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January 2025

Return to Helgoland

Celebrating 100 years of quantum mechanics

Art-science crossover

The stained-glass structure inspired by a quantum chip

Blackboard to boardroom

How students can pick up entrepreneurial skills

Environmental influence

Eyeing up the impact of clouds on climate change

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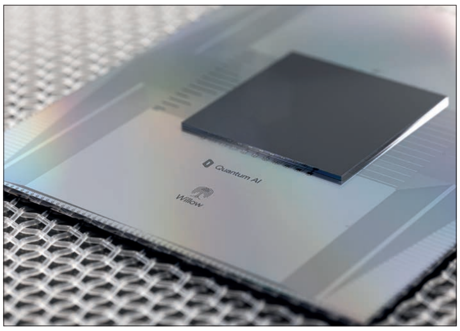
Volume 38 No 1

AUDIO *Physics World* editors discuss their highlights of the January issue



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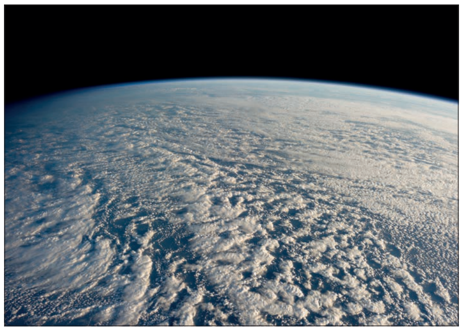

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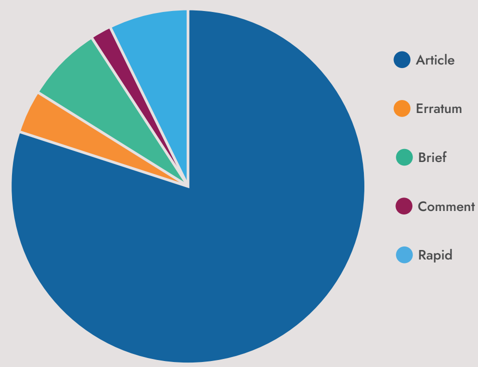

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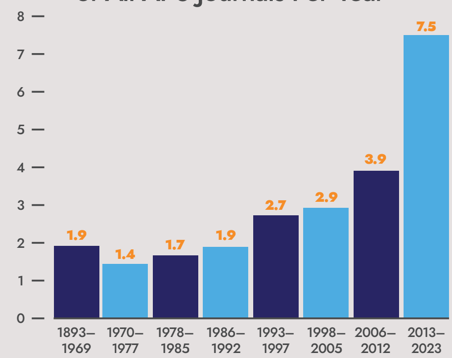

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APS

News & Analysis

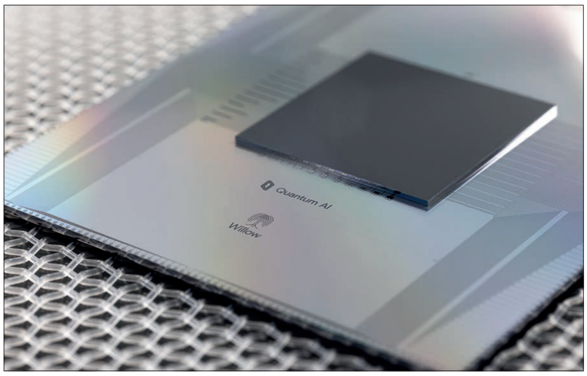
Quantum error correction wins award

The *Physics World* 2024 Breakthrough of the Year goes to two groups that have made significant advances in quantum error correction methods, as **Margaret Harris** reports

The *Physics World* 2024 Breakthrough of the Year has been awarded to Mikhail Lukin, Dolev Bluvstein and colleagues at Harvard University, the Massachusetts Institute of Technology and QuEra Computing, and independently to Hartmut Neven and colleagues at Google Quantum AI. The teams won for demonstrating quantum error correction on an atomic processor with 48 logical qubits (*Nature* **626** 58), and for implementing quantum error correction below the surface code threshold in a superconducting chip, respectively (*Nature* 10.1038/s41586-024-08449-y). The results by these two teams make it far more likely that quantum computers will become practical problem-solving machines, not just noisy, intermediate-scale tools for scientific research.

Errors caused by interactions with the environment – noise – are the Achilles heel of every quantum computer, and correcting them has been called a "defining challenge" for the technology. Lukin, Bluvstein and colleagues explored neutral atom arrays – grids of ultracold rubidium atoms trapped by optical tweezers. These atoms can be put into highly excited Rydberg states, which enables the atoms to act as qubits that can exchange quantum information. They created a programmable quantum processor that is based on the control of logical qubits in neutral atom arrays, and used their platform to run a series of programmable logical algorithms. This approach allowed the team to vastly improve on the results of recent experiments: encoding up to 48 logical qubits, containing up to 228 two-qubit logic gates. With its in-built error correction, the processor dramatically improved the performance of the algorithms run by the team.

The Google group, meanwhile, unveiled a new superconducting processor called Willow with several improvements over the previous chips. These include gates (the building blocks of logical operations) that retain their "quantumness" five times longer and a Google Deepmind-developed machine learning algorithm that interprets errors in real time. When the team used this new tech to create nine surface code distance-3 arrays, four distance-5 arrays and one 101-qubit distance-7 array on their 105-qubit processor, the error rate was suppressed by a factor of 2.4 as additional qubits were added. The work could, in principle, lead to an unlimited increase in qubit quality, and ultimately to an unlimited increase in the length and complexity of the algorithms that quantum computers can run.



Google Quantum AI

Groundbreaking device
Google Quantum AI's new Willow chip includes a Google Deepmind-developed machine-learning algorithm that interprets errors in real time.

This year's top breakthroughs were selected by a panel of *Physics World* editors, who sifted through hundreds of research updates published on the website in 2024 across all fields of physics. In addition to having been reported on *Physics World* in 2024, the winner and nine other highly commended pieces of research must meet the following criteria: significant advance in knowledge or understanding; importance of work for scientific progress and/or development of real-world applications; and be of general interest to *Physics World* readers.

Highly commended

The nine other highly commended breakthroughs follow in no particular order.

In condensed-matter physics, to Walter de Heer, Lei Ma and colleagues at Tianjin University and the Georgia Institute of Technology, and independently to Marcelo Lozada-Hidalgo of the University of Manchester and a multinational team of colleagues, for creating a functional semiconductor made from graphene (*Nature* **625** 60), and for using graphene to make a switch that supports both memory and logic functions (*Nature* **630** 619), respectively. The Manchester-led team's achievement was to harness graphene's ability to conduct both protons and electrons in a device that performs logic operations with a proton current while simultaneously encoding a bit of memory with an electron current. These functions are normally performed by separate circuit elements, which increases data transfer times and power consumption. Conversely, de Heer, Ma and colleagues engineered a form of graphene that doesn't conduct as easily. Their new "epigraphene" has a bandgap that, like silicon, could allow it to be made into a transistor, but with favourable properties that silicon lacks, such as high thermal conductivity.

In particle physics, to the AEgIS collaboration at CERN, and Kosuke Yoshioka and colleagues at the University of Tokyo, for independently demonstrating laser cooling of positronium (*Phys. Rev. Lett.* **132** 083402 and *Nature* **633** 793). Positronium, an atom-like bound state of an electron and a positron, is created in the lab to allow physicists to study antimatter. Currently, it is created in "warm" clouds in which the atoms have a large distribution of velocities, making precision spectroscopy difficult. Cooling positronium to low temperatures could open up novel ways to study the properties of antimatter. It also enables researchers to produce one to two orders of magnitude more antihydrogen – an antiatom comprising a positron and an antiproton.

In medical physics, to Roman Bauer at the University of Surrey, UK, Marco Durante from the GSI Helmholtz Centre for Heavy Ion Research, Germany, and Nicolò Cogno from GSI and Massachusetts General Hospital/Harvard Medical School, US, for creating a computational model that could improve radiotherapy outcomes for patients with lung cancer (*Communications Medicine* **4** 16). Radiotherapy is an effective treatment for lung cancer but can harm healthy tissue. To minimize radiation damage and help personalize treatment, the team combined a model of lung tissue with a Monte Carlo simulator to simulate irradiation of alveoli (the tiny air sacs within the lungs) at microscopic and nanoscopic scales. Based on the radiation dose delivered to each cell and its distribution, the model predicts whether each cell will live or die, and determines the severity of radiation damage hours, days, months or even years after treatment. Importantly, the researchers found that their model delivered results that matched experimental observations, suggesting that it could be used within a clinical setting.

Another breakthrough in medical physics goes to a team of researchers at Stanford University in the US for developing a method to make the skin of live mice temporarily transparent (*Science* **385** eadm6869). One of the challenges of imaging biological tissue using optical techniques is that tissue scatters light, which makes it opaque. The team, led by Zihao Ou, Mark Brongersma and Guosong Hong, found that the common yellow food dye tartrazine strongly absorbs near-ultraviolet and blue light and can help make biological tissue transparent. Applying the dye onto the abdomen, scalp and hindlimbs of live mice enabled the researchers to see internal organs, such as the liver, small intestine and bladder, through the skin without requiring any surgery. They could also visualize blood flow in the rodents' brains and the fine structure of muscle sarcomere fibres in their hind limbs. The effect can be reversed by simply rinsing off the dye. If extended to humans, it could help make some types of invasive biopsies a thing of the past.

In nuclear physics, to David Moore, Jiaxiang Wang and colleagues at Yale University, US, for detecting the nuclear decay of individual helium nuclei by embedding radioactive lead-212 atoms in a micron-sized silica sphere and measuring the sphere's recoil as nuclei escape from it (*Phys. Rev. Lett.* **133** 023602). Their technique relies on the conservation of momentum, and it can gauge forces as small as 10^{-20} N and accelerations as tiny as 10^{-7} g. The researchers hope that a similar technique may one day be used to detect neutrinos.

In theoretical physics, to Andrew Denniston at the Massachusetts Institute of Technology in the US, Tomáš Ježo at Germany's University of Münster and an international team for being the first to unify two distinct descriptions of atomic nuclei (*Phys. Rev. Lett.* **133** 152502). They combined the particle physics perspective – where nuclei comprise quarks and gluons – with the traditional nuclear physics view that treats nuclei as collections of interacting nucleons (protons and neutrons). The team has provided fresh insights into short-range correlated nucleon pairs – which are fleeting interactions where two nucleons come exceptionally close and engage in strong interactions for mere femtoseconds. The model was tested and refined using experimental data from scattering experiments involving 19 different nuclei with very different masses (from helium-3 to lead-208).

In optics, to Jelena Vučković, Joshua Yang, Kasper Van Gasse, Daniil Lukin and colleagues at Stanford University in the US for developing a compact, integrated titanium:sapphire laser that needs only a simple green LED as a pump source (*Nature* **630** 853). They have reduced the cost and footprint of a titanium:sapphire laser by three orders of magnitude and the power consumption by two. Traditional titanium:sapphire lasers have to be pumped with high-powered lasers – and therefore cost in excess of $100 000. In contrast, the team was able to pump its device using a $37 green laser diode. The researchers also achieved two things that had not been possible before with a titanium:sapphire laser– namely, adjust the laser wavelength and create a laser amplifier. Their device represents a key step towards the democratization of a laser type that plays important roles in scientific research and industry.

AUDIO

Listen to two interviews with our Breakthrough winners: Mikhail Lukin and Dolev Bluvstein (top) and Hartmut Neven (bottom).

Another advance in optics goes to two related teams for their use of entangled photons in imaging. Both groups include Chloé Vernière and Hugo Defienne of Sorbonne University in France, who used quantum entanglement to encode an image into a beam of light (*Phys. Rev. Lett.* **133** 093601). Here the image is only visible to an observer using a single-photon sensitive camera – otherwise the image is hidden from view. The technique could be used to create optical systems with reduced sensitivity to scattering. This could be useful for imaging biological tissues and long-range optical communications. In separate work, Vernière and Defienne teamed up with Patrick Cameron at the UK's University of Glasgow and others to use entangled photons to enhance adaptive optical imaging (*Science* **383** 1142). The team showed that the technique can be used to produce higher-resolution images than conventional bright-field microscopy.

In space, to the China National Space Administration for the first retrieval of material from the Moon's far side. Landing on the lunar far side is difficult due to its distance and terrain of giant craters with few flat surfaces. The Chang'e-6 mission was launched on 3 May and successfully touched down on 1 June in the Apollo basin, which lies in the north-eastern side of the South Pole-Aitken Basin. The lander used its robotic scoop and drill to obtain about 1.9 kg of materials within 48 hours. It headed back to Earth, landing in Inner Mongolia on 25 June. In November 2024 scientists released the first results from the mission finding that fragments of basalt – a type of volcanic rock – date back to 2.8 billion years ago, indicating that the lunar far side was volcanically active at that time (*Nature* 10.1038/s41586-024-08382-0 and *Science* 10.1126/science.adt1093).

Margaret Harris is an online editor of *Physics World*. Additional reporting by *Physics World* editors **Tami Freeman**, **Hamish Johnston** and **Michael Banks**

Physics ‘deep tech’ missing out on £4.5bn

A major new report by the Institute of Physics finds that venture-capital investors often struggle to invest in physics, as **Michael Banks** explains

UK physics “deep tech” could be missing out on almost a £1bn of investment each year. That is according to a new report by the Institute of Physics (IOP), which publishes *Physics World*. It finds that venture capital investors often struggle to invest in high-innovation physics industries given the lack of a “one-size-fits-all” commercialization pathway that is seen in other areas such as biotech.

According to the report, physics-based businesses add about £230bn to the UK economy each year and employ more than 2.7 million full-time employees. The UK also has one of the largest venture-capital markets in Europe and the highest rates of spin-out activity, especially in biotech. Despite this, however, venture capital investment in “deep tech” physics – start-ups whose business model is based on hi-tech innovation or significant scientific advances – remains low, attracting £7.4bn or 30% of UK science venture-capital investment.

To find out the reasons for this discrepancy, the IOP interviewed science-led businesses as well as 32 leading venture capital investors. Based on these discussions, it was found that many investors are confused about certain aspects of physics-based start-ups, finding that they often do not follow the familiar lifecycle of development seen in other areas such as biotech. Physics businesses are not, for example, always able to transition from being tech-focused to being product-led in the early stages of development, which prevents venture capitalists from committing large amounts of money. Another issue is that venture capitalists are less familiar with the technologies, timescales and “returns profile” of physics deep tech.

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Unleashing potential The Institute of Physics is calling for a co-ordinated effort from government and investors as well as the business and science communities to address the issues raised in its report.

Lost potential

The IOP report estimates that if the full investment potential of physics deep tech is unlocked then it could result in an extra £4.5bn of additional funding over the next five years. In a foreword to the report, Hermann Hauser, the tech entrepreneur and founder of Acorn Computers, highlights “uncovered issues within the system that are holding back UK venture capital investment” into physics-based tech. “Physics deep-tech businesses generate huge value and have unique characteristics – so our national approach to finance for these businesses must be articulated in ways that recognize their needs,” writes Hauser.

At the same time, investors see a lot of opportunity in subjects such as quantum and semiconductor physics as well as with artificial intelligences and nuclear fusion. Jo Slota-Newson, a managing partner at Almanac Ventures who co-wrote the report, says there is “huge potential” for physics deep-tech businesses but “venture capital funds are being held back from raising and deploying capital to support this crucial sector”.

The IOP is now calling for a co-ordinated effort from government, investors as well as the business and science communities to develop “investment pathways” to address the issues raised in the report. For example, the UK government should ensure grant and debt-financing options are available to support physics tech at “all stages of development”.

Slota-Newson, who has a background in science including a PhD in chemistry from the University of Cambridge, says that such moves should be “at the heart” of the UK’s government’s plans for growth. “Investors, innovators and government need to work together to deliver an environment where at every stage in their development there are opportunities for our deep-tech entrepreneurs to access funding and support,” adds Slota-Newson. “If we achieve that we can build the science-driven, innovative economy, which will provide a sustainable future of growth, security and prosperity.”

Sharing success

The report also says that the IOP should play a role by continuing to highlight successful physics deep-tech businesses and to help them attract investment from both the UK and international venture-capital firms. Indeed, Tom Grinyer, group chief executive officer of the IOP, says that getting the model right could “supercharge the UK economy as a global leader in the technologies that will define the next industrial revolution”.

“Physics deep tech is central to the UK’s future prosperity – the growth industries of the future lean very heavily on physics and will help both generate economic growth and help move us to a lower carbon, more sustainable economy,” says Grinyer. “By leveraging government support, sharing information better and designing our financial support of this key sector in a more intelligent way we can unlock billions in extra investment.”

That view is backed by Hauser. “Increased investment, economic growth, and solutions to some of our biggest societal challenges [will move] us towards a better world for future generations,” he says. “The prize is too big to miss”.

Michael Banks is news editor of *Physics World*

Facilities

Africa aims for 2035 synchrotron construction start

Officials at the African Light Source (AfLS) Foundation are targeting 2035 as the start of construction for the continent's first synchrotron light source. On 9 December 2024 the foundation released its "geopolitical" conceptual design report, which aims to encourage African leaders to pledge the $2bn that will be needed to build and then operate the facility for a decade.

There are more than 50 synchrotron light sources around the world, but Africa is the only habitable continent without one. Scientists in Africa have been agitating for a light source on the continent for decades, with the idea for an African synchrotron having been discussed since at least 2000. In 2018 the African Union's executive council called on its member states to support a pan-African synchrotron and the following year Ghanaian president Nana Addo Dankwa Akufo-Addo began championing the project.

The new 388-page report, which has over 120 contributors from around the world, lays out a comprehensive case for a dedicated synchrotron in Africa, stating it is "simply not tenable" for the continent to not have one. Such a facility would bring many benefits to Africa, ranging from capacity building and driving innovation to financial returns. It cites a 2021 study of the UK's £1.2bn Diamond Light Source, which essentially paid for itself after just 13 years.

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One for the future Africa is the only habitable continent that does not have a synchrotron light source.

"Without its own synchrotron facility, Africa will be left further behind at a corresponding accelerated rate and will be almost impossible to catch up to the rest of the world," says Sekazi Mtingwa, a US-based theoretical high-energy physicist. Mtingwa is one of the founders of the South-Africa-based AfLS Foundation and editor-in-chief of the report.

The AfLS Foundation believes its report will persuade African governments to back the initiative. "The 2035 date is far away and gives us time to convince African governments," Simon Connell, chair of the AfLS Foundation, told *Physics World*. He says it wants the funding to "predominantly come from African governments" rather than international grants. "The grant-funded situation is bedevilled by [the question of] where the next grant will come from," he says. Yet financial support will not be easy. Some have questioned whether Africa can afford a synchrotron.

John Mugabe, a professor of science and innovation policy at the University of Pretoria in South Africa, notes that the light source is not even mentioned in the African Union's science plans or in the science, technology and innovation initiatives of the G20, an international forum of 20 countries. "I do not think that there is adequate African political backing for the initiative," he says.

However, a boost for the AfLS came on 12 December when the African Academy of Sciences, which is based in Nairobi, Kenya, and had been pushing for its own light source – the African Synchrotron Initiative – signed a memorandum of understanding with the AfLS to co-develop a synchrotron.

Sarah Wild

Batteries

US ploughs $50m into sodium-ion battery development

The US Department of Energy (DOE) has awarded $50m to a consortium of national laboratories and universities to develop sodium-ion batteries as a sustainable, low-cost alternative to lithium-ion technology. The money from the DOE over the next five years will be used to create the Low-cost Earth-abundant Na-ion Storage (LENS) consortium.

