campus, overseeing the move of science and support services and ensuring everything was ready for live science operations.

Other appointments

Ragha Adapa - Kapitza Hub Manager
Archie Balls - Rutherford Hub Finance Assistant
Matthew Billing - Nanofabrication Facility Technician
Jiasheng Chen - AMCS-VERSMAG Instrument Scientist
Kim Dorsett - Postgraduate Administrator
Geoff Elliot - Deputy H&S Manager
Katie Fanstone - Kapitza Hub Finance Administrator
Paul Game - Department Finance Advisor
Jack Good - Nanofabrication Facility Technician
Shaoliang Guan - XPS Facility Scientist
Gil Krikler - Research Laboratory Technician
Yugen Miyazaki - Development Manager for CORDE, the Collaborative R&D Environment (previously known as National Facility for Physics)
Nora Mor - Kapitza Hub Finance Assistant
David Ward - CORDE Characterisation Manager
Mia Wootton - Research Grants Administrator

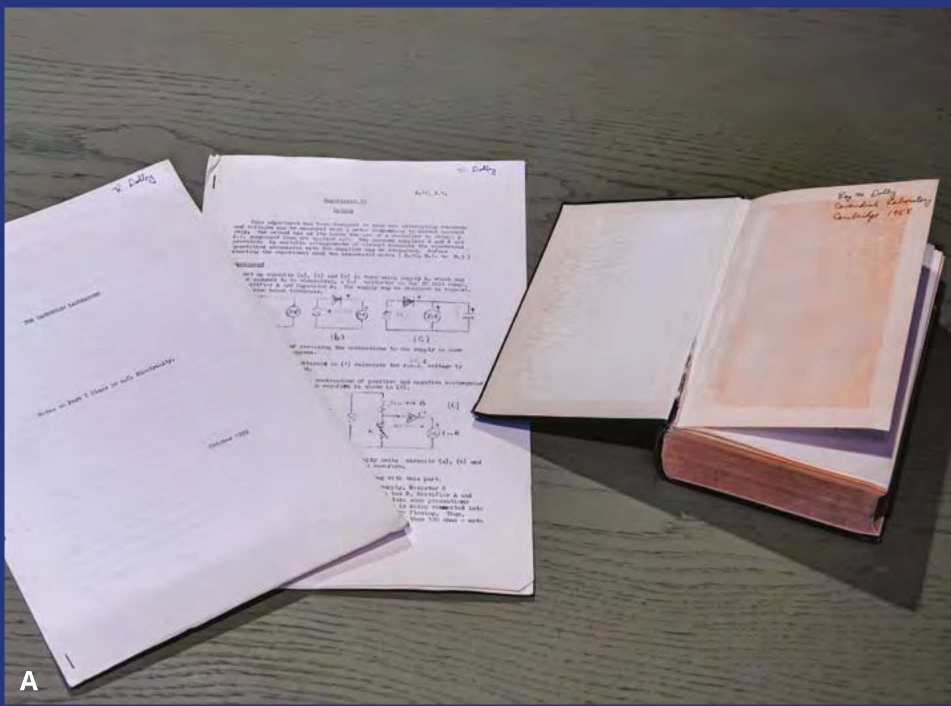
The Dolby Collection arrives at the Cavendish

Harry Cliff

In February, a rather special delivery arrived at the Cavendish Laboratory from San Francisco, California: a collection of items donated by the Dolby family. This group of objects from the life and work of the American engineer and inventor Ray Dolby, will soon be put on display in the main entrance of the newly constructed Ray Dolby Centre as part of a memorial to the man whose legacy enabled the construction of the new laboratory.

As a former Science Museum curator, few things give me more pleasure than delving into a box of historic artefacts, and this one contains some real treasures. The collection includes several examples of Dolby's key inventions, alongside a number of more personal items that speak to his time at the Cavendish, as well as to his lifelong love of music.