Lithium-ion batteries currently dominate the electric-vehicle market and they are also used in smartphones and to store energy from renewable sources such as wind and solar. Relying on a single battery technology such as lithium-ion creates dependencies on critical elements such as lithium, cobalt and nickel. Sodium, however, is an abundant, inexpensive element and offers a promising way to diversify battery materials. The downside is that sodium-ion batteries currently store less energy per unit weight and volume than lithium-ion batteries.

Argonne National Laboratory

Salt of the Earth Sodium-ion batteries offer a sustainable, low-cost alternative to lithium-ion technology.

LENS will be led by Argonne National Laboratory and includes five other DOE national laboratories including Brookhaven, Lawrence Berkeley and Sandia, as well eight US universities.

The LENS consortium will now develop high-energy electrode materials and electrolytes for sodium-ion batteries as well as design, integrate and benchmark battery cells with the aim of creating high-energy, long-lasting batteries. "The challenge ahead is improving sodium-ion energy density so that it first matches and then exceeds that of phosphate-based lithium-ion batteries while minimizing and eliminating the use of all critical elements," says LENS consortium director Venkat Srinivasan.

● Venkat Srinivasan, William Mustain and Martin Freer appeared on a Physics World Live panel discussion about battery technology held on 21 November 2024, which you can watch online at tinyurl.com/39fnvz4z

Michael Banks

Scientists braced for Trump presidency

Early indications of the direction of Donald Trump's second term as US president are already spooking some scientists, as **Peter Gwynne** reports

Before Donald Trump takes oath for a second term as US president on 20 January, the US scientific community is preparing for what the next four years may look like. Many already have a sense of trepidation given his track record from his first term in office. There are concerns, for example, about his nominations for cabinet and other key positions. Others are worried about the role that SpaceX boss Elon Musk will play as the head of a new "department of government efficiency".

Neal Lane, a senior fellow in science and technology at Rice University's Baker Institute and science adviser to former president Bill Clinton, told *Physics World* that he does not see "any good news for science, especially any fields or studies that seem to be offensive to important segments of Trump's supporter base". Lane says that includes research related to "climate change, reproduction, gender and any other aspects of diversity, environmental protection and justice, biodiversity, public health, vaccinations, most fields of the social sciences and many others".

John Holdren, who was science adviser to Barack Obama and is a member of Harvard University's Kennedy School and the Woodwell Climate Research Center, is equally pessimistic. "The stated intentions of president-elect Trump and his acolytes concerning energy and climate policies are deeply dismaying," he says. "If history is any guide, Trump will also try to put a large crimp in federal research on climate science and advanced clean energy."

During his first term in office between 2017 and 2021, Trump tried to ban immigration from Muslim-majority countries and created the China Initiative that led to charges against some US scientists for collaborations with colleagues in Chinese universities. He also famously used a Sharpie pen to change the apparent course of Hurricane Duran on a National Weather Service map, resulting in consternation from researchers.

When COVID-19 emerged, he suggested ineffective and possibly dangerous treatments for it and had a fraught relationship with Anthony Fauci, who was then in charge of the country's response to the pandemic. Lane says that the administration is likely to continue "to downplay evidence-based science in setting policies and allow misinformation" to be published on agency websites. "That would result not only in damage to the integrity of US science, but to the trust the American public places in science," Lane adds. "Ultimately, it could affect people's lives and livelihoods."


Cristobal Herrera-Ulashkevich/EPA-EFE/Shutterstock

More of the same If his first term is anything to go by, Donald Trump's second term as US president is likely to ruffle many scientists' feathers.

On the other hand, under Trump's stewardship, the COVID-19 vaccine was developed at record-breaking speed, and while it took 18 months in office before he nominated a science adviser, his pick of meteorologist Kelvin Droegemeier was generally applauded by the scientific community. Funding for science also increased during Trump's first term. "We saw budgets for science agencies go up due to a variety of factors, so that's something we hope for again," says Jennifer Grodsky, Boston University's vice-president for federal relations.

And the nominees are...

In Trump's first term, various members of his presidential staff and cabinet managed to dissuade him from pursuing some more unorthodox ideas related to science and medicine. And when they failed to do so, Congress acted as a hard brake. The Senate has a constitutional responsibility to advise the president on (and consent by a simple majority to) presidential nominations for cabinet positions, ambassadorships and other high offices. Since the new Senate will take office on 3 January with a Republican majority of 53 to 47 Democrats, many Trump nominees will likely be ready to take office when he becomes president on 20 January.

Most nominees for posts, however, are fully behind Trump's desire to "drain the swamp" of Washington's "politics as usual" and have some non-mainstream views on science. Stanford University health economist Jay Bhattacharya, for example, who has been picked to lead the National Institutes of Health, was a vocal critic of the US response to the COVID-19 pandemic who stated that lockdowns caused irreparable harm. Vaccine sceptic Robert F Kennedy Jr, an environmental lawyer, has been chosen to head the Department of Health and Human Services while Marty Makary, a Johns Hopkins University surgeon and cancer specialist who shares many of Kennedy's attitudes about health, is tagged to lead the Food and Drug Administration.

While the nominees to head environmental and energy agencies come from more mainstream candidates, they could – if approved – implement significant changes in policy from the Biden administration. Trump wants, for example, to open protected areas to drilling and mining. He also aims to take the US out of the Paris Accord on climate change for a second time – after Biden rescinded the first removal.

As a sign of things to come, Trump has already nominated Lee Zeldin as administrator of the Environmental Protection Agency (EPA). A former Republican Congressman from New York and a critic of much environmental legislation, Zeldin says that the EPA will "restore US energy dominance" while "protecting access to clean air and water". But his focus on pro-business deregulation is set to dismay environmentalists who applauded the Biden administration's EPA ban on several toxic substances and limitation on the amounts of "forever" chemicals in water.

When it comes to energy, Trump has nominated Chris Wright, founder and chief executive office of the Denver-based fracking company Liberty Energy, to head the Department of Energy. While Wright accepts that fossil fuels contribute to global warming, he has also referenced scientific studies that support his claim that climate change "alarmists" are wrong about the impact of a warmer world. If approved, Wright will participate in a new National Energy Council that Department of the Interior nominee Doug Burgum will chair. A software company billionaire and current governor of North Dakota, Burgum has mirrored Wright in accusing the "radical left" of engaging in a war against US energy to reduce climate change.

Swimming against the tide

Lane predicts that the Trump administration will attempt to privatize agencies within government departments, potentially including the National Oceanic and Atmospheric Administration, which is part of the US Department of Commerce. "That could result in forcing people to pay to get timely weather reports," he says. "To find out, for example, where a hurricane is headed or to receive better tornado warnings."

> The new department of government efficiency could target science-related agencies

A different threat to science comes from Musk's department of government efficiency, which he will run together with the biotechnology billionaire Vivek Ramaswamy. As the owner of SpaceX, Starlink and Tesla, Musk – currently the world's richest person – asserts that the department can cut $2 trillion from the roughly $6.5 trillion annual US government budget. While some are sceptical of that pledge, scientists fear the effort could target science-related agencies. The Department of Education, for example, could be shut – and several prominent Republicans, including Trump, having already called for its elimination.

Another possible target for budget cuts is NASA, which is already in financial trouble, having been forced to postpone the next lunar Artemis mission to April 2026 and the planned crewed Moon landing to mid-2027. Trump has nominated Jared Isaacman – a billionaire associate of Musk – as the agency's administrator. Co-founder of the aerospace firm Draken International, Isaacman developed and financed September's Polaris Dawn mission, in which he and three other private astronauts were taken into orbit by Musk's SpaceX rockets. If confirmed in office, Isaacman is expected to expand existing links between NASA and the commercial space sector.

Another impact of Trump's second term could be on collaborations between US and foreign scientists. A return to the China Initiative, which Biden rescinded, seems possible. And Trump has promised to continue the hard line against immigrants that marked his first term in office. Some university leaders have already warned overseas students not to travel home during the winter break in case they are not allowed back into the US. "New executive orders that may impact travel may be implemented," a statement by the leadership of Massachusetts Institute of Technology noted. "Any processing delays could impact students' ability to return to the US as planned."

For Holdren, the next four years simply promises to be a rocky time. "Swimming against the tide of a hostile White House will not be easy," he adds. "Let us hope all who understand the challenge will rise to it."

Peter Gwynne is *Physics World*'s North America correspondent

Funding

NASA's Jet Propulsion Lab announces further staff layoffs

NASA's Jet Propulsion Laboratory (JPL) has announced another round of staff layoffs. The move, which began in mid-November, involves about 325 people, representing 5% of the lab's employees. It follows layoffs in February 2024 of about 530 JPL staff and 140 of the lab's outside contractors. According to JPL director Laurie Leshin, the second reduction in employees is occurring "across technical, business and support areas of the laboratory".

NASA/JPL-Caltech

Downsizing About 325 people, representing roughly 5% of the lab's employees, will be affected by the cuts.

JPL, which the California Institute of Technology runs for NASA, carries out many of the agency's planetary exploration projects. These include the Europa Clipper mission, which launched in October, and the Perseverance and Curiosity Mars rovers. The earlier layoffs at JPL stemmed from uncertainty over its budget for 2024. Indeed, the Mars Sample Return (MSR) has impacted JPL's financial flexibility. The mission has experienced a series of delays and other problems, with samples now not expected to return to Earth before 2040.

US Congress has not yet settled on NASA's budget for this financial year, which began on 1 October 2024, but projections of likely spending on specific NASA institutions and programmes convinced JPL's leadership to downsize. "With lower budgets and based on the forecasted work ahead, we had to tighten our belts across the board," Leshin wrote in a memo to employees. She notes that the number of layoffs is lower than that projected a few months ago "thanks in part to the hard work of so many people across JPL". Leshin adds that the election of Donald Trump to the US presidency had no impact on the layoff decision. "[Even] though the coming leadership transition at NASA may introduce both new uncertainties and new opportunities, this action would be happening regardless of the recent election outcome," she says.

Leshin has reassured the lab's staff that the current round of layoffs should be the final one. "I believe this is the last cross-lab workforce action we will need to take in the foreseeable future," she wrote. "After this action, we will be at about 5500 JPL regular employees. I believe this is a stable, supportable staffing level moving forward."

Peter Gwynne
Boston, MA

Research updates

Graphene Hall effect explained

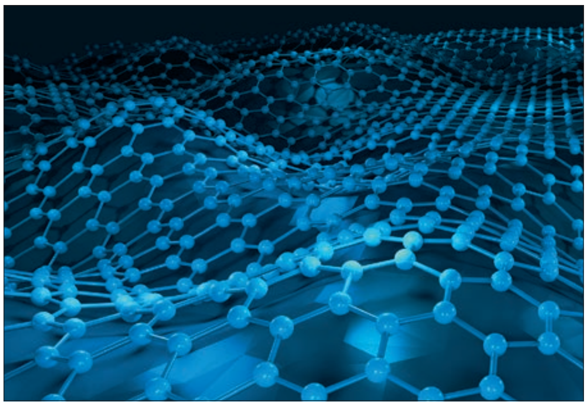
A topological flat band may account for the fractional quantum anomalous Hall effect that has recently been observed in pentalayer moiré graphene, as **Isabelle Dumé** reports

Physicists in the US have found an explanation for why electrons in a material called pentalayer moiré graphene carry fractional charges even in the absence of a magnetic field. This phenomenon is known as the fractional quantum anomalous Hall effect, and separate US research teams have independently suggested that an interaction-induced topological "flat" band in the material's electronic structure may be responsible.

Scientists already knew that electrons in graphene could, in effect, split into fractions of themselves in the presence of a very strong magnetic field. This is an example of the fractional quantum Hall effect, which occurs when a material's Hall conductance is quantized at fractional multiples of e^2/h. In 2023, several teams of researchers introduced a new twist by observing this fractional quantization in the absence of a magnetic field. The fractional quantum anomalous Hall effect, as it was dubbed, was initially observed in a material called twisted molybdenum ditelluride ($MoTe_2$).

Then, in February last year, a Massachusetts Institute of Technology (MIT) team led by physicist Long Ju spotted the same effect in pentalayer moiré graphene. This material consists of a layer of a 2D hexagonal boron nitride (hBN) with five layers of graphene stacked on top of it. The graphene and hBN layers are twisted at a small angle with respect to each other, resulting in a moiré pattern that can induce conflicting properties, such as superconductivity and insulating behaviour, within the structure. Although Ju and colleagues were the first to observe the fractional quantum anomalous Hall effect in graphene, they did not explain why it occurred.

In the latest group of studies, scientists have now put forward a possible solution to the mystery. According to MIT's Senthil Todadri, the effect could stem from the fact that electrons in 2D materials like graphene are confined in such small spaces that they start interacting strongly (*Phys. Rev. Lett.* **133** 206502). This means that they can no longer be considered as independent charges that naturally repel each other. A team from Johns Hopkins, led by Ya-Hui Zhang, and a Harvard/Berkeley team led by Ashvin Vishwanath and Daniel E Parker reached similar conclusions (*Phys. Rev. Lett.* **133** 206503 and **133** 206504).



iStock/RED_SPY

Peaks and troughs Researchers have described how electrons in graphene can carry fractional charges even in the absence of a magnetic field.

Mountain and valleys

Todadri and colleagues began with a model of pentalayer graphene that treats the inter-electron Coulomb repulsion in an approximate way, replacing the "push" of all the other electrons on any given electron with a single potential. "Such a strategy is routinely employed in quantum mechanical calculations of, say, the structure of atoms, molecules or solids," he notes. The team found that the moiré arrangement of pentalayer graphene induces a weak electron potential that forces electrons passing through it to arrange themselves in crystal-like periodic patterns that form a "flat" electronic band. This band is absent in calculations that do not account for electron–electron interactions, they say.

Such flat bands are especially interesting because electrons in them become "dispersionless" – that is, their kinetic energy is suppressed. As the electrons slow almost to a halt, their effective mass approaches infinity, leading to exotic topological phenomena as well as strongly correlated states of matter associated with high-temperature superconductivity and magnetism. Other quantum properties of solids such as fractional splitting of electrons can also occur.

The reason why topological flat bands in pentalayer graphene form could be due to "mountain and valley" landscapes that naturally appear in the electronic crystal. Electrons in this material experience these landscapes as pseudo-magnetic fields, which affect their motion and, in effect, do away with the need to apply a real magnetic field to induce the fractional Hall quantization. "This interaction-induced topological band is also predicted by our theory to occur in the four- and six-layer versions of multilayer graphene," Todadri says. "These structures may then be expected to host phases where electron fractions appear."

In the study, the MIT team presented only a crude treatment of the fractional states. Future work, Todadri says, may focus on understanding the precise role of the moiré potential produced by aligning the graphene with a substrate. One possibility, he suggests, is that it simply pins the topological electron crystal in place. However, it could also stabilize the crystal by tipping its energy to be lower than a competing liquid state. Another open question is whether these fractional electron phenomena at zero magnetic field require a periodic potential in the first place. "The important next step is to develop a better theoretical understanding of these states," Todadri told *Physics World*.

Quantum

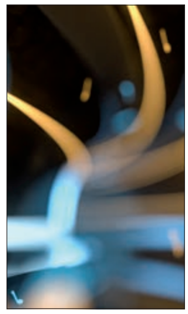
Mechanical quantum bits sound good for applications

Researchers in Switzerland have created a mechanical qubit using an acoustic wave resonator, marking a significant step forward in quantum "acoustodynamics". While the qubit is not yet good enough for quantum logic operations, the researchers hope that further efforts could lead to applications in quantum sensing and memories (*Science* **386** 783).

In contemporary quantum computing platforms such as trapped ions quantum information is held in electromagnetic states and transmitted using photons. In quantum acoustodynamics, however, the quantum information is stored in the quantum states of mechanical resonators. These devices interact with their surroundings via quantized vibrations (phonons), which cannot propagate through a vacuum. Isolated mechanical resonators can therefore have much longer lifetimes that their electromagnetic counterparts, which could be handy for making quantum memories.

Producing a mechanical qubit, however, has proved difficult. A good qubit must have two energy levels, akin to the 1 and 0 states of a classical bit. It can then be placed (or initialized) in one of those levels and remain in a coherent superposition of the two without other levels interfering. This is possible if the system has unevenly spaced energy levels – which is true in an atom or ion, and can be engineered in a superconducting qubit. Driving a qubit using photons with the exact transition energy then excites Rabi oscillations, in which the population of the upper level rises and falls periodically. However, acoustic resonators are harmonic oscillators, and the energy levels of a harmonic oscillator are evenly spaced.

In the new work, the team used a superconducting transmon qubit coupled to an acoustic resonator on a sapphire chip. The frequency of the superconducting qubit was slightly off-resonance with that of the mechanical resonator. Without being driven in any way, the superconducting qubit coupled to the mechanical resonator and created a shift in the frequencies of the ground state and first excited state of the resonator. This created the desired two-level system in the resonator.


iStock/Jian Fan

Making waves In quantum acoustodynamics, quantum information can be stored in the quantum states of mechanical resonators.

The researchers then injected microwave signals at the frequency of the mechanical resonator, converting them into acoustic signals using piezoelectric aluminium nitride. "We simply put our superconducting qubit on resonance with our mechanical qubit to swap an excitation back into the superconducting qubit and then simply read out the superconducting qubit itself," says Igor Kladarić from ETH Zurich.

The team confirmed that the mechanical resonator undergoes Rabi oscillations between the first and second excited states, with less than 10% probability of leakage into the second excited state, and was therefore a true mechanical qubit.

Tim Wogan

Optics

Lens breakthrough paves the way for ultrathin cameras

Researchers from Korea and the US have pioneered an innovative metasurface-based folded-lens system. The work could lead to a new generation of slimline cameras for use in smartphones and augmented/virtual reality devices (*Sci. Adv.* 10 eadr2319).

Traditional lens modules, built from vertically stacked refractive lenses, have fundamental thickness limitations mainly due to the need for space between lenses and the intrinsic volume of each individual lens. To overcome these restrictions, the researchers developed a lens system using metasurface folded optics. The approach enables unprecedented manipulation of light with exceptional control of intensity, phase and polarization while at the same time maintaining thicknesses of less than a millimetre.


Shutterstock_Halfpoint

Vision of the future Potential applications for the folded-lens system include lightweight camera systems for augmented reality glasses and smartphones.

The team placed the metasurface optics horizontally on a glass wafer. These metasurfaces direct light through multiple folded diagonal paths within the substrate, optimizing space usage and demonstrating the feasibility of a 0.7 mm-thick lens module for ultrathin cameras. "We adapted traditional imaging system design techniques, using the commercial tool Zemax, for metasurface systems," says Youngjin Kim from Seoul National University. "We then used nanoscale simulations to design the metasurface nanostructures and, finally, we employed lithography-based nanofabrication to create a prototype sample."

The researchers evaluated their proposed lens system by illuminating it with an 852 nm laser, observing that it could achieve near-diffraction-limited imaging quality. The folding of the optical path length reduced the lens module thickness to half of the effective focal length (1.4 mm), overcoming inherent limitations of conventional optical systems.

Kim says that potential applications include fully integrated, miniaturized, lightweight camera systems for augmented reality glasses, offering solutions to "camera bump" issues in smartphones and as miniaturized microscopes for *in vivo* imaging of live animals. More general advantages of using novel folded-lens systems in such devices – compared with existing approaches – include the ultraslim and lightweight "form factor", and the potential for mass production using standard semiconductor fabrication processes.

Abigail Williams

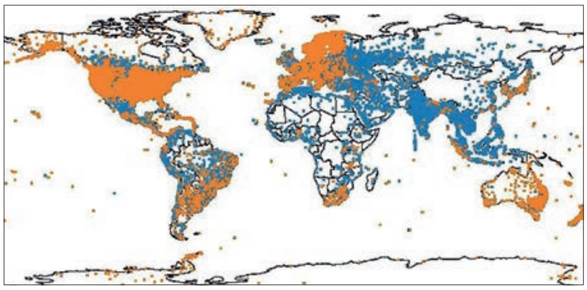
Earth observation

Smartphones monitor Earth's ever-changing ionosphere

A plan to use millions of smartphones to map out real-time variations in Earth's ionosphere has been tested by researchers in the US. The system could improve the accuracy of global navigation satellite systems (GNSSs), such as GPS, and provide new insights into the ionosphere (*Nature* 635 365).

A GNSS uses a network of satellites to broadcast radio signals to ground-based receivers. Each receiver calculates its position based on the arrival times of signals from several satellites. These signals first pass through Earth's ionosphere – a layer of weakly-ionized plasma about 50–1500 km above Earth's surface. As a GNSS signal travels through the ionosphere, it interacts with free electrons and this slows down the signal slightly – an effect that depends on the frequency of the signal.

The problem is that the free-electron density can spike dramatically during solar storms and is affected by geographical factors such as the distance from the equator. Variations in free-electron density can lead to significant location errors if not accounted for properly. To deal with this problem, navigation satellites send out two separate signals at different frequencies. These are received by dedicated monitoring stations on the Earth's surface with the differences between arrival times of the two frequencies being used to create real-time maps of the free-electron density of the ionosphere. Such maps can then be used to correct location errors. However, these monitoring stations are expensive to install, which results in large gaps in ionosphere maps.



Global coverage During initial tests, the researchers used phone data to map plasma bubbles over India and South America.

In their study, Brian Williams and colleagues at Google Research in California took advantage of the fact that many modern mobile phones have sensors that detect GNSS signals at two different frequencies. "Instead of thinking of the ionosphere as interfering with GPS positioning, we can flip this on its head and think of the GPS receiver as an instrument to measure the ionosphere," says Williams. One issue is that smartphones are not designed for mapping the ionosphere and the signals that they receive are often distorted by surrounding buildings – and even users' bodies. Yet while each individual measurement is relatively poor, a large number of measurements can be used to improve the overall accuracy of the map.

In initial tests, the researchers aggregated ionosphere measurements from millions of Android devices and were able to map plasma bubbles over India and South America and the effects of a small solar storm over North America. Such observations doubled the coverage area of existing maps. If a smartphone-based network was rolled out, ionosphere-related location errors could be reduced by several metres.

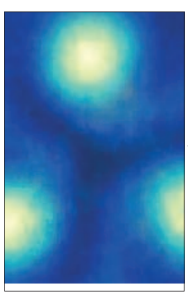
Sam Jarman

Condensed-matter physics

Quantized vortices seen in a supersolid for the first time

Quantized vortices – one of the defining features of superfluidity – have been seen in a supersolid for the first time. Observed by researchers in Austria, these vortices provide further confirmation that supersolids can be modelled as superfluids with a crystalline structure. This model could have variety of other applications in quantum physics and astronomy (*Nature* **635** 327).

A superfluid is any system, such as Bose–Einstein condensates (BECs), that can flow without any friction. More than five decades ago, physicists suggested that some systems could also exhibit crystalline order and superfluidity simultaneously in a unique state of matter called a supersolid. In such a state, the atoms would be described by the same wavefunction and are therefore delocalized across the entire crystal lattice. The order of the supersolid would therefore be defined by the nodes and antinodes of this wavefunction.



Causing a stir Researchers at the University of Innsbruck utilized a technique called magnetostirring to rotate a Bose–Einstein condensate of magnetic dysprosium-164 atoms.

Until now, no-one had observed an important aspect of superfluidity in a supersolid: that a superfluid never carries bulk angular momentum. If a superfluid is placed in a container and the container is rotated at moderate angular velocity, it simply flows freely against the edges. As the angular momentum of the container increases, however, it becomes energetically costly to maintain the decoupling between the container and the superfluid. "Still, globally, the system is irrotational," says Francesca Ferlaino at the University of Innsbruck, "so there's really a necessity for the superfluid to heal itself from rotation." In a normal superfluid, this "healing" occurs by the formation of small, quantized vortices that dissipate the angular momentum, allowing the system to remain globally irrotational. It was unclear, however, how the vortices might sit inside a supersolid lattice.

Ferlaino and colleagues utilized a technique called magnetostirring to rotate a BEC of magnetic dysprosium-164 atoms. They caused the atoms to rotate simply by rotating the magnetic field. As the group increased the field's rotation rate, however, they observed vortices forming in the condensate and migrating to the "density minima". "The order that the vortices assume is largely imparted by the crystalline structure – although their distance is dependent on the repulsion between vortices," says Ferlaino.

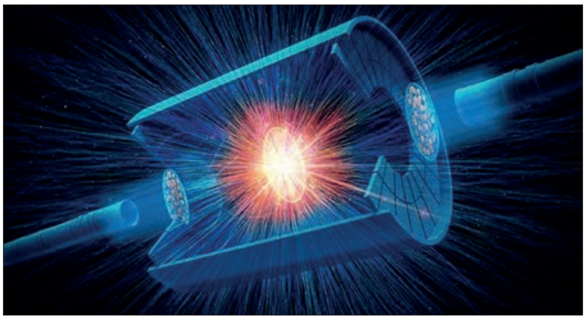
Tim Wogan

Nuclear physics

Nuclear shapes revealed in high-energy collisions

Scientists in the STAR collaboration have unveiled a pioneering method for investigating the shapes of atomic nuclei by colliding them at near light-speed in particle accelerators. Their innovative approach offers unprecedented insight into nuclear structure and could deepen our understanding of strong nuclear forces and their role in the composition of neutron stars and the evolution of the early universe (*Nature* **635** 67).

Understanding the properties of nuclei is daunting, largely due to the complexities of quantum chromodynamics (QCD), the fundamental theory governing the strong interaction. Calculations in QCD are notoriously difficult at low relative velocities, typical for nucleons within nuclei. One way to study nuclear shapes is to excite a nucleus to a higher energy state, often by colliding it with a fixed target. By measuring how long it takes the nucleus to return to its ground state, researchers can gather information about its shape. However, this relaxation process takes far longer than typical nuclear interactions, thus providing only an averaged image of the nucleus without any finer details.



Chunjian Zhang/Fudan University and Jiangyong Jia/Stony Brook University

Smashing result The STAR collaboration have created a new technique to study nuclear shapes by smashing nuclei together at extremely high energies.

Another method is to bombard nuclei with high-energy electrons, analysing the scattering data to infer structural details. However, this technique only reveals localized properties of the nucleus, falling short when capturing the overall shape, which depends on the coordinated movement of nucleons across the entire nucleus.

The approach taken by the STAR collaboration – consisting of hundreds of scientists and engineers from the US and elsewhere – circumvents these limitations by smashing nuclei together at extremely high energies and analysing the collision products. Since these high-energy collisions are much faster than typical nuclear processes, the new method promises a more detailed snapshot of nuclear shape.

When two nuclei collide at near-light speeds, they annihilate, turning into an expanding ball of plasma made of quarks and gluons. This plasma lasts only about 10^{-23} s before forming thousands of new composite particles, which are then caught by detectors. By studying the speeds and angles at which these particles are ejected, scientists can infer the shape of the colliding nuclei.

"You cannot image the same nuclei again and again because you destroy them in the collision," explains Jiangyong Jia from Stony Brook University. "But by looking at the whole collection of images from many different collisions, scientists can reconstruct the subtle properties of the 3D structure of the smashed nuclei."

To verify the reliability of this method the STAR researchers compared their findings with those obtained through established techniques on nuclei with well-known shapes finding that the collisions aligned remarkably well with established results. The researchers now want to analyse nuclei whose shapes are not as well understood.

Andrey Feldman

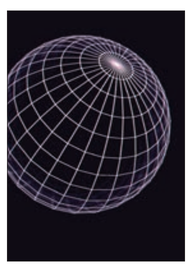
Nuclear shape transitions visualized for the first time

Xenon nuclei change shape as they collide, transforming from soft, oval-shaped particles to rigid, spherical ones. This finding, which is based on simulations of experiments at CERN's Large Hadron Collider (LHC), provides a first look at how the shapes of atomic nuclei respond to extreme conditions. While the technique is still at the theoretical stage, the researchers say that ultra-relativistic nuclear collisions at the LHC could allow for the first experimental observations of these so-called nuclear shape phase transitions (*Phys. Rev. Lett.* 133 192301).

Like electrons, nucleons exist in different energy levels, or shells. To minimize the energy of the system, these shells take different shapes, with possibilities including pear, spherical, oval or peanut-shell-like formations. These shapes affect many properties of the atomic nucleus as well as nuclear processes such as the strong interactions between protons and neutrons.

In the new work, a team led by You Zhou at the Niels Bohr Institute in Denmark and Huichao Song at Peking University studied xenon-129. This isotope has 54 protons and 75 neutrons and is considered a relatively large atom, making its nuclear shape easier, in principle, to study than that of smaller atoms. Usually, the nucleus of xenon-129 is oval-shaped (a γ-soft rotor). However, low-energy nuclear theory predicts that it can transition to a spherical, prolate or oblate shape under certain conditions.

To test the viability of such experiments, the researchers simulated accelerating atoms to near relativistic speeds, equivalent to the energies involved at the LHC. At these energies, when nuclei collide with each other, their constituent protons and neutrons break down into smaller particles. These smaller particles are mainly quarks and gluons, and together they form a quark–gluon plasma, which is a liquid with virtually no viscosity.



You Zhou, NBI

Shape shifter The nucleus of the xenon atom can assume different shapes depending on the balance of internal forces at play.

Zhou, Song and colleagues modelled the properties of this "almost perfect" liquid using an advanced hydrodynamic model they developed called IBBE-VISHNU. According to these analyses, the Xe nuclei go from being soft and oval-shaped to rigid and spherical as they collide. Zhou adds that future experiments could validate the nuclear shape phase transitions they have observed in their simulations.

Isabelle Dumé

Opinion

physicsworld

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A quantum celebration

How to stay on top of all things quantum during the next 12 months

Welcome to *Physics World*'s coverage supporting the International Year of Quantum Science and Technology (IYQ). The IYQ is a worldwide celebration, endorsed by the United Nations, to increase the public's awareness of quantum science and its applications. The year 2025 was chosen as it marks the centenary of the development of quantum mechanics by Werner Heisenberg.

With six "founding partners", including the Institute of Physics (IOP), the IYQ has ambitious aims. These are to show how quantum science can do everything from grow the economy, support industry and improve our health to help the climate, deliver clean energy and reduce inequalities in education and research. You can join in by creating an event or donating money to the IYQ Global Fund.

INTERNATIONAL YEAR OF
Quantum Science and Technology

Quantum science is burgeoning, with huge advances in basic research and applications such as quantum computing, communication, cryptography and sensors. Tech giants such as Google, IBM and Microsoft are active in the field (pp3–4) as are countless thriving start-ups (pp17–18). Businesses in related areas – from banking to aerospace – are eyeing up quantum's possibilities too.

An official IYQ opening ceremony will be held at UNESCO headquarters in Paris next month. But the highlight of the year for physicists will undoubtedly be a workshop on 9–14 June in Helgoland – the tiny island off the coast of Germany where Heisenberg made his breakthrough exactly 100 years ago. Many leading lights from quantum physics will be there, including five Nobel-prize winners. In this month's cover feature, you can find out what attendees will be discussing (pp24–29).

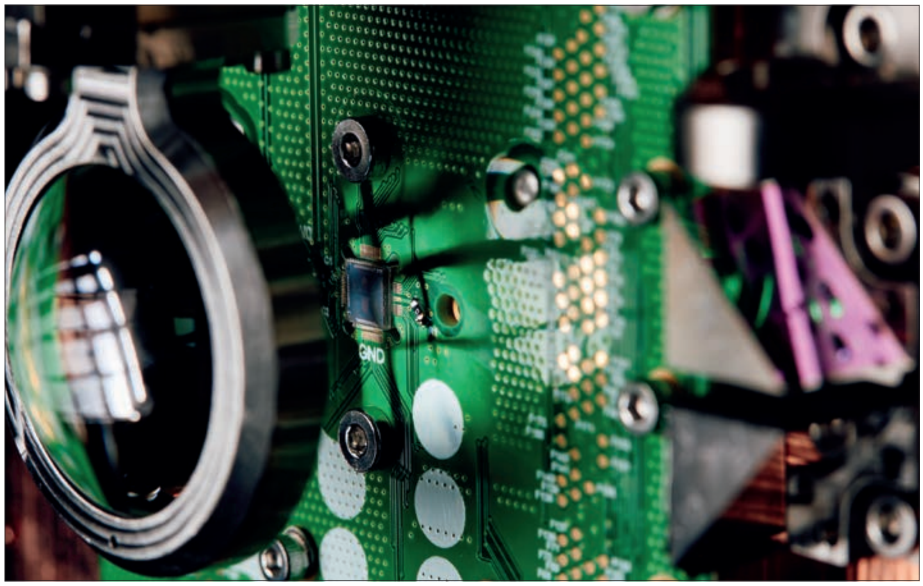
Other quantum coverage in 2025 will include special episodes of the *Physics World* podcasts and Physics World Live. The next edition of *Physics World Careers* has a quantum theme, and there'll also be a bumper, quantum-themed issue of the *Physics World Briefing* in May. The quantum channel on the *Physics World* website will be regularly updated throughout the year so you don't miss a thing.

The IOP has numerous quantum-themed public events lined up, while IOP Publishing will be active too, especially in the journal *Quantum Science and Technology*. What's more, the IYQ is a truly global initiative, seeking to spread the benefits of quantum science across the planet, including to the Global South. From head-scratching science to ground-breaking, practical applications, the IYQ deserves to be a huge success – in fact, I am sure it will be.

Matin Durrani, editor-in-chief, *Physics World*

Transactions Business marvels

James McKenzie takes a first look at some of the innovative companies to have scooped the latest round of business awards from the Institute of Physics



Oxford Ionics

One to watch Oxford Ionics has developed scalable quantum computers based on trapped ion qubits.

I have mentioned many times in this column the value of the business awards given by the Institute of Physics (IOP), which can be a real "stamp of approval" for firms developing new technology. Having helped to select the 2024 winners, it was great to see eight companies winning a main IOP Business Innovation Award this time round, bringing the total number of firms honoured over the last 13 years to 86. Some have won awards on more than one occasion, with Fetu being one of the latest to join this elite group.

Set up by Jonathan Fenton in 2016, FeTu originally won an IOP Business Start-up Award in 2020 for its innovative Fenton Turbine. According to Fenton, who is chief executive, it is the closest we have ever got to the ideal, closed-cycle reversible heat engine first imagined by thermodynamics pioneer Nicolas Carnot in 1824. The turbine, the firm claims, could replace compressors, air conditioners, fridges, vacuum pumps and heat pumps with efficiency savings across the board.

Back in 2020, it might have sounded like a "too-good-to-be-true" technology, but Fenton has sensibly set out to prove that's not the case, with some remarkable results. The turbine is complex to describe but the first version promised to cut the energy cost of compressing gases like air by 25%. They claim has already been proven in independent tests carried out by researchers at the University of Bath.

One challenge of any technology with many different applications is picking which to focus on first. Having decided to focus on a couple of unique selling factors in large markets, FeTu has now won a 2024 Business Innovation Award for developing a revolutionary heat engine that can generate electrical power from waste heat and geothermal sources as low as 40 °C. It has a huge market potential as it is currently not possible to do this economically.

Innovative ideas

Another winner of an IOP Business Innovation Award is Oxford Ionics, a quantum-computing firm set up in 2019 by Chris Balance and Tom Harty after doing PhDs at the University of Oxford. Their firm's qubits are based on trapped ions, which traditionally have been controlled with lasers. It's an approach that works well for small processors, but becomes untenable and error-prone as the size of the processor scales, and the number of qubits increases.

Instead of lasers, Oxford Ionics' trapped-ion processors use a proprietary, patented electronic system to control the qubits. It was for this system that the company was recognized by the IOP, along with its ability to scale the architecture so that the chips can be made in large quantities on standard semiconductor production lines. That's essential if we are to build practical quantum computers.

Whilst it's still early days in the commercialization of quantum computing, Oxford Ionics is an exciting company to watch. It has already won contracts to supply the UK's National Quantum Computing Centre at Harwell and has bagged a large contract with its partner Infineon Technologies AG in Munich to build a state-of-the-art portable quantum computer for Germany's cybersecurity innovation agency. The two firms are one of three independent contractors selected by the agency, which is investing a total of €35m in the project.

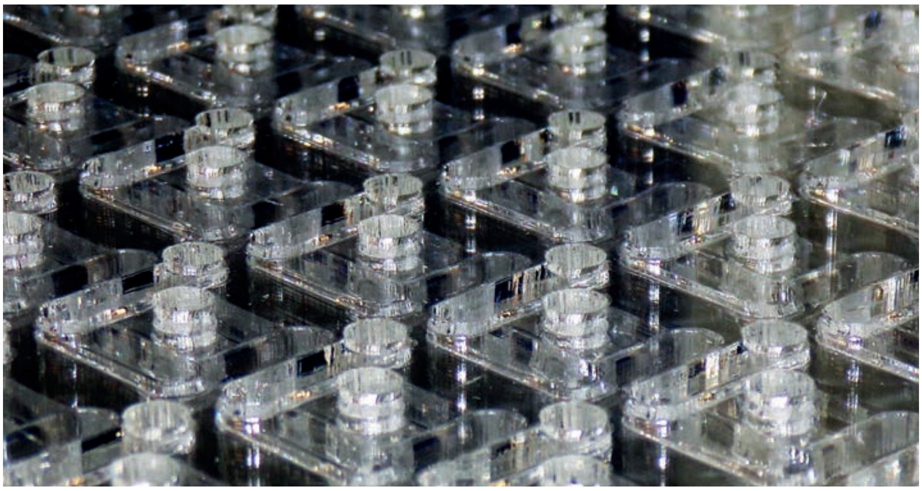
I should also mention Dublin-based Equal1, which won the IOP's £10 000 quantum Business Innovation and Growth (qBIG) Prize in 2024. Equal1 is developing rack-mountable quantum computers powered by a system that integrates quantum and classical components onto a single silicon chip using commercial fabrication processes. The company, which aims to develop compact quantum computers, also won 10 months of mentoring from the award's sponsors Quantum Exponential.

Meanwhile, Covesion – a photonics and quantum components supplier founded in 2009 – has won an IOP Business Innovation Award for its magnesium-doped, periodically poled, lithium niobate (MgO:PPLN) crystals and waveguides. They allow light to be easily converted from one frequency to another, providing access to wavelengths that are not available from commercial laser sources.

With a manufacturing base in Southampton, Covesion works with customers and industry partners to help them design and make high quality MgO:PPLN products used in a wide range of applications. They include quantum computing, communication, sensing and timing; frequency doubling of femtosecond lasers; mid-infrared generation; atom cooling; terahertz generation and biomedical imaging. The shear breadth and global nature of the customer base is impressive.

Sounds promising

Among the companies to win an IOP Business Start-up Award is Metasonixx, based in Brighton. Spun off from the universities of Bristol and Sussex in 2019, the firm makes



Metasonixx Sonoblind Air

Sounds good Metasonixx is turning metamaterials into commercial reality as noise-abatement products.

mass-produced acoustic metamaterial panels, which can dramatically attenuate sound (10 dB in its Sonoblind) and yet still allow air to flow freely (3 dB or 50% attenuation). That might seem counter-intuitive, but that's where the innovation comes in and the panels can help with noise management and ventilation, allowing industrial ventilators and heat pumps to be more widely used.