The earliest items date from Dolby's time at Cambridge as a Marshall Scholar from 1957 to 1961, when he was studying for a PhD in the Cavendish's Electron Microscope Group under Ellis Cosslett. These include a copy of his hand-annotated notes from working as a demonstrator in the undergraduate practical classes on 'A.C. Electricity' in 1959, along with an Oxford Concise Dictionary bearing the inscription 'Ray M. Dolby, Cavendish Laboratory, Cambridge, 1958'.



Capping off his time as a graduate student is his original unbound copy of his PhD dissertation titled 'Long Wavelength X-Ray Microanalysis'. The theoretical analysis section of his dissertation is particularly notable as it shows Dolby's developing interest in extracting signals from noisy backgrounds, the seeds of the ideas that he would use in developing the Dolby Noise Reduction system a few years later.

A more personal item in the collection is Ray Dolby's clarinet, along with sheet music for pieces by Mozart and Clarence Raybould. Dolby had a keen interest in music, taking up the piano aged ten and playing clarinet in his school orchestra. He particularly enjoyed symphonic music and opera, and it was his love of music and fascination with audio recording that gave impetus to his work on noise reduction.

C

D

Completing the collection are a number of the key pieces of technology that Dolby developed at Dolby Laboratories, first in London in the 1960s and later in San Francisco. A standout item is an original A301 compressor board from Dolby's first noise reduction system used in professional studio recordings. The technology, introduced in 1966, was quickly adopted by London-based Decca Records, who used Dolby's Noise Reduction System for the first time to produce a recording of Mozart's Piano Sonatas by Wilhelm Backhaus in 1967. A copy of this historic record is included as part of the collection.

Together, these objects will provide a wonderful memorial to Ray Dolby's life and work, which visitors will discover when entering the Ray Dolby Centre.

IMAGES:

A. Lab notes and dictionary.

B. PhD dissertation.

C. Clarinet and sheet music.

D. A301 Compressor circuit board and Wilhelm Backhaus record.

150th anniversary: your memories needed

A warm thank you to all of you who have already shared with us their stories and treasured memories of their time at the Cavendish, in preparation for our 150th anniversary.

Please continue to send anything you would like to share with us and the Cavendish community, be it a photo, a diary entry, an interesting fact, or a funny anecdote.

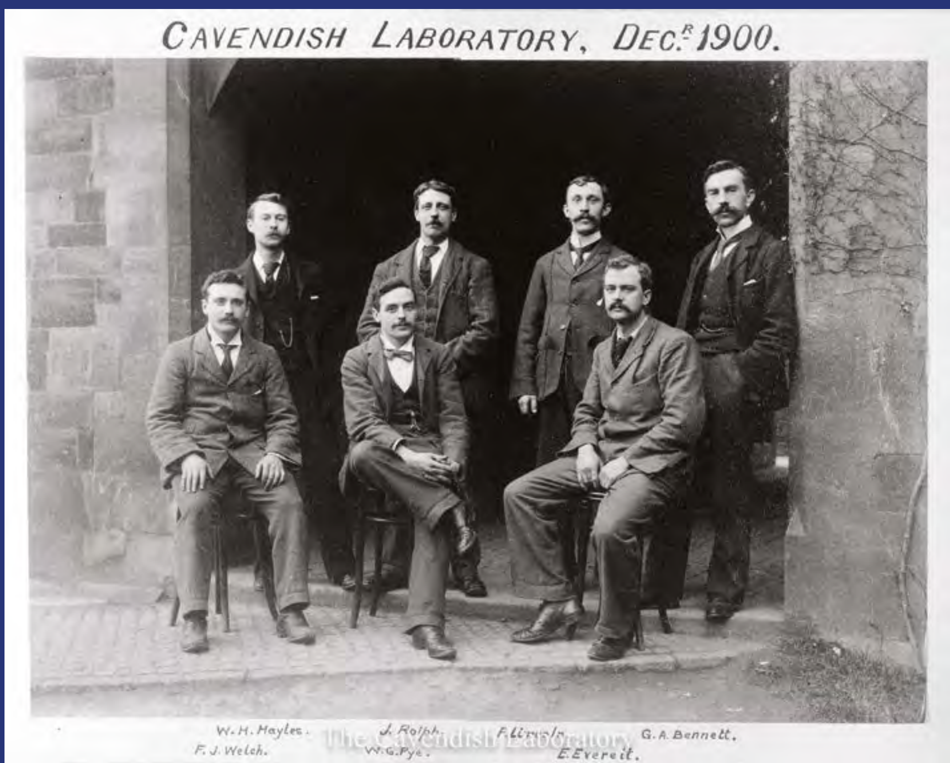
As 2024 also marks the 50th anniversary of our occupation of the West Cambridge site, we are particularly interested to hear from those who remember moving to the 'new Cavendish' in 1974. Do you recall what it was like to study or work in those brand-new labs? Did the move from the city centre to the then not very densely populated West Cambridge site have an impact (positive or otherwise) on your experience? We would also be very keen to collect any photo of that time you may have, for our archives.