The company really got going in 2020, when it got a grant from UK Research and Innovation to see if its metamaterials could cut noise in hospitals to help patients recovering from COVID-19 and improve the well-being of staff. After Metasonixx won the Armourers and Brasiers Venture Prize in 2021 for their successes on COVID wards, the firm decided to mass-produce panels that could perform as well as traditional noise-reduction solutions but are modular and greener, with one-third of the mass and occupying one-twelfth of the space.

From a physics point of view, panels that can let air and light through in this way are interferential filters, but working over four doublings of frequency (or octaves). With manufacturing and first sales in 2023, their desk separators are now being tested in noisy offices worldwide. Metasonixx believes its products, which allow air to flow through them, could help to boost the use of industrial ventilators and heat pumps, thereby helping in the quest to meet net-zero targets.

Winning awards for Metasonixx is not a new experience, having also picked up a "Seal of Excellence Award" from the European Commission in 2023 and honoured at Bristol's Tech-Xpo in 2024. Its new IOP award will sit very nicely in this innovative company's trophy cabinet.

● Next month, James McKenzie will look at the rest of the 2024 IOP Business Award winners in imaging and medical technology. Entries for 2025 open in February.

James McKenzie is a physicist who helps bring new technology and products to market. He is writing here in a personal capacity.

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Students must not fund academia

Jonte Hance says that the recent increase in tuition fees will only delay the inevitable fall of the UK academic system

In an e-mail to staff in September 2024, Christopher Day, the vice-chancellor of Newcastle University in the UK, announced a £35m shortfall in its finances for 2024. Unfortunately, Newcastle is not alone in facing financial difficulties. The problem is largely due to UK universities obtaining much of their funding by charging international students exorbitant tuition fees of tens of thousands of pounds per year. In 2022 international students made up 26% of the total student population. But with the number of international students coming to the UK recently falling and tuition fees for domestic students having increased by less than 6% over the last decade, the income from students is no longer enough to keep our universities afloat.

Both Day and Universities UK (UUK) – the advocacy organization for universities in the UK – pushed for the UK government to allow universities to increase fees for both international and domestic students. They suggested raising the cap on tuition fees for UK students to £13 000 per year, much more than the new cap that was set in November 2024 at £9535. Increasing tuition fees further, however, would be a disaster for our education system.

The introduction of student fees was sold to universities in the late 1990s as a way to get more money, and sold to the wider public as a way to allow "market fairness" to improve the quality of education given by universities. In truth, it was never about either of these things.

Tuition fees were about making sure that the UK government would not have to worry about universities pressuring them to increase funding. Universities instead would have to rationalize higher fees with the students themselves. But it is far easier to argue that "we need more money from you, the government, to continue the social good we do" than it is to say "we need more money from you, the students, to keep giving you the same piece of paper".

Degree-level education in the UK is now treated as a private commodity, to be sold by universities and bought by students, with domestic students taking out a loan from the government that they pay back once they earn above a certain threshold. But this implies that it is only students who profit from the education and that the only benefit for them of a degree is a high-paid job.

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Mutual benefits Universities bring value to the wider community, not just the students.

> University education brings huge social, cultural and economic benefits to the community at a local, regional and national level

Education ends up reduced to an initial financial outlay for a potential future financial gain, with employers looking for job applicants with a degree regardless of what it is in. We might as well just sell students pieces of paper boasting about how much money they have "invested" in themselves.

Yet going to university brings so much more to students than just a boost to their future earnings. Just look, for example, at the high student satisfaction for arts and humanities degrees compared to business or engineering degrees. University education also brings huge social, cultural and economic benefits to the wider community at a local, regional and national level.

UUK estimates that for every £1 of public money invested in the higher-education sector across the UK, £14 is put back into the economy – totalling £265bn per year. Few other areas of government spending give such large economic returns for the UK. No wonder, then, that other countries continue to fund their universities centrally through taxes rather than fees. (Countries such as Germany that do levy fees charge only a nominal amount, as the UK once did.)

Some might say that the public should not pay for students to go to university. But that argument doesn't stack up. We all pay for roads, schools and hospitals from general taxation whether we use those services or not, so the same should apply for university education. Students from Scotland who study in the country have their fees paid by the state, for example.

Up in arms

Thankfully, some subsidy still remains in the system, mainly for technical degrees such as the sciences and medicine. These courses on average cost more to run than humanities and social sciences courses due to the cost of practical work and equipment. However, as budgets tighten, even this is being threatened.

In 2004 Newcastle closed its physics degree programme due to its costs. While the university soon reversed the mistake, it lives long in the memories of those who today still talk about the incalculable damage this and similar cuts did to UK physics. Indeed, I worry whether this renewed focus on profitability, which over the last few years has led to many humanities programmes and departments closing at UK universities, could again lead to closures in the sciences. Without additional funding, it seems inevitable.

University leaders should have been up in arms when student fees were introduced in the early 2000s. Instead, most went along with them, and are now reaping what they sowed. University vice-chancellors shouldn't be asking the government to allow universities to charge ever higher fees – they should be telling the government that we need more money to keep doing the good we do for this country. They should not view universities as private businesses and instead lobby the government to reinstate a no-fee system and to support universities again as being social institutions.

If this doesn't happen, then the UK academic system will fall. Even if we do manage to somehow cut costs in the short term by around £35m per university, it will only prolong the inevitable. I hope vice chancellors and the UK government wake up to this fact before it is too late.

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Bringing pride to physics

Artemis Peck and **Wendy Sadler** explain that we need more initiatives to make sure queer people feel comfortable and welcome in science

Ask the average person in the street to describe a physicist and they will probably outline an eccentric older man with grey wiry hair wearing a lab coat or tweed jacket with elbow patches and a pair of glasses. While some members of the physics community do look like that – and there's nothing wrong with it if they do – it's certainly not representative of the whole. Indeed, since the 1960s researchers have been regularly testing children's perceptions of scientists with the "draw-a-scientist test". This has seen a decrease in "masculine-coded" results from 99.4% in the 1970s to 73% in 2018. That figure is still high, but the drop is a welcome development that is likely due to an increase in female scientists being featured in both traditional and social media.

Despite such progress, however, physics still comes across as a cisgender-heterosexual-dominated subject. Some may claim that science doesn't care about identity and, yes, in an ideal world this would be true – you would leave identity at the lab door and just get on with doing physics. Yet this is a classic example of inequity. While treating everybody the same sounds great in practice, a one-size-fits-all approach doesn't create a conducive atmosphere for work and study. So how do we encourage the queer community into science and make them feel more comfortable?

To find out, we surveyed 160 students and staff at UK universities who identify as queer about their experiences and inspirations. When asked to rate how comfortable queer people feel in different scenarios between one ("completely uncomfortable) and 10 ("completely comfortable"), respondents' average score was 7.96 when it came to how they felt among their peers but just 5.66 in an academic setting. This difference was even starker with people who identify as transgender, who reported a score of 8.0 with peers and as low as 4.96 within academia.

We also did follow-up interviews with respondents who left contact information to get a more detailed picture. From these interviews, the idea of "belonging" came up a lot. Participants stated that if they don't see people like them at a job interview, they will think twice about accepting a position in that organization. Almost half of

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Open arms Targeted outreach to queer audiences could have a similar impact to efforts to boost the number of women in science.

transgender respondents say they will have difficulty getting into a science-related career compared with just 8.9% of queer cisgender respondents.

The lack of role models in science is a critical factor. Over three-quarters of respondents generally disagreed with the statement "there are enough queer role models in STEM", with some saying it is "severely lacking" while also acknowledging how complicated it can be for queer people to put themselves "out there".

While teachers are an important inspiration for both transgender and cisgender people, fictional role models play a greater role for transgender people. On a scale from one (being no influence) to seven (most influence), transgender people were slightly more inclined towards fictional role models than cisgender people (at 4.25 versus 3.52). This is an important avenue for transgender people through the "queer coding" of traditionally cisgender heterosexual characters. One of the survey responses explained how as a child they interpreted The Doctor from TV's *Doctor Who* as a queer role model.

Targeted schemes

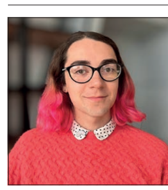
Queer people clearly do not feel well represented in science, neither within their institutions nor in the media. The solutions to both issues are intertwined. The media will not see an increase in queer scientists until we have more queer scientists, and we won't have more queer scientists until queer people can see science as a safe and welcoming career option. Time magazine's top 100 influential people for 2020, for example, contained 17 scientists, but the *Guardian*'s list of LGBTQ+ influencers for 2024 contained no scientists at all.

There are things we can do to make science more accepting on a personal level such as displaying pronouns as standard in all communication, and signposting to queer networks within or beyond our organizations. One interviewee suggested queer people wear something like a Pride pin badge to create more visibility within the science community so that newly recruited queer people feel like they belong.

We also need targeted outreach to queer audiences in a similar way to how schemes have been created to increase women's participation in science. Local Pride events or queer youth group meetings could be a good way to reach queer people without making them feel singled out and "othered". The Institute of Physics, which publishes *Physics World*, regularly attends Pride events, for example, and this type of activity should be encouraged in other physics and science-based groups and industries to show they are actively seeking and welcoming connections and talent from the queer community.

As well as increasing access to real-life role models, fiction could be used to create accessible role models, especially for the transgender community. More scientific characters in films, books and TV series who identify as queer would help to give future queer scientists people they can relate to and help them feel they belong in science. By making these small but meaningful changes in institutions and supporting related cultural initiatives, we can show that science can indeed be for everybody and not just a select few.

● This article is based on the results of a final year BSc project by Artemis Peck



Artemis Peck and **Wendy Sadler** are at the School of Physics & Astronomy, Cardiff University, UK, e-mail sadlerwj@cardiff.ac.uk

Return to Helgoland: the centenary of quantum mechanics

INTERNATIONAL YEAR OF Quantum Science and Technology

One of the most significant events in the International Year of Quantum Science and Technology is a workshop being held in June 2025 in Helgoland – the island where Werner Heisenberg laid the foundations for quantum mechanics 100 years ago. **Robert P Crease** asks delegates what they'll be discussing and wonders whether Heisenberg's work was as definitive as we like to think

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At 3 a.m. one morning in June 1925, an exhausted, allergy-ridden 23-year old climbed a rock at the edge of a small island off the coast of Germany in the North Sea. Werner Heisenberg, who was an unknown physics post-doc at the time, had just cobbled together, in crude and unfamiliar mathematics, a framework that would shortly become what we know as "matrix mechanics". If we insist on pegging the birth of quantum mechanics to a particular place and time, Helgoland in June 1925 it is.

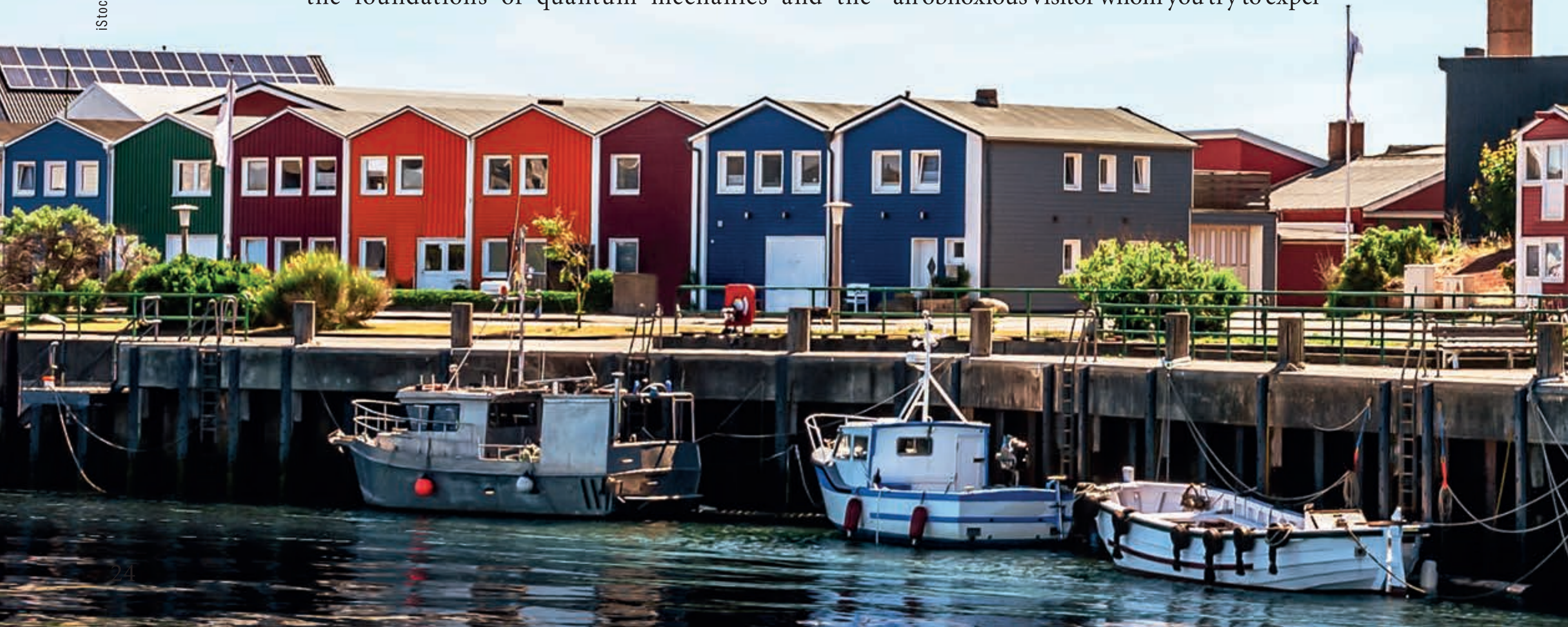
Heisenberg's work a century ago is the reason why the United Nations has proclaimed 2025 to be the International Year of Quantum Science and Technology. It's a global initiative to raise the public's awareness of quantum science and its applications, with numerous activities in the works throughout the year. One of the most significant events for physicists will be a workshop running from 9–14 June on Helgoland, exactly 100 years on from the very place where quantum mechanics supposedly began.

Entitled "Helgoland 2025", the event is designed to honour Heisenberg's development of matrix mechanics, which organizers have dubbed "the first formulation of quantum theory". The workshop, they say, will explore "the increasingly fruitful intersection between the foundations of quantum mechanics and the application of these foundations in real-world settings". But why was Heisenberg's work so vital to the development of quantum mechanics? Was it really as definitive as we like to think? And is the oft-repeated Helgoland story really true?

How it all began

The events leading up to Heisenberg's trip can be traced back to the work of Max Planck in 1900. Planck was trying to produce a formula for how certain kinds of materials absorb and emit light depending on energy. In what he later referred to as an "act of sheer desperation", Planck found himself having to use the idea of the "quantum", which implied that electromagnetic radiation is not continuous but can be absorbed and emitted only in discrete chunks.

Standing out as a smudge on the beautiful design of classical physics, the idea of quantization appeared of limited use. Some physicists called it "ugly", "grotesque" and "distasteful"; it was surely a theoretical sticking plaster that could soon be peeled off. But the quantum proved indispensable, cropping up in more and more branches of physics, including the structure of the hydrogen atom, thermodynamics and solid-state physics. It was like an obnoxious visitor whom you try to expel



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"Quantum theory" was like having instructions for how to get from place A to place B. What you really wanted was a "quantum mechanics" – a map that showed you how to go from any place to any other

from your house but can't. Worse, its presence seemed to grow. The quantum, remarked one scientist at the time, was a "lusty infant".

Attempts to domesticate that infant in the first quarter of the 20th century were made not only by Planck but other physicists too, such as Wolfgang Pauli, Max Born, Niels Bohr and Ralph Kronig. They succeeded only in producing rules for calculating certain phenomena that started with classical theory and imposed conditions. "Quantum theory" was like having instructions for how to get from place A to place B. What you really wanted was a "quantum mechanics" – a map that, working with one set of rules, showed you how to go from any place to any other.

Heisenberg was a young crusader in this effort. Born on 5 December 1901 – the year after Planck's revolutionary discovery – Heisenberg had the character often associated with artists, with dashing looks, good musicianship and a physical frailty including a severe vulnerability to allergies. That summer in 1923, Heisenberg had just finished his PhD under Arnold Sommerfeld at the Ludwig Maximilian University in Munich and was starting a postdoc with Born at the University of Göttingen.

Like others, Heisenberg was stymied in his attempts to develop a mathematical framework for the frequencies, amplitudes, orbitals, positions and momenta of quantum phenomena. Maybe, he wondered, the trouble was trying to cast these phenomena in a Newtonian-like visualizable form. Instead of treating them as classical properties with specific values, he decided to look at them in purely mathematical terms as operators acting on functions. It was then that an "unfortunate personal setback" occurred.

Destination Helgoland

Referring to a bout of hay fever that had wiped him out, Heisenberg asked Born for a two-week leave of absence from Göttingen and took a boat to Helgoland. The island, which lies some 50 km off Germany's mainland, is barely 1 km^2 in size. However, its strategic military location had given it an outsized history that saw it swapped several times between different European powers. Part of Denmark from 1714, the island was occupied by Britain in 1807 before coming under Germany's control in 1890.

During the First World War, Germany turned the island into a military base and evacuated all its residents. By the time Heisenberg arrived, the soldiers had long gone and Helgoland was starting to recover its reputation as a centre for commercial fishing and a bracing tourist destination. Most importantly for Heisenberg, it had fresh winds and was remote from allergen producers.

Heisenberg arrived at Helgoland on Saturday 6 June 1925 coughing and sneezing, and with such a swollen face that his landlady decided he had been in a fight. She installed him in a quiet room on the second floor of her *Gasthaus* that overlooked the beach and

Into a new world
It was on the island of Helgoland off the coast of Germany in June 1925 that Werner Heisenberg created matrix mechanics.

IanDagnall Computing/Alamy Stock Photo

Max-Planck-Institute, courtesy of AIP Emilio Segrè Visual Archives

That winning feeling Werner Heisenberg (right) won the 1932 Nobel Prize for Physics "for the creation of quantum mechanics". He was given the prize in December 1933, with that year's award shared by Paul Dirac and Erwin Schrödinger, shown here (left) with Crown Prince Gustav Adolf, later King of Sweden (middle) at the Nobel ceremony in Stockholm.

Delicate figure Werner Heisenberg was said to be sensitive, good looking and talented at music but vulnerable to allergies.

the North Sea. But he didn't stop working. "What exactly happened on that barren, grassless island during the next ten days has been the subject of much speculation and no little romanticism," wrote historian David Cassidy in his definitive 1992 book *Uncertainty: The Life and Science of Werner Heisenberg.*

In Heisenberg's telling, decades later, he kept turning over all he knew and began to construct equations of observables – of frequencies and amplitudes – in what he called "quantum-mechanical series". He outlined a rough mathematical scheme, but one so awkward and clumsy that he wasn't even sure it obeyed the conservation of energy, as it surely must. One night Heisenberg turned to that issue.

"When the first terms seemed to accord with the energy principle, I became rather excited," he wrote much later in his 1971 book *Physics and Beyond*. But he was still so tired that he began to stumble over the maths. "As a result, it was almost three o'clock in the morning before the final result of my computations lay before me." The work still seemed finished yet incomplete – it succeeded in giving him a glimpse of a new world though not one worked out in detail – but his emotions were weighted with fear and longing.

"I was deeply alarmed," Heisenberg continued. "I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structure nature had so generously spread out before me. I was far too excited to sleep and so, as a new day dawned, I made for the southern tip of the island, where I had been longing to climb a rock jutting out into the sea. I now did so without too much trouble, and waited for the sun to rise."

> To modern ears, Heisenberg's comments may seem unremarkable. But his proposition certainly would have been nearly unthinkable to those steeped in Newtonian mechanics

What happened on Helgoland?

Historians are suspicious of Heisenberg's account. In their 2023 book *Constructing Quantum Mechanics Volume 2: The Arch 1923–1927*, Anthony Duncan and Michel Janssen suggest that Heisenberg made "somewhat less progress in his visit to Helgoland in June 1925 than later hagiographical accounts of this episode claim". They believe that Heisenberg, in *Physics and Beyond*, may "have misremembered exactly how much he accomplished in Helgoland four decades earlier".

What's more – as Cassidy wondered in *Uncertainty* – how could Heisenberg have been so sure that the result agreed with the conservation of energy without having carted all his reference books along to the island, which he surely had not. Could it really be, Cassidy speculated sceptically, that Heisenberg had memorized the relevant data?

Alexei Kojevnikov – another historian – even doubts that Heisenberg was entirely candid about the reasons behind his inspiration. In his 2020 book *The Copenhagen Network: The Birth of Quantum Mechanics from a Postdoctoral Perspective*, Kojevnikov notes that fleeing from strong-willed mentors such as Bohr, Born, Kronig, Pauli and Sommerfeld was key to Heisenberg's creativity. "In order to accomplish his most daring intellectual breakthrough," Kojevnikov writes, "Heisenberg had to escape from the authority of his academic supervisors into the temporary loneliness and freedom on a small island in the North Sea."

Whatever did occur on the island, one thing is clear. "Heisenberg had his breakthrough," decides Cassidy in his book. He left Helgoland 10 days after he arrived, returned to Göttingen, and dashed off a paper that was published in *Zeitschrift für Physik* in September 1925 (**33** 879). In the article, Heisenberg wrote that "it is not possible to assign a point in space that is a function of time to an electron by means of observable quantities." He then suggested that "it seems more advisable to give up completely on any hope of an observation of the

Helgoland 2025: have you packed your tent?

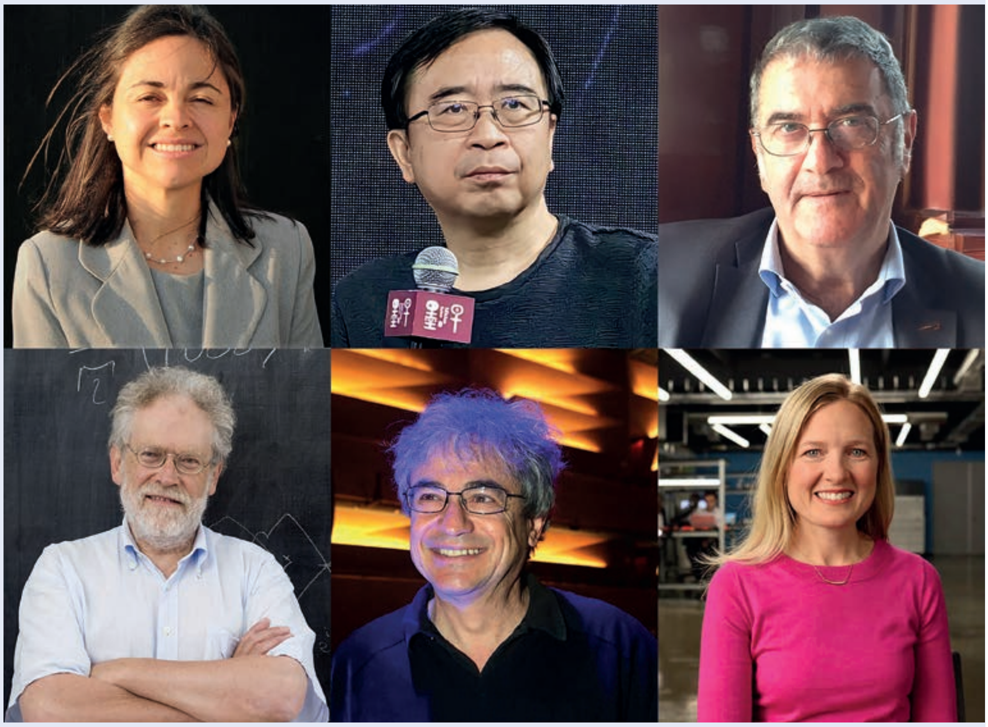
Running from 9–14 June 2025 on the island where Werner Heisenberg did his pioneering work on quantum mechanics, the Helgoland 2025 workshop is a who's who of quantum physics. Five Nobel laureates in the field of quantum foundations are coming. David Wineland and Serge Haroche, who won in 2012 for measuring and manipulating individual quantum systems, will be there. So too will Alain Aspect, John Clauser and Anton Zeilinger, who were honoured in 2022 for their work on quantum-information science.

There'll be Charles Bennett and Gilles Brassard, who pioneered quantum cryptography, quantum teleportation and other applications, as well quantum-sensing guru Carlton Caves. Researchers from industry are intending to be present, including Krysta Svore, who's vice-president of Microsoft Quantum.

Other attendees are from the intersection of foundations and applications. There will be researchers working on gravitation, mostly from quantum gravity phenomenology, where the aim is to seek experimental signatures of the effect. Others work on quantum clocks, quantum cryptography, and innovative ways of controlling light, such as using squeezed light at LIGO, to detect gravitational waves.

The programme starts in Hamburg on 9 June with a banquet and a few talks. Attendees will then take a ferry to Helgoland the following morning for a week of lectures, panel discussions and poster sessions. All talks are plenary, but in the evenings panels of a half-dozen or so people will address bigger questions familiar to every quantum physicist but rarely discussed in research papers. What is it about quantum mechanics, for instance, that makes it so compatible with so many interpretations?

If you're thinking of going, you're almost certainly out of luck. Registration closed in April 2024, while hotels, Airbnb and Booking.com venues are nearly exhausted. Participants are having to share double rooms or invited to camp on the beaches – with their own gear.



Entangled minds Helgoland 2025 boasts a who's who of quantum physics including (clockwise from top right) Serge Haroche, Krysta Svore, Carlo Rovelli, Anton Zeilinger, Ana Maria Rey and Jan-Wei Pan.

hitherto-unobservable quantities (such as the position and orbital period of the electron)."

To modern ears, Heisenberg's comments may seem unremarkable. But his proposition certainly would have been nearly unthinkable to those steeped in Newtonian mechanics. Of course, the idea of completely abandoning the observability of those quantities wasn't quite true. Under certain conditions, it can make sense to speak of observing them. But they certainly captured the direction he was taking.

The only trouble was that his scheme, with its "quantum-mechanical relations", produced formulae that were "noncommutative" – a distressing asymmetry that was surely an incorrect feature in a physical theory. Heisenberg all but shoved this feature under the rug in his *Zeitschrift für Physik* article, where he relegated the point to a single sentence.

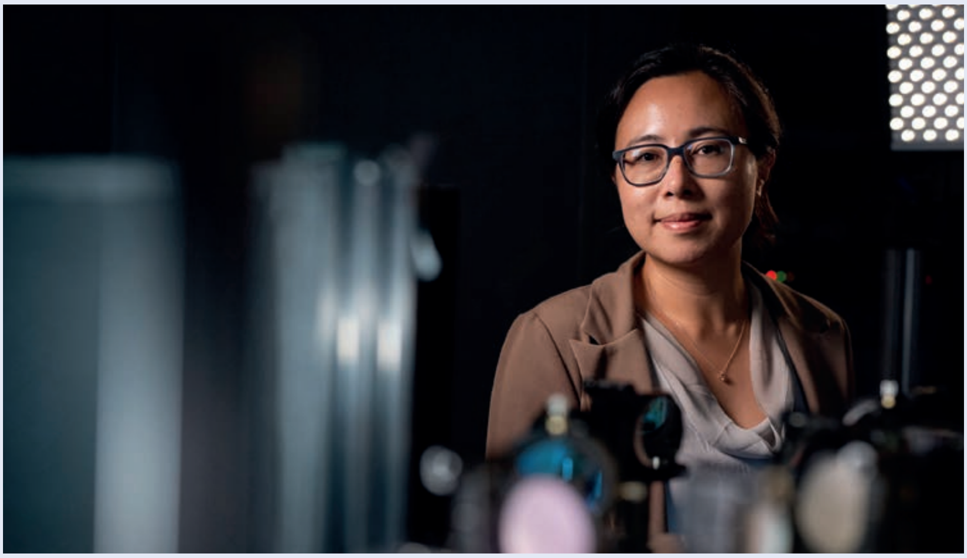
The more mathematically trained Born, on the other hand, sensed something familiar about the maths and soon recognized that Heisenberg's bizarre "quantum-mechanical relations" with their strange tables were what mathematicians called matrices. Heisenberg was unhappy with that particular name for his work, and considered returning to what he had called "quantum-mechanical series".

Fortunately, he didn't, for it would have made the rationale for the Helgoland 2025 conference clunkier to describe. Born was delighted with the connection to traditional mathematics. In particular he found that when the matrix p associated with momentum and the matrix q associated with position are multiplied in different orders, the difference between them is proportional to Planck's constant, h.

As Born wrote in his 1956 book *Physics in My Generation*: "I shall never forget the thrill I experienced when I succeeded in condensing Heisenberg's ideas on quantum conditions in the mysterious equation $pq - qp = h/2\pi i$, which is the centre of the new mechanics and was later found to imply the uncertainty relations". In February 1926, Born, Heisenberg and Jordan published a landmark paper that worked out the implications of this equation (*Zeit. Phys.* **35** 557). At last, physicists had a map of the quantum domain.

Almost four decades later in an interview with the historian Thomas Kuhn, Heisenberg recalled Pauli's "extremely enthusiastic" reaction to the developments. "[Pauli] said something like '*Morgenröte einer Neuzeit*'," Heisenberg told Kuhn. "The dawn of a new era." But it

Nathalie de Leon: heading for Helgoland



Precision thinker Nathalie de Leon from Princeton University is one of the researchers invited to the Helgoland meeting in June 2025.

Princeton University/Sameer A Khan

In June 2022, Nathalie de Leon, a physicist at Princeton University working on quantum computing and quantum metrology, was startled to receive an invitation to the Helgoland conference. "It's not often you get [one] a full three years in advance," says de Leon, who also found it unusual that participants had to attend for the entire six days. But she was not surprised at the composition of the conference with its mix of theorists, experimentalists and people applying what she calls the "weirder" aspects of quantum theory.

"When I was a graduate student [in the late 2000s], it was still the case that quantum theorists and researchers who built things like quantum computers were well aware of each other but they didn't talk to each other much," she recalls. "In their grant proposals, the physicists had to show they knew what the computer scientists were doing, and the computer scientists had to justify their work with appeals to physics. But they didn't often collaborate." De Leon points out that over the last five or 10 years, however, more and more opportunities for these groups to collaborate have emerged. "Companies like IBM, Google, QuEra and Quantinuum now have theorists and academics trying to develop the hardware to make quantum tech a practical reality," she says.

Some quantum applications have even cropped up in highly sophisticated technical devices, such as the huge Laser Interferometer Gravitational Wave Observatory (LIGO). "A crazy amount of classical engineering was used to build this giant interferometer," says de Leon, "which got all the way down to a minuscule sensitivity. Then as a last step the scientists injected something called squeezed light, which is a direct consequence of quantum mechanics and quantum measurement." According to de Leon, that squeezing let us see something like eight times more of the universe. "It's one of the few places where we get a real tangible advantage out of the strangeness of quantum mechanics," she adds.

Other, more practical benefits are also bound to emerge from quantum information theory and quantum measurement. "We don't yet have quantum technologies on the open consumer market in the same way we have lasers you can buy on Amazon for $15," de Leon says. But groups gathering in Helgoland will give us a better sense of where everything is heading. "Things," she adds, "are moving so fast."

A century on from Heisenberg's visit to Helgoland, quantum mechanics still has physicists scratching their heads

wasn't entirely smooth sailing after that dawn. Some physicists were unenthusiastic about Heisenberg's new mechanics, while others were outright sceptical.

Yet successful applications kept coming. Pauli applied the equation to light emitted by the hydrogen atom and derived the Balmer formula, a rule that had been known empirically since the mid-1880s. Then, in one of the most startling coincidences in the history of science, the Austrian physicist Erwin Schrödinger produced a complete map of the quantum domain stemming from a much more familiar mathematical basis called "wave mechanics". Crucially, Heisenberg's matrix mechanics and Schrödinger's maps turned out to be identical.

Even more fundamental implications followed. In an article published in *Naturwissenschaften* (**14** 899) in September 1926, Heisenberg wrote that our "ordinary intuition" does not work in the subatomic realm. "Because the electron and the atom possess not any degree of physical reality as the objects of our daily experience," he said, "investigation of the type of physical reality which is proper to electrons and atoms is precisely the subject of quantum mechanics."

Quantum mechanics, alarmingly, was upending reality itself, for the uncertainty it introduced was not only mathematical but "ontological" – meaning it had to do with the fundamental features of the universe. Early the next year, Heisenberg, in correspondence with Pauli, derived the equation $\Delta p\,\Delta q \geq h/4\pi$, the "uncertainty principle", which became the touchstone of quantum mechanics. The birth complications, however, persisted. Some even got worse.

Catalytic conference

A century on from Heisenberg's visit to Helgoland, quantum mechanics still has physicists scratching their heads. "I think most people agree that we are still trying to make sense of even basic non-relativistic quantum mechanics," admits Jack Harris, a quantum physicist at Yale University who is co-organizing Helgoland 2025 with Časlav Brukner, Steven Girvin and Florian Marquardt.

"We really don't fully understand the quantum world yet," adds Igor Pikovsky from the Stevens Institute in New Jersey, who works in gravitational phenomena and quantum optics. "We apply it, we generalize it, we develop quantum field theories and so on, but still a lot of it is uncharted territory." Philosophers and quantum physicists with strong opinions have debated interpretations and foundational issues for a long time, he points out, but the results of those discussions have been unclear.

Helgoland 2025 hopes to change all that. Advances in experimental techniques let us ask new kinds of fundamental questions about quantum mechanics. "You

Helgoland 2025 will focus on the two-way street between foundations and applications in what promises to be a unique event

have new opportunities for studying quantum physics at completely different scales," says Pikovsky. "You can make macroscopic, Schrödinger-cat-like systems, or very massive quantum systems to test. You don't need to debate philosophically about whether there's a measurement problem or a classical-quantum barrier – you can start studying these questions experimentally."

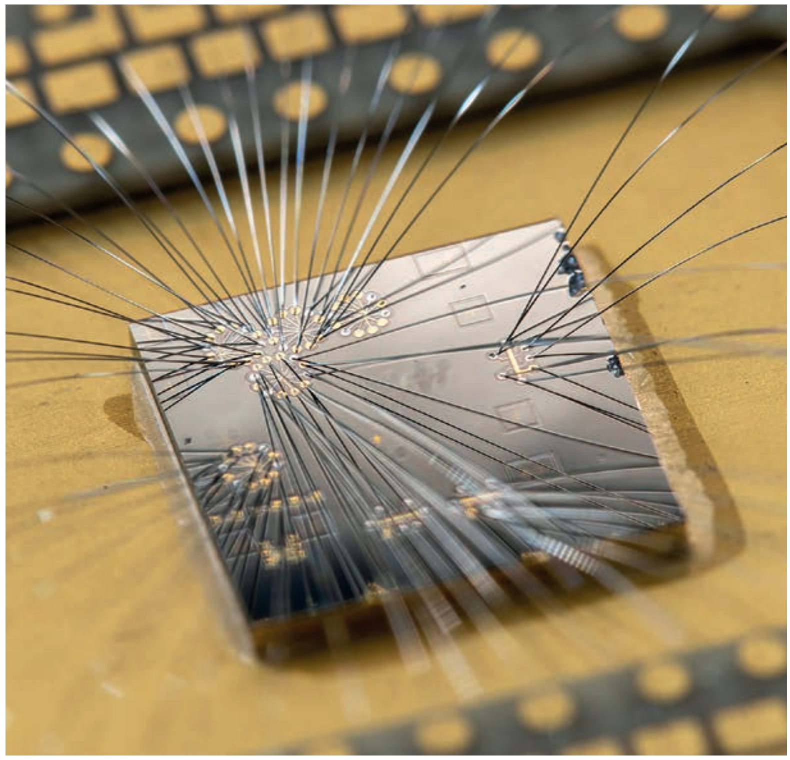
One phenomenon fundamental to the puzzle of quantum mechanics is entanglement, which prevents the quantum state of a system from being described independently of the state of others. Thanks to the Einstein–Podolsky–Rosen (EPR) paper of 1935 (*Phys. Rev.* **47** 777), Chien-Shiung Wu and Irving Shaknov's experimental demonstration of entanglement in extended systems in 1949, and John Bell's theorem in 1964 (*Physics* **1** 195), physicists know that entanglement in extended systems is a large part of what's so weird about quantum mechanics.

Understanding all that entanglement entails, in turn, has led physicists to realize that information is a fundamental physical concept in quantum mechanics. "Even a basic physical quantum system behaves differently depending on how information about it is stored in other systems," Harris says. "That's a starting point both for deep insights into what quantum mechanics tells us about the world, and also for applying it."

Helgoland 2025 will therefore focus on the two-way street between foundations and applications in what promises to be a unique event. "The conference is intended to be a bit catalytic," Harris adds. "[There will be] people who didn't realize that others were working on similar issues in different fields, and a lot of people who will never have met each other". The disciplinary diversity will be augmented by the presence of students as well as poster sessions, which tend to bring in an even broader variety of research topics.

One of those looking forward to such encounters is Ana Maria Rey – a theoretical physicist at the University of Colorado, Boulder, and a JILA fellow who studies quantum phenomena in ways that have improved atomic clocks and quantum computing. "There will be people who work on black holes whose work is familiar to me but who I haven't met yet," she says. Finding people should be easy: Helgoland is tiny and only a hand-picked group of people have been invited to attend (see the box "Helgoland 2025: have you packed your tent?", p27).

What's also unusual about Helgoland is that it has as many practically-minded as theoretically-minded participants. But that doesn't faze Magdalena Zych, a physicist from Stockholm University in Sweden. "I'm biased because academically I grew up in Vienna, where Anton Zeilinger's group always had people working on theory and applications," she says.



IBM

Strange world
We might not fully understand quantum physics, but novel experimental techniques are helping us to make progress, while applications in areas such as quantum computing and cryptography are booming.

Zych's group has, for example, recently discovered a way to use the uncertainty principle to get a better understanding of the semi-classical space–time trajectories of composite particles. She plans to talk about this research at Helgoland, finding it appropriate given that it relies on Heisenberg's principle, is a product of specific theoretical work and is valid more generally. "It relates to the arch of the conference, looking both backwards and forwards, and from theory to applications."

Sadly, participants will not be able to visit Heisenberg's Gasthaus, nor any other building where he might have been. During the Second World War, Germany again relocated Helgoland's inhabitants and turned the island into a military base. After the war, the Allies piled up unexploded ordinances on the island and set them off, in what is said to be one of the biggest conventional explosions in history. The razed homeland was then given back to its inhabitants.

Helgoland still has rocky outcroppings at its southern end, one of which may or may not be the site of Heisenberg's early morning climb and vision. But despite the powerful mythology of his story, participants at Helgoland 2025 are not being asked to herald another dawn. "We will not," says Harris, "be 300 Heisenbergs going for hikes. We certainly won't be trying to get away from each other."