We would also like to do a focus on our technical staff and their often silent yet invaluable contributions to the successes of the laboratory over the years. If the story of Thomson's talented assistant Ebenezer Everett and a few others are relatively widely known, we recognise that many other unsung heroes have fuelled our scientific achievements and must be celebrated. If you have worked or studied alongside a technician who made a difference, from way back or a more recent past, please also tell us about them.

Your narratives will be woven into the fabric of our 150-year history, creating a tapestry of shared memories that will be showcased during the year of festivities, planned to run from June 2024 to June 2025, and in the special 150th anniversary edition of CavMag in the autumn.

Please submit all your stories, memories and ideas in the form of a title, short description and an image or a video to **communications@phy.cam.ac.uk**

If you have any questions or need additional information do not hesitate to contact us at the same email address.



Mapping the history of Cambridge Innovation

ABOVE: Promotional material for the Stereoscan II, Cambridge Scientific Instrument Company Archive, Box 50, Cambridge University Library. The first commercial scanning electron microscopes delivered in 1964 were produced by the Cambridge Instrument Company, building on research and development in the Cambridge University Engineering Laboratory.

The Cambridge History of Innovation Project (CHIP) is underway! The CHIP team (Shailendra Vyakarnam, Katrina Dean, and Peter Rees) are currently surveying and collecting archival material and oral history interviewee candidates to curate a public archive of Cambridge technology innovation from the Cambridge Scientific Instrument Company to recent times.

They are very keen to capture the roles of the Cavendish Laboratory in the history of technology innovation. This archive aims to facilitate deep research and diverse storytelling about Cambridge innovation. CHIP is based in the Cambridge University Library, alongside existing significant archival collections including the papers of Isaac Newton, Charles Darwin, Stephen Hawking, and many others. CHIP is supported by Higher Education Innovation Funding.

If you are interested in the CHIP project, contact the Project Archivist, Peter Rees at **pr381@cam.ac.uk**. If you would like to share memories, connections, or archival materials which might be relevant for this public archive, please do get in touch. For more details see **www.lib.cam.ac.uk/chip**

CavMag goes digital

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Read every feature article, every news bite and every interview in an immersive, interactive and truly accessible digital environment. We have designed this new digital version of our magazine to be fully responsive, which means our stories can be enjoyed on all devices and screen sizes.

We are accompanying this launch with a new Alumni e-newsletter, which will be sent to you around the same time as CavMag arrives in your mailbox, to highlight some of the exciting articles included in the newest issues.

Receive CavMag the way that suits you

To opt out of receiving the print edition and/or be sent an email when the latest edition is available online, please visit **www.alumni.cam.ac.uk/update**

Tell us what you think

We will continue developing this platform over the coming year to improve it even further for our next issue in the autumn. If you have any feedback, please get in touch to let us know what you think at **cavmag@phy.cam.ac.uk**

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 the Head of Department.

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 Samantha Stokes (**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 Mete Atatüre (**hod@phy.cam.ac.uk**), who will be very pleased to talk to you confidentially.

Contact

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