The historian of science Mario Biagioli once wrote an article entitled "The scientific revolution is undead", underlining how arbitrary it is to pin key developments in science – no matter how influential or long-lasting – to specific beginnings and endings, for each new generation of scientists finds ever more to mine in the radical discoveries of predecessors. With so many people working on so many foundational issues set to be at Helgoland 2025, new light is bound to emerge. A century on, the quantum revolution is alive and well. ■

Glass art in the age of quantum tech

Stained glass has been used for centuries to create wonderful colours and patterns using light. **Oksana Kondratyeva** describes how she has worked with Rigetti Computing to make an unusual new quantum-inspired piece of stained-glass art

Oksana Kondratyeva is a London-based designer and producer of architectural glass art. Born in Ukraine, she has a PhD in the theory of architecture

INTERNATIONAL YEAR OF
Quantum Science and Technology

Stained glass is the most "physical" of all art forms. If you've ever been inside Chartres Cathedral in France or York Minster in the UK, you'll know how such glass can transform a building by turning sunlight into gloriously captivating multicoloured patterns. What you might not realize, however, is that centuries of scientific innovation have forged this form of art.

Byzantine glaziers started making leaded glass windows back in the 6th century CE before the technique spread widely across Europe. But our ability to stain glass only emerged in the 14th century when medieval alchemists found that coating glass with silver nitrate and firing it in a kiln gave the material a range of orange and yellow hues.

Later, a range of other techniques were developed to produce various decorative effects, with stained glass becoming both an art and a craft. Particularly important has been the use of hydrofluoric acid – a poisonous and highly corrosive liquid – to strip off the surface of glass, layer by layer, to alter its colour and thickness.

Known as hydrofluoric acid etching, the technique is widely used by modern architectural glass artists. Beautiful patterns can be created by altering the strength and temperature of the acid and varying the time for which the glass is exposed to it. Materials like wax, bitumen and lead foil can also be used as resists to leave parts of the glass untouched.

Like other "glass artists", I am an experimentalist of sorts. We use an empirical knowledge of glass to make beautiful objects – and sometimes even make new discoveries. In fact, some historians say that hydrofluoric acid was first created in 1670 by a German glassworker named Heinrich Schwanhardt.

While treating a mineral called fluorspar with acid, he saw that the lenses in his spectacles went cloudy – prompting him to start using the same reaction to etch glass. Only much later – in the late 18th century – did chemists carry out "proper" lab experiments to show that fluorspar (calcium fluoride) reacts with the acid to create what we now call hydrofluoric acid.

From the 19th century onwards, acid-etching techniques started to be used by numerous stained-glass artists and studios throughout Britain and Ireland. Dublin-born Harry Clarke (1889–1931) was the leading proponent of the hydrofluoric acid-etching technique, which he mastered in an exceptionally personal and imaginative manner.

View this e-magazine online to watch a video of Oksana Kondratyeva creating the artwork *Per scientiam ad astra*.

Art of glass

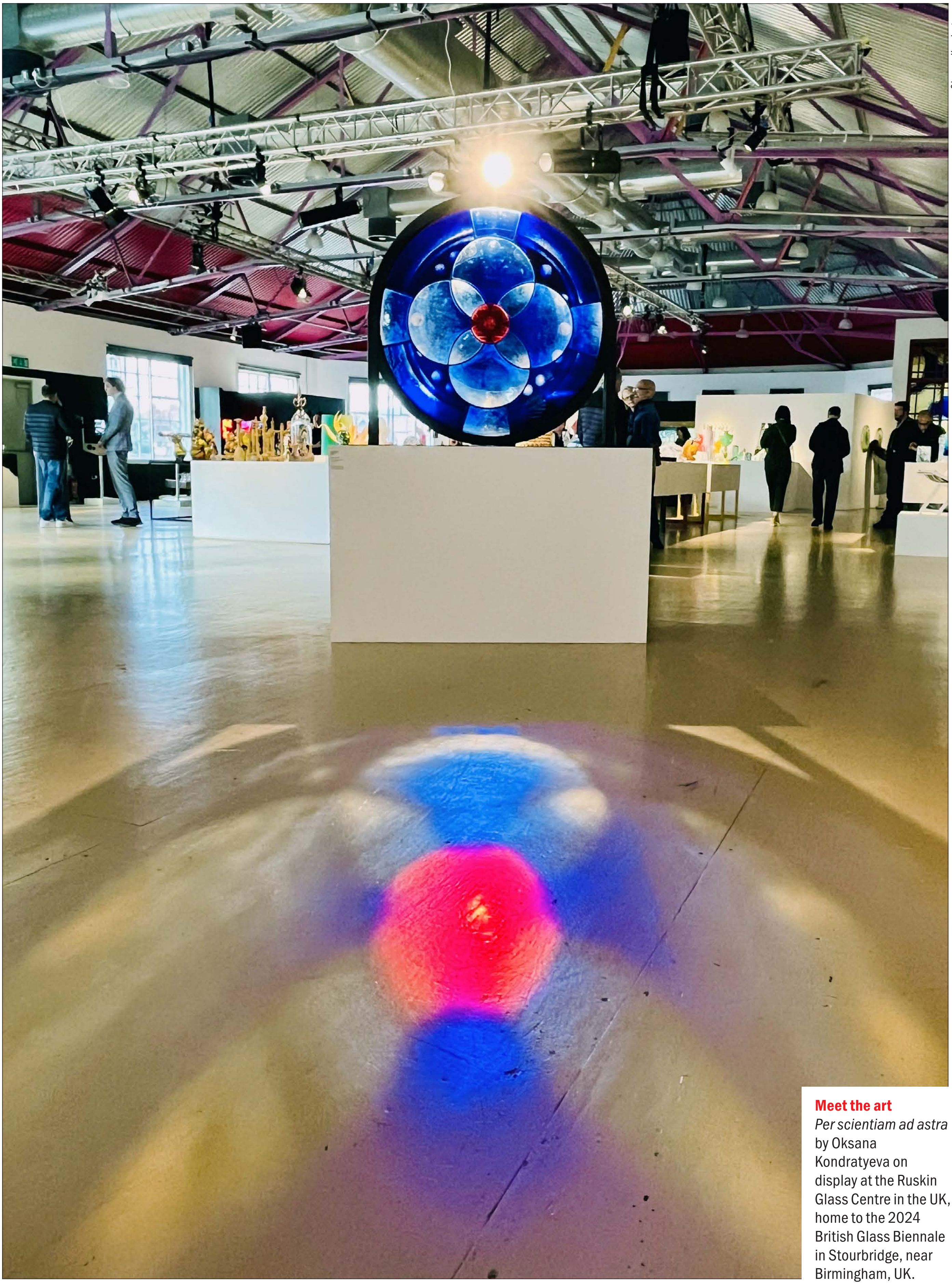
I first came across acid etching in 2010 while studying glass and architecture at Central Saint Martins, which is part of the University of the Arts London. The technique intrigued me and I started wondering about its origins and how it works, from a scientific point of view. What chemical processes are involved? What happens if you vary how the acid is applied? And how can that create new decorative effects?

Unable to find full answers to my questions, I started carrying out my own experiments and investigations. I wanted to understand how fluorspar – which can be colourless, deep green or even purple – can be turned into hydrofluoric acid and what goes on at a chemical level when it etches glass.

During my investigations, which I published in 2014 in *The Journal of Stained Glass* (**38** 146), I was astonished to find references to glass in the famous lectures given by Richard Feynman about quantum electrodynamics. Published in book form as *QED: the Strange Theory of Light and Matter*, Feynman explained the partial reflection of light by experimenting with blocks of glass.

He showed that the amount of light reflected increases with the thickness of the glass, pointing out that photons interact with electrons throughout the material, not just on the surface. "A piece of glass," Feynman wrote, "is a terrible monster of complexity – huge numbers of electrons are jiggling about."

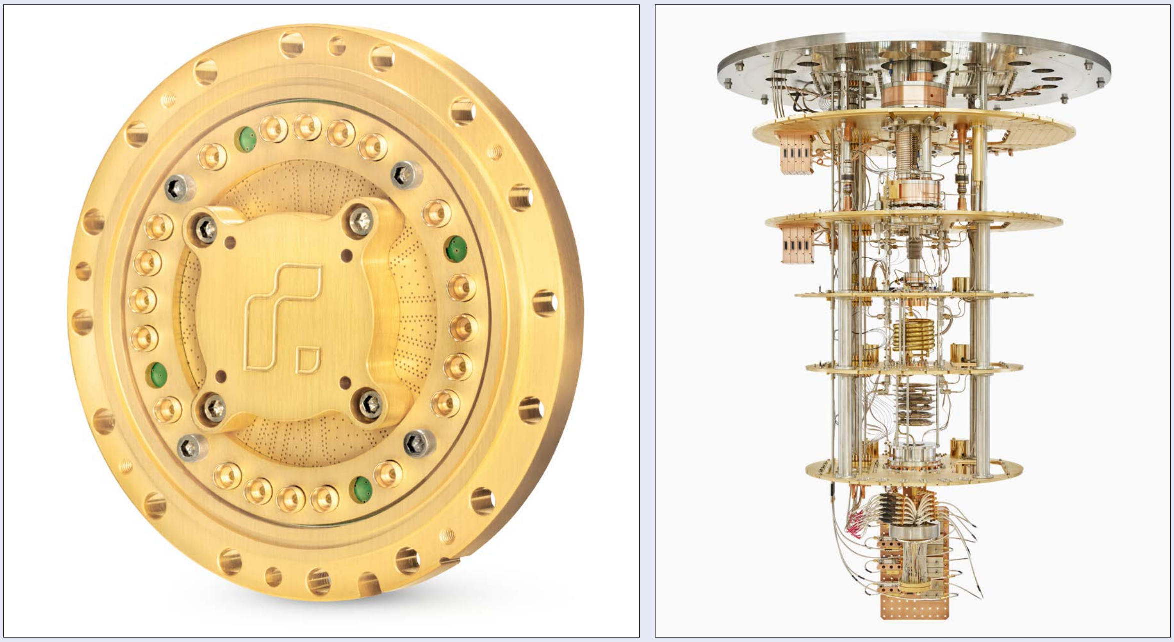
In my own work, I've recently been experimenting with



Oksana Kondratyeva

Meet the art
Per scientiam ad astra by Oksana Kondratyeva on display at the Ruskin Glass Centre in the UK, home to the 2024 British Glass Biennale in Stourbridge, near Birmingham, UK.

Rigetti Computing's quantum chip



Rigetti Computing

Art from science (left) The packaging for Rigetti Computing's quantum chip that inspired the stained-glass artwork made by Oksana Kondratyeva. (right) The Rigetti quantum computer, with packaging visible at the bottom attached to the input/output plate.

The quantum computers developed by US firm Rigetti Computing are based on superconducting qubits made from materials such as aluminium, indium and niobium. The qubits are manufactured using a mix of novel fabrication methods and well-established semiconductor and micro-electromechanical systems (MEMS) processing techniques. The quantum chip – containing the qubits and other components such as readout resonators – are carefully assembled inside a gold-plated copper packaging that connects it to a printed circuit board (PCB).

The PCB in turn routes the signals to microwave connectors, with the whole system cooled to below 10 millikelvin using dilution refrigeration. The environment in which the quantum bits operate is carefully engineered so that they don't lose their coherence. Rigetti's design could, in principle, be scaled up to create much larger and more reliable quantum processors with many more qubits.

The packaging for the quantum chip, on which Oksana Kondratyeva's artwork is based, is a disc 81.5 mm in diameter and 12 mm deep. With the chip at its centre, the packaging is mounted at the bottom of a tower-like structure that, along with the rest of the fridge and wiring, forms the fully assembled quantum computer. Signals are delivered to and from the chip to drive qubit operations and return measured results.

glass of different thickness to make a piece of art inspired by the packaging for a quantum chip made by Rigetti Computing. Entitled *Per scientiam ad astra* (through science to the stars), the artwork was displayed at the 2024 British Glass Biennale at the Ruskin Glass Centre in Stourbridge, UK – a historically significant area for glass-making that pioneered the creation of etched glass in the 19th century.

A quantum rose

Creating an artwork based on quantum technology might be an unusual thing to do, but when I saw a photo of the packaging for a quantum chip back in 2020, I was astounded by the elegant geometry of this enigmatic object, which holds the "brain" of the company's quantum computer (see box above). Reminding me of the beautiful circular rose windows of medieval cathedrals, I wanted to use glass to create a "quantum rose" for the 21st century. Later, Rigetti got in touch with me after my plans were reported on in *Physics World* in June 2022.

As you can imagine, hydrofluoric acid etching is an extremely dangerous technique, given how corrosive the liquid is. I acid-etch glass from the German company LambertsGlas in a specially equipped studio with a ventilation cabinet to extract fumes and I wear a protective suit with a respiratory mask. At this point, I look more like an astronaut than an artist.

With 2025 being the International Year of Quantum Science and Technology, I hope my artwork raises interesting questions at the intersection between art and science

Acid etching can be done in lots of different ways (see *Materials Today Proceedings* **55** 56) – but I prefer to apply the acid freely with a cotton or plastic brush, coining my technique "acid painting". The resulting artwork, which took me several months to make, is just over a metre in diameter.

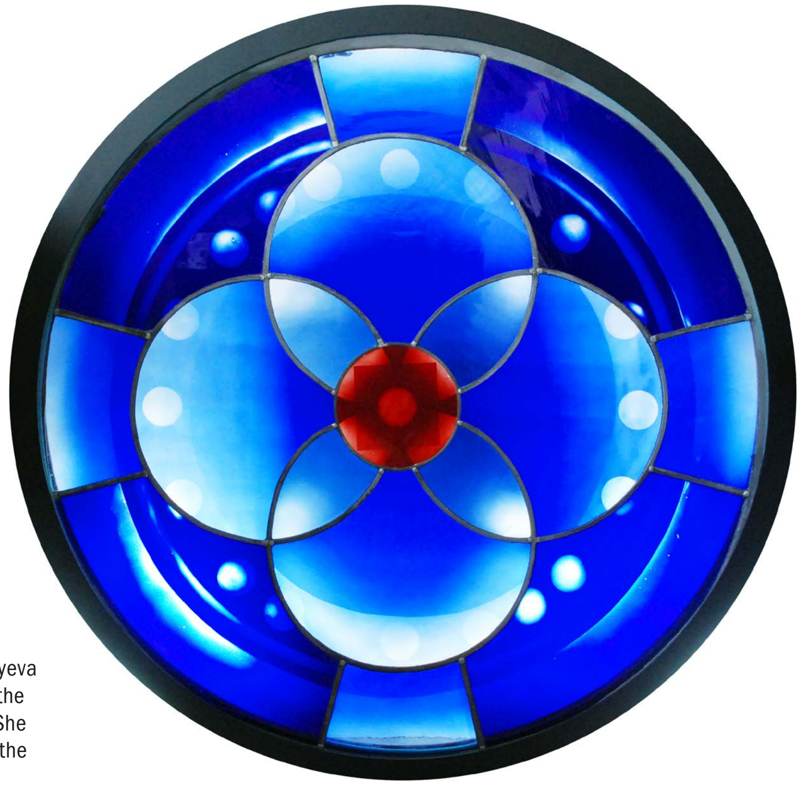
Mostly blue with a red focal point, the artwork constantly changes as you move around it. Visitors to the British Glass Biennale seemed to be attracted to it, with comments such as "empowering" and "ethereal". *Per scientiam ad astra* will now move to a private residence that just happens to be not far from the UK's National Quantum Computing Centre in Oxfordshire, where one of Rigetti's quantum computers is housed.

Art–science crossover

Stained-glass windows were once "illuminated books" for people who could not read – mysterious transmitters of knowledge that told stories about human life. The

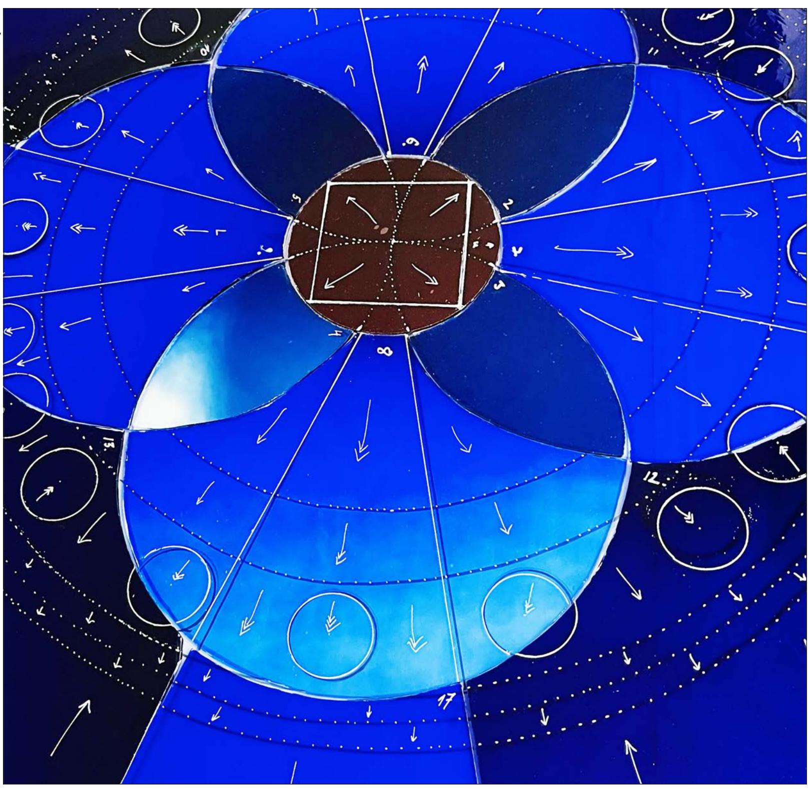
Olga Satina

Oksana Kondratyeva

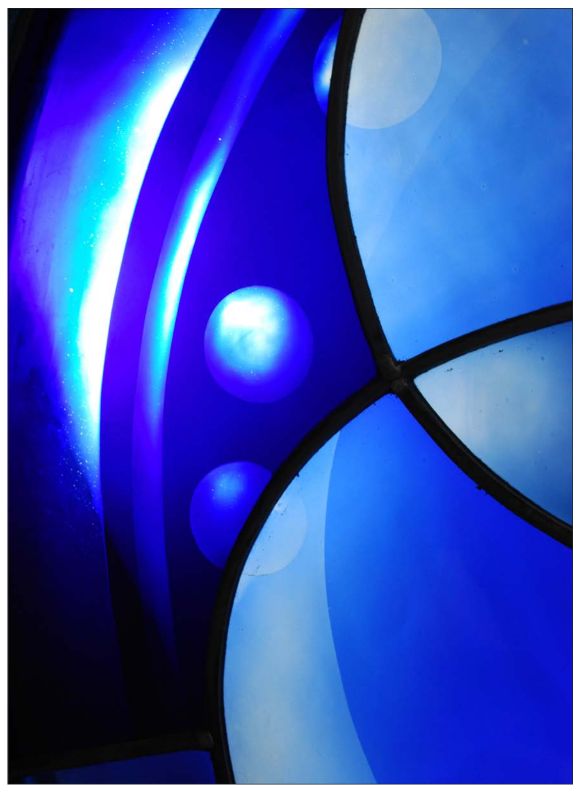


Through science to art Ukraine-born artist Oksana Kondratyeva, pictured (above) in her London studio, was inspired by a Rigetti quantum computer to create *Per scientiam ad astra* (right). Kondratyeva etched mouth-blown glass with hydrofluoric acid. Each fragment of the artwork (e.g. below right) was individually acid-etched and leaded. She temporarily marked arrows onto the glass (below left) as a guide for the layered acid-etching, reflecting her artistic thought.

Oksana Kondratyeva



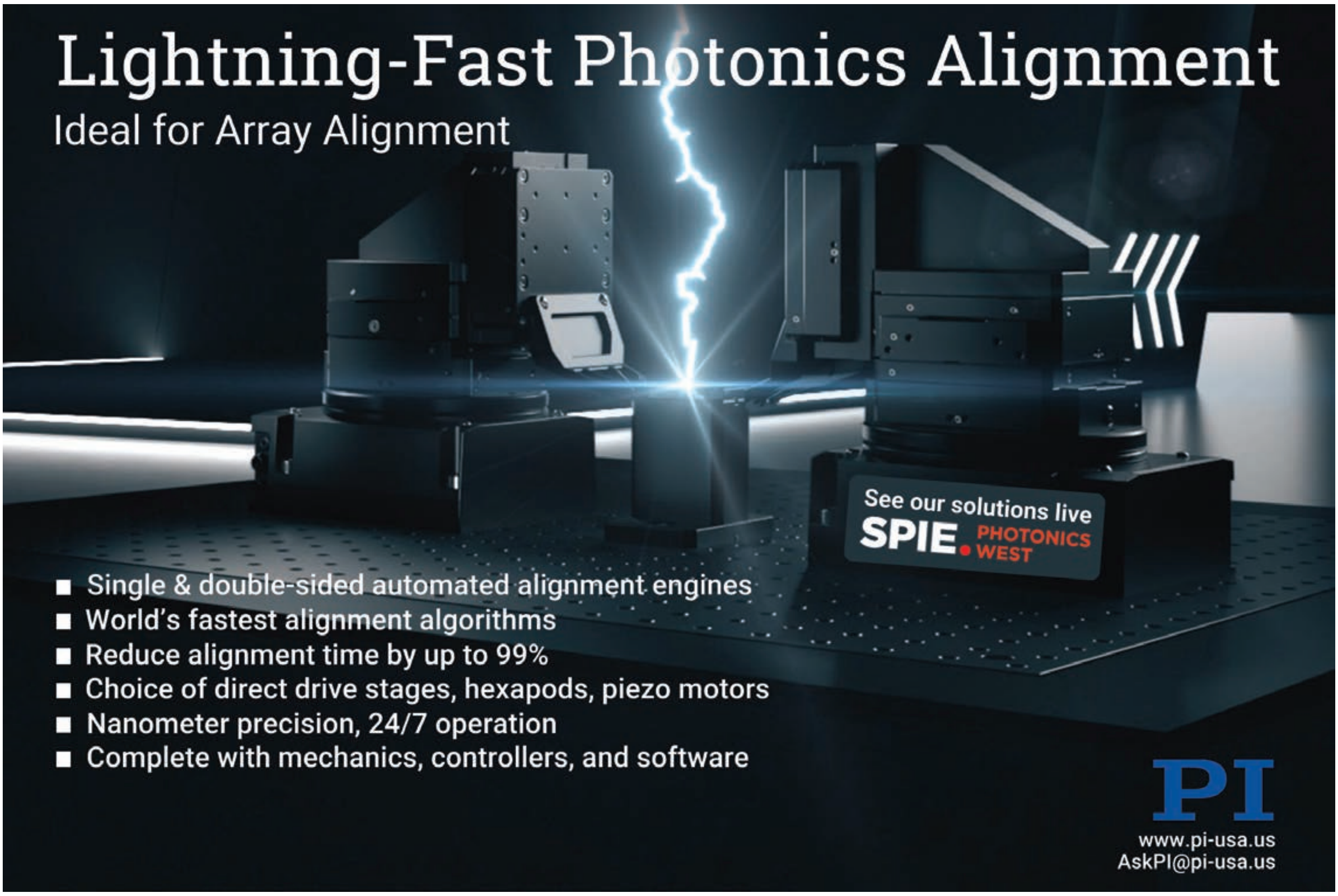
Oksana Kondratyeva



same, in a way, is true of quantum computers, which are broadening our understanding of reality. And just as mathematical equations can have an inner beauty, so too do quantum computers through the myriad technological innovations that underpin them.

With 2025 being the International Year of Quantum Science and Technology, I hope my artwork raises interesting questions at the intersection between art and science, continuing the "two-cultures" dialogue introduced by C P Snow in 1959. Is it a metaphorical window into the secret architecture of the universe? Or is it a visualization of our reality, where Newtonian and quantum-mechanical worlds merge?

Working with stained glass requires an understanding of how materials behave but that knowledge will only get you so far. To reveal new regions of reality and its beauty, unexpectedness plays a role too. Stained-glass art is the convergence of certainty and uncertainty, where science and art come together. Art can unite people; and through the beauty in art, we can create a better reality. ■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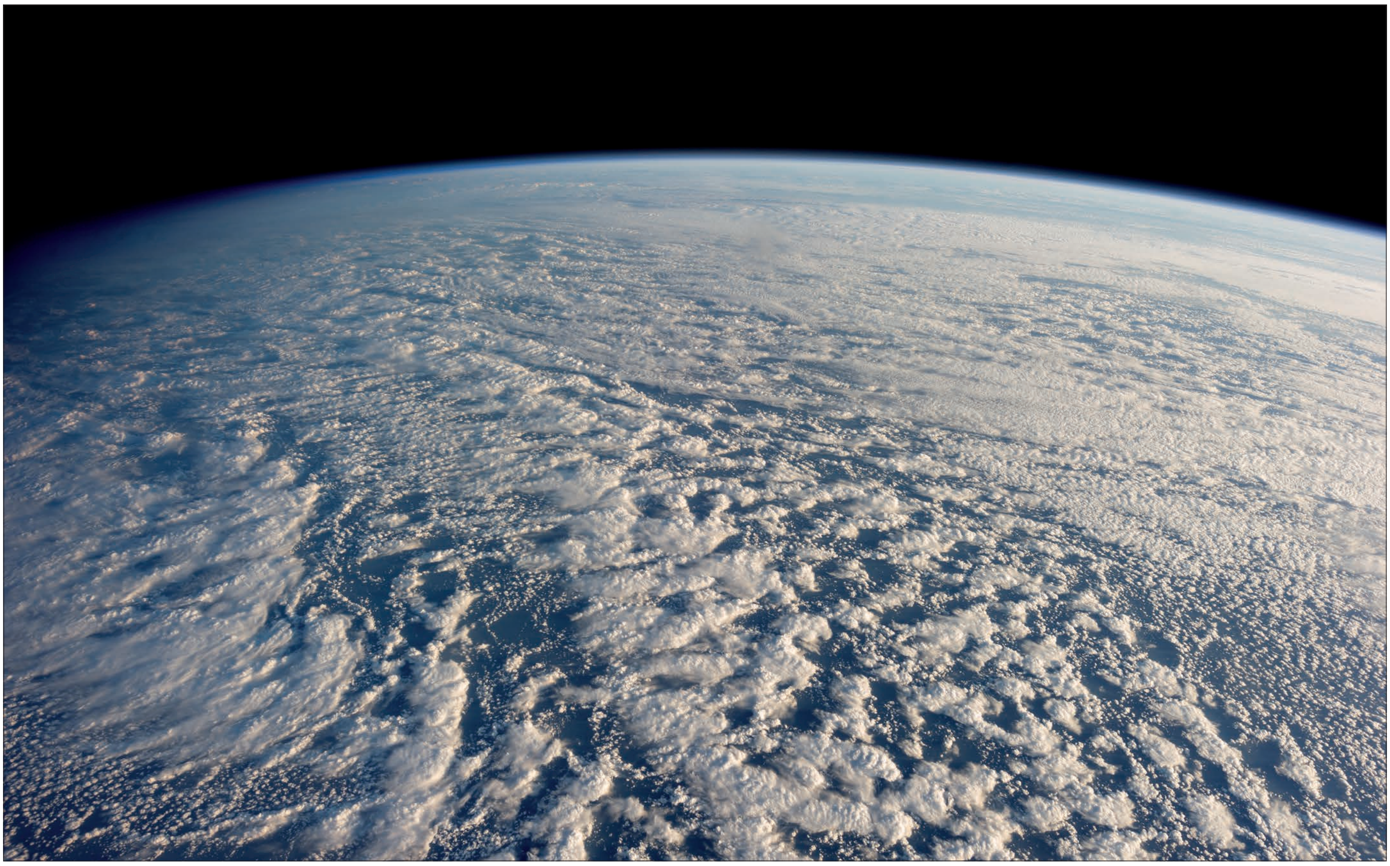


Science & Analysis Laboratory, NASA Johnson Space Center

Cloudy with a chance of warming

For all of us concerned about the climate, 2023 was a grim year. One of the biggest uncertainties in predicting future climate change is the impact of clouds. **Michael Allen** speaks to the physicists and atmospheric scientists studying the properties and processes of cloud physics – from structure and phase-transitions to modelling and manipulations

For all of us concerned about climate change, 2023 was a grim year. According to the World Meteorological Organisation (WMO), it was the warmest year documented so far, with records broken – and in some cases smashed – for ocean heat, sea-level rise, Antarctic sea-ice loss and glacier retreat.

Capping off the warmest 10-year period on record, global average near-surface temperature hit 1.45 °C above pre-industrial levels. "Never have we been so close – albeit on a temporary basis at the moment – to the 1.5 °C lower limit of the Paris Agreement on climate change," said WMO secretary-general Celeste Saulo in a statement last year.

The heatwaves, floods, droughts and wildfires of 2023 are clear signs of the increasing dangers of the climate crisis. As we look to the future and wonder how much the world will warm, accurate climate models are vital.

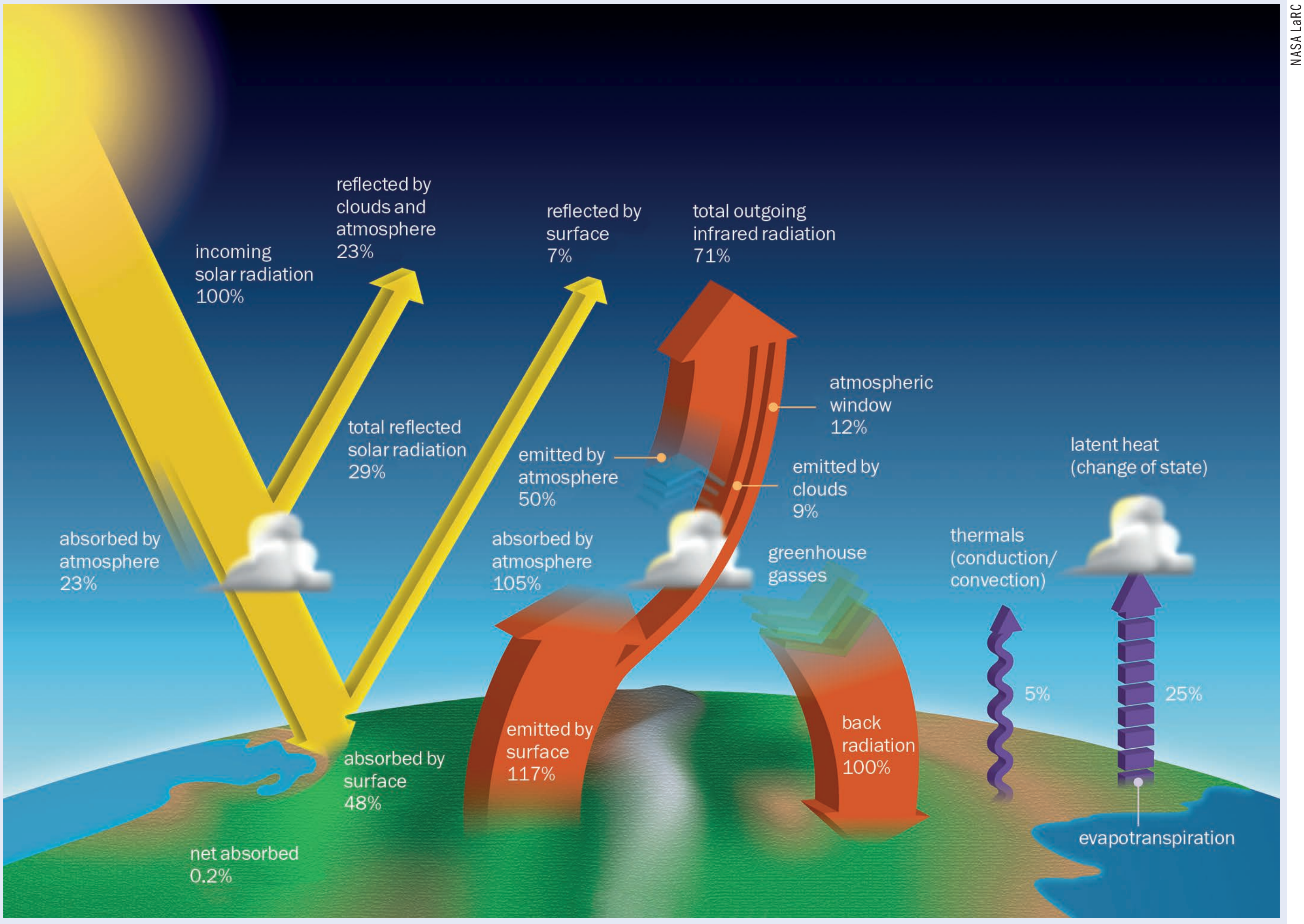
For the physicists who build and run these models, one major challenge is figuring out how clouds are changing as the world warms, and how those changes will impact the climate system. According to the Intergovernmental Panel on Climate Change (IPCC), these feedbacks create the biggest uncertainties in predicting future climate change.

Michael Allen is a science writer based in the UK

Cloud cover, high and low

Clouds play a key role in the climate system, as they have a profound impact on the Earth's radiation budget. That is the balance between the amount of energy coming in from solar radiation, and the amount of energy going

1 Earth's energy budget



How energy flows into and away from the Earth. Based on data from multiple sources including NASA's CERES satellite instrument, which measures reflected solar and emitted infrared radiation fluxes. All values are fluxes in watts per square metre and are averages based on 10 years of data. First published in 2014.

back out to space, which is both the reflected (shortwave) and thermal (longwave) energy radiated from the Earth.

According to NASA, about 29% of solar energy that hits Earth's atmosphere is reflected back into space, primarily by clouds (figure 1). And clouds also have a greenhouse effect, warming the planet by absorbing and trapping the outgoing thermal radiation.

"Even a subtle change in global cloud properties could be enough to have a noticeable effect on the global energy budget and therefore the amount of warming," explains climate scientist Paulo Ceppi of Imperial College London, who is an expert on the impact of clouds on global climate.

A key factor in this dynamic is "cloud fraction" – a measurement that climate scientists use to determine the percentage of the Earth covered by clouds at a given time. More specifically, it's the portion of the Earth's surface covered by cloud, relative to the portion that is uncovered. Cloud fraction is determined via satellite imagery and is the portion of each pixel (1-km-pixel resolution cloud mask) in an image that is covered by clouds (figure 2).

Apart from the amount of cover, what also matter are the altitude of clouds and their optical thickness. Higher, cooler clouds absorb more thermal energy originating from the Earth's surface, and therefore have a greater greenhouse warming effect than low clouds. They also tend to be thinner, so they let more sunlight through and overall have a net warming effect. Low clouds, on the other hand, have a weak greenhouse effect, but tend to be thicker and reflect more solar radiation. They generally have a net cooling effect.

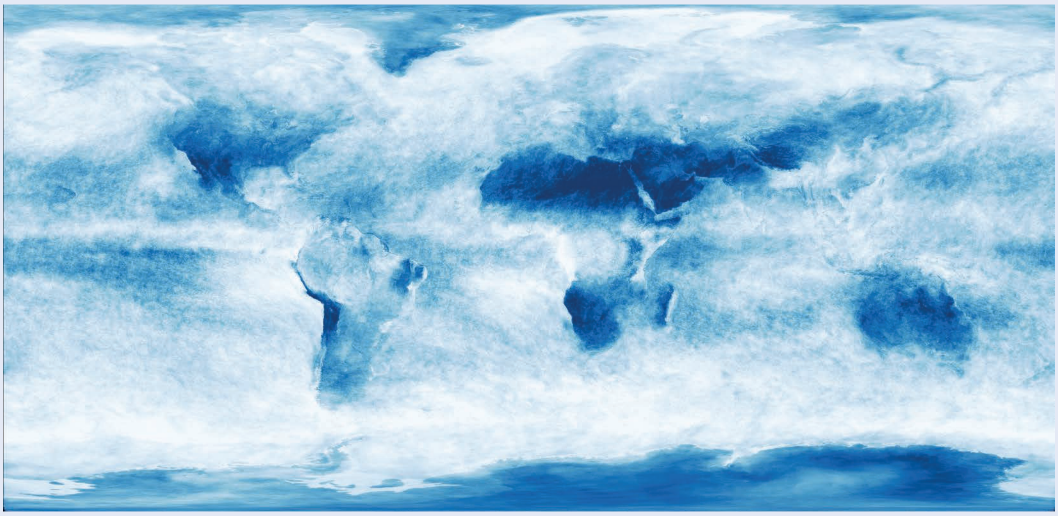
As the climate warms, cloud properties are changing, altering the radiation budget and influencing the amount of warming. Indeed, there are two key changes: rising cloud tops and a reduction in low cloud amount.

The most understood effect, Ceppi explains, is that as global temperatures increase, clouds rise higher into the troposphere, which is the lowermost atmospheric layer. This is because as the troposphere warms it expands, increasing to greater altitudes. Over the last 40 years the top of the troposphere, known as the tropopause, has risen by about 50 metres per decade (*Sci. Adv.* 10.1126/sciadv.abi8065).

"You are left with clouds that rise higher up on average, so have a greater greenhouse warming effect," Ceppi says. He adds that modelling data and satellite observations support the idea that cloud tops are rising.

Conversely, coverage of low clouds, which reflect sunlight and cool the Earth's surface, is decreasing with warming. This reduction is mainly in marine low clouds

2 Cloud fraction



View this e-magazine online to watch a video animation of cloud cover variation from 2000 to 2024.

These maps show what fraction of an area was cloudy on average each month, according to measurements collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. MODIS collects information in gridded boxes, or pixels. Cloud fraction is the portion of each pixel that is covered by clouds. Colours range from blue (no clouds) to white (totally cloudy). The band of persistent clouds around the equator is the Intertropical Convergence Zone – where the easterly trade winds in the Northern and Southern Hemispheres meet, pushing warm, moist air high into the atmosphere. The air expands and cools, and the water vapour condenses into clouds and rain. The cloud band shifts slightly north and south of the equator with the seasons. In tropical countries, this shifting of the zone is what causes rainy and dry seasons.

over tropical and subtropical regions. "We are talking a few per cent, so not something that you would necessarily notice with your bare eyes, but it's enough to have an effect of amplifying global warming," he adds.

These changes in low clouds are partly responsible for some of the extreme ocean heatwaves seen in recent years (figure 3). While the mechanisms behind these events are complex, one known driver is this reduction in low cloud cover, which allows more solar radiation to hit the ocean (*Science* **325** 460).

"It's cloud feedback on a more local scale," Ceppi says. "So, the ocean surface warms locally and that prompts low cloud dissipation, which leads to more solar radiation being absorbed at the surface, which prompts further warming and therefore amplifies and sustains those events."

Despite these insights, several questions remain unanswered. For example, Ceppi explains that while we know that low cloud changes will amplify warming, the strength of these effects needs further investigation, to reduce the uncertainty range.

Also, as high clouds move higher, there may be other important changes, such as shifts in optical thickness, which is a measure of how much light is scattered or absorbed by cloud droplets, instead of passing through the atmosphere. "We are a little less certain about what else happens to [high clouds]," says Ceppi.

Diurnal changes

It's not just the spatial distribution of clouds that impacts climate. Recent research has found an increasing asymmetry in cloud-cover changes between day and night. Simply put, daytime clouds tend to cool Earth's surface by reflecting solar radiation, while at night clouds trap thermal radiation and have a warming effect. This shift in diurnal distribution could create a feedback loop that amplifies global warming.

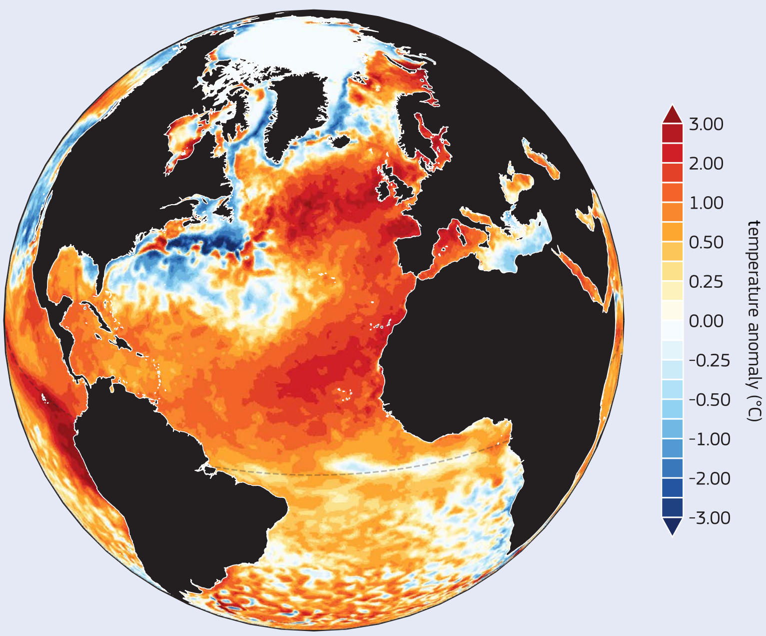
The new study was led by theoretical meteorologist Johannes Quaas at Leipzig University, together with Hao Luo and Yong Han from Sun Yat-sen University in China, who found that as the climate warms, cloud cover – especially in the lower atmosphere – decreases more during the day than at night (*Sci. Adv.* 10.1126/sciadv.ado5179).

By analysing satellite observations and data from the sixth phase of the Coupled Model Intercomparison Project (CMIP6) – which incorporates historical data collected between 1970 and 2014 as well as projections up to the year 2100 – the researchers concluded that this diurnal asymmetry is largely due to rising concentrations of greenhouse gases that make the lower troposphere more stable, which in turn increases the overall heating.

Fewer clouds form during the day, thereby reducing the amount of shortwave radiation that is reflected away. Night-time clouds are more stable, which in turn

Recent research has found an increasing asymmetry in cloud-cover changes between day and night. This shift could create a feedback loop that amplifies global warming

3 Ocean heat



ERA5. Courtesy: Copernicus Climate Change Service/ECMWF

Sea surface temperature anomaly (°C) for the month of June 2023, relative to the 1991–2020 reference period. The global ocean experienced an average daily marine heatwave coverage of 32%, well above the previous record of 23% in 2016. At the end of 2023, most of the global ocean between 20° S and 20° N had been in heatwave conditions since early November.

increases the longwave greenhouse effect. "Our study shows that this asymmetry causes a positive feedback loop that amplifies global warming," says Quaas. This growing asymmetry is mainly driven by a daytime increase in turbulence in the lower troposphere as the climate warms, meaning that clouds are less likely to form and remain stable during the day.

Mixed-phase clouds

Climate models are affected by more than just the distribution of clouds in space. What also matters is the distribution of liquid water and ice within clouds. In fact, researchers have found that the way in which models simulate this effect influences their predictions of warming in response to greenhouse gas emissions.

So-called "mixed-phase" clouds are those that contain water vapour, ice particles and supercooled liquid droplets, and exist in a three-phase colloidal system. Such clouds are ubiquitous in the troposphere. These clouds are found at all latitudes from the polar regions to the tropics and they play an important role in the climate system.

As the atmosphere warms, mixed-phase clouds tend to shift from ice to liquid water. This transition makes these clouds more reflective, enhancing their cooling effect on the Earth's surface – a negative feedback that dampens global warming.

In 2016 Trude Storelvmo, an atmospheric scientist at the University of Oslo in Norway, and her colleagues made an important discovery: many climate models overestimate this negative feedback (*Geophys. Res. Lett.* 10.1029/2023GL105053). Indeed, the models often simulate clouds with too much ice and not enough liquid water. This error exaggerates the cooling effect from the phase transition. Essentially, the clouds in these simulations have too much ice to lose, causing the models to overestimate the increase in their reflectiveness as they warm.

One problem is that these models oversimplify cloud structure, failing to capture the true heterogeneity of mixed-phase clouds. Satellite, balloon and aircraft observations reveal that these clouds are not uniformly mixed, either vertically or horizontally. Instead, they contain pockets of ice and liquid water, leading to complex interactions that are inadequately represented in the simulations. As a result, they overestimate ice formation and underestimate liquid cloud development.

Storelvmo's work also found that initially, increased cloud reflectivity has a strong effect that helps mitigate global warming. But as the atmosphere continues to warm, the increase in reflectiveness slows. This shift is intuitive: as the clouds become more liquid, they have less ice to lose. At some point they become predominantly liquid, eliminating the phase transition. The clouds cannot become anymore liquid – and thus reflective – and warming accelerates.

Liquid cloud tops

Earlier this year, Storelvmo and colleagues carried out a new study, using satellite data to study the vertical composition of mixed-phase clouds. The team discovered that globally, these clouds are more liquid at the top (*Commun. Earth Environ.* **5** 390).

Storelvmo explains that this top cloud layer is important as "it is the first part of the cloud that radiation interacts with". When the researchers adjusted climate models to correctly capture this vertical composition, it had a significant impact, triggering an additional degree of warming in a "high-carbon emissions" scenario by the end of this century, compared with current climate projections.

"It is not inconceivable that we will reach temperatures where most of [the negative feedback from clouds] is lost, with current CO_2 emissions," says Storelvmo. The point at which this happens is unclear, but is something that scientists are actively working on.

The study also revealed that while changes to mixed-phased clouds in the northern mid-to-high latitudes mainly influence the climate in the northern hemisphere, changes to clouds in the same southern latitudes have global implications.

"When we modify clouds in the southern extratropic that's communicated all the way to the Arctic – it's actually influencing warming in the arctic," says Storelvmo. The reasons for this are not fully understood, but Storelvmo says other studies have seen this effect too.

"It's an open and active area of research, but it seems that the atmospheric circulation helps pass on perturbations from the Southern Ocean much more efficiently than northern perturbations," she explains.

The aerosol problem

As well as generating the greenhouse gases that drive the climate crisis, fossil fuel burning also produces aerosols. The resulting aerosol pollution is a huge public health issue. The recent "State of Global Air Report 2024" from the Health Effects Institute found that globally eight million people died because of air pollution in 2021. Dirty air is also now the second-leading cause of death in children under five, after malnutrition.

To tackle these health implications, many coun-

Shutterstock/A M Syed

Deadly conundrum According to some measures, Lahore in Pakistan is the city with the worst air pollution in the world. Air pollution is responsible for tens of millions of deaths every year. But improving air quality can actually exacerbate the climate crisis, as it decreases the small particles in clouds, which are key to reflecting radiation.

tries and organizations have introduced air-quality clean-up policies. But cleaning up air pollution has an unfortunate side-effect: it exacerbates the climate crisis. Indeed, a recent study has even warned that aggressive aerosol mitigation policies will hinder our chances of keeping global warming below 2 °C (*Earth's Future* 10.1029/2023EF004233).

Jim Haywood, an atmospheric scientist at the University of Exeter, says that aerosols have two major cooling impacts on climate. The first is through the direct scattering of sunlight back out to space. The second is via the changes they induce in clouds.

When you add small pollution particles to clouds, explains Haywood, it creates "clouds that are made up of a larger number of small cloud droplets and those clouds are more reflective". The shrinking in cloud droplet size can also reduce precipitation – adding more liquid water in clouds. The clouds therefore last longer, cover a greater area and become more reflective.

But if atmospheric aerosol concentrations are reduced, so too are these reflective, planet-cooling effects. "This masking effect by the aerosols is taken out and we unveil more and more of the full greenhouse warming," says Quaas.

A good example of this is recent policy aimed at cleaning up shipping fuels by lowering sulphur concentrations. At the start of 2020 the International Maritime Organisation introduced regulations that slashed the limit on sulphur content in fuels from 3.5% to 0.5%.

Haywood explains that this has reduced the additional reflectivity that this pollution created in clouds and caused a sharp increase in global warming rates. "We've done some simulations with climate models, and they seem to be suggestive of at least three to four years acceleration of global warming," he adds.

Overall models suggest that if we remove all the world's polluting aerosols, we can expect to see around 0.4 °C of additional warming, says Quaas. He acknowledges that we must improve air quality "because we cannot just accept people dying and ecosystems deteriorating". By doing so, we must also be prepared for this additional warming. But more work is needed, "because the current uncertainty is too large", he continues. Uncertainty in the figures is around 50%, according to Quaas, which means that slashing aerosol pollution could cause anywhere from 0.2 to 0.6 °C of additional warming.

Haywood says that while current models do a relatively good job of representing how aerosols reduce cloud droplet size and increase cloud brightness, they do a poor job of showing how aerosols effect cloud fraction.

Cloud manipulation

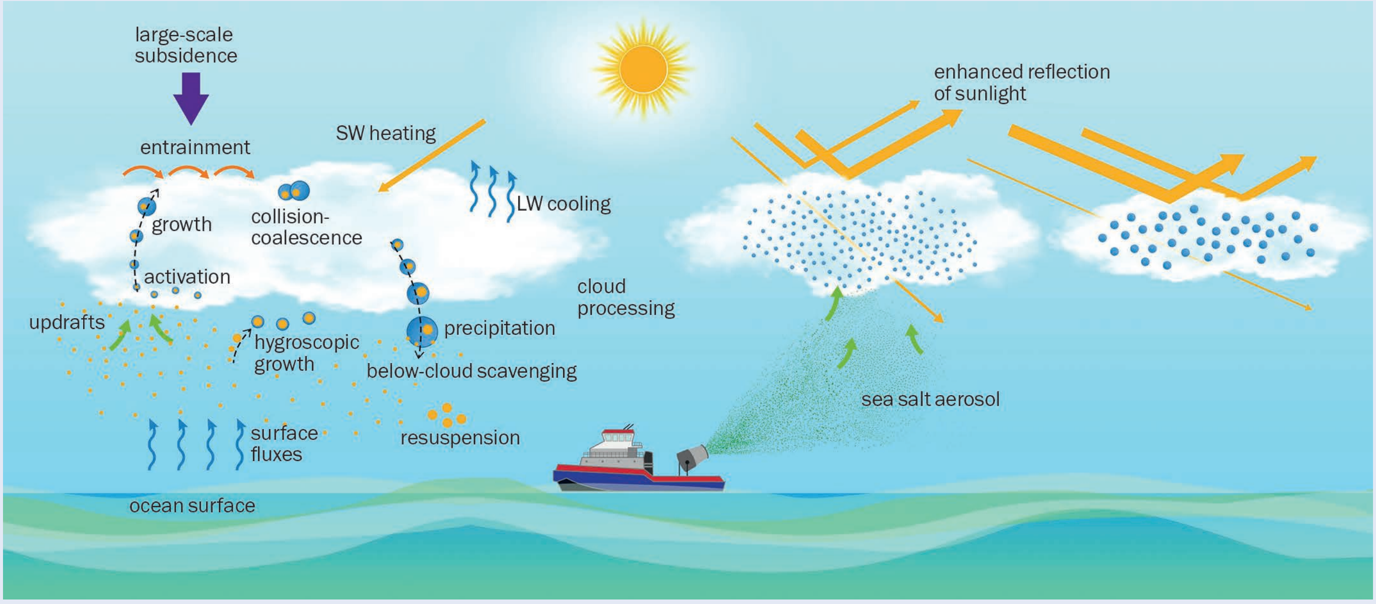
The fact that aerosols cool the planet by brightening clouds opens an obvious question: could we use aerosols to deliberately manipulate cloud properties to mitigate climate change?

"There are more recent proposals to combat the impacts, or the worst of the impacts of global warming, through either stratospheric aerosol injection or marine cloud brightening, but they are really in their infancy and need to be understood an awful lot better before any kind of deployment can even be considered," says Haywood. "You need to know not just how the aerosols might interact with clouds, but also how the cloud then interacts with the climate system and the [atmospheric] teleconnections that changing cloud properties can induce."

Haywood recently co-authored a position paper, together with a group of atmospheric scientists in the US and Europe, arguing that a programme of physical science research is needed to evaluate the viability and risks of marine cloud brightening (*Sci. Adv.* **10** eadi8594).

A proposed form of solar radiation management, known as marine cloud brightening, would involve injecting aerosol particles into low-level, liquid marine

4 Marine cloud brightening



In this proposal, ship-based generators would ingest seawater and produce fine aerosol haze droplets with an equivalent dry diameter of approximately 50 nm. In optimal conditions, many of these haze droplets would be lofted into the cloud by updrafts, where they would modify cloud microphysics processes, such as increasing droplet number concentrations, suppressing rain formation, and extending the coverage and lifetime of the clouds. At the cloud scale, the degree of cloud brightening and surface cooling would depend on how effectively the droplet number concentrations can be increased, droplet sizes reduced, and cloud amount and lifetime increased.

clouds – mainly those covering large areas of subtropical oceans – to increase their reflectiveness (figure 4).

Most marine cloud-brightening proposals suggest using saltwater spray as the aerosol. In theory, when sprayed into the air the saltwater would evaporate to produce fine haze particles, which would then be transported by air currents into cloud. Once in the clouds, these particles would increase the number of cloud droplets, and so increase cloud brightness.

Graham Feingold, research scientist at NOAA's Chemical Laboratory in Boulder, Colorado, says that there are still unanswered questions on everything from particle generation to their interactions with clouds, and the overall impact on cloud brightness and atmospheric systems.

Feingold, an author on the position paper, says that a key challenge lies in predicting how additional particles will affect cloud properties. For instance, while more haze droplets might theoretically brighten clouds, it could also lead to unintended effects like increased evaporation or rain, which could even reduce cloud coverage.

Another difficult challenge is the inconstancy of cloud response to aerosols. "Ship traffic is really regular," explains Feingold, "but if you look at satellite imagery on a daily basis in a certain area, sometimes you see really clear, beautiful ship tracks and other times you don't – and the ship traffic hasn't changed but the meteorology has." This variability depends on cloud susceptibility to aerosols, which is influenced by meteorological conditions.

And even if cloud systems that respond well to marine cloud brightening are identified, it would not be sensible to repeatedly target them. "Seeding the same area persistently could have some really serious knock-on effects on regional temperature and rainfall," says Feingold.

Essentially, aerosol injections into the same area day after day would create localized radiative cooling, which would impact regional climate patterns. This highlights the ethical concerns with cloud brightening, as such effects could benefit some regions while negatively impacting others.

Addressing many of these questions requires significant advances in current climate models, so that the entire process – from the effects of aerosols on cloud microphysics through to the larger impact on clouds and then global climate circulations – can be accurately simulated. Bridging these knowledge gaps will require controlled field experiments, such as aerosol releases from point sources in areas of interest, while taking observational data using tools like drones, aeroplanes and satellites. Such experiments would help scientists get a "handle on this connection between emitted particles and brightening", says Feingold.

But physicists can only do so much. "We are not trying to push marine cloud brightening, we are trying to understand it," says Feingold. He argues that a parallel effort to discuss the governance of marine cloud brightening is also needed.

In recent years, much progress has been made in determining the impact of clouds, when it comes to regulating our planet's climate, and their importance in climate modelling. "While major advances in the understanding of cloud processes have increased the level of confidence and decreased the uncertainty range for the cloud feedback by about 50% compared to AR5 [IPCC report], clouds remain the largest contribution to overall uncertainty in climate feedbacks (high confidence)," states the IPCC's latest Assessment Report (AR6), published in 2021. Physicists and atmospheric scientists will continue to study how cloud systems will respond to our ever-changing climate and planet, but ultimately, it is wider society that needs to decide the way forward.

Reviews

Setting the scale

Tom Tierney reviews *Celsius: a Life and Death by Degrees* by Ian Hembrow

Courtesy: Museum Gustavianum, photograph by Mikael Wallerstedt

Object of precision The original Delisle thermometer that Celsius marked with his 100-degree scale.

Celsius: a Life and Death by Degrees
Ian Hembrow
2024 History Press
304pp £25hb

On Christmas Day in 1741, when Swedish scientist Anders Celsius first noted down the temperature in his Uppsala observatory using his own 100-point – or "Centi-grade" – scale, he would have had no idea that this was to be his greatest legacy.

A newly published, engrossing biography – *Celsius: a Life and Death by Degrees* – by Ian Hembrow, tells the life story of the man whose name is so well known. The book reveals the broader scope of Celsius' scientific contributions beyond the famous centigrade scale, as well as highlighting the collaborative nature of scientific endeavours, and drawing parallels to modern scientific challenges such as climate change.

That winter, Celsius, who was at the time in his early 40s, was making repeated measurements of the period of a pendulum – the time it takes for one complete swing back and forth. He could use that to calculate a precise value for the acceleration caused by gravity, and he was expecting to find that value to be very slightly greater in Sweden than at more southern latitudes. That would provide further evidence for the flattening of the Earth at the poles, something that Celsius had already helped establish. But it required great precision in the experimental work, and Celsius was worried that the length (and therefore the period) of the pendulum would vary slightly with temperature. He had started these measurements that summer and now it was winter, which meant he had lit a fire to hopefully match the summer temperatures. But would that suffice?

Throughout his career, Celsius had been a champion of precise measurement, and he knew that temperature readings were often far from precise. He was using a thermometer sent to him by the French astronomer Joseph-Nicolas Delisle, with a design based on the expansion of mercury. That method was promising, but Delisle used a scale that took the boiling point of water and the temperature in the basement of his home in Paris as its two reference points. Celsius was unconvinced by the latter. So he made adaptations (which are still there to be seen in an Uppsala museum), twisting wire around the glass tube at the boiling and freezing points of water, and dividing the length between the two into 100 even steps.

The centigrade scale, later renamed in his honour, was born. In his first recorded readings he found the temperature in the pleasantly heated room to be a little over 80 degrees! Following Delisle's system – perhaps noting that this would mean he had to do less work with negative numbers – he placed the boiling point at zero on his scale, and the freezing point at 100. It was some years later, after his death, that a scientific consensus flipped the scale on its head to create the version we know so well today.

Hembrow does a great job at placing this moment in the context of the time, and within the context of Celsius' life. He spends considerable time recounting the scientist's many other achievements and the milestones of his fascinating life.

The expedition that had established the flattening of the Earth at the poles was the culmination of a four-year grand tour that Celsius had undertaken in his early 30s. Already a professor at Uppsala University, in the town where he had grown up in an academic family, he travelled to Germany, Italy, France and London. There he saw at first hand the great observatories that he had heard of and established links with the people who had built and maintained them.

On his extended travels he became a respected figure in the world of science and so it was no surprise when he was selected to join a French expedition to the Arctic in 1736, led by mathematician Pierre Louis Maupertuis, to measure a degree of latitude. Isaac Newton had died just a few years before and his ideas relating to gravitation were not yet universally accepted. If it could be shown that the distance between two lines of latitude was greater near the poles than on the equator, that would prove Newton right about the shape of the Earth, a key prediction of his theory of gravitation.

After a period of time in London equipping themselves with the precision instruments, the team started the arduous journey to the Far North. Once there they had to survey the land – a task made challenging by the thick forest and hilly territory. They selected nine mountains to climb with their heavy equipment, felling dozens of trees on each and then creating a sturdy wooden marker on each peak. This allowed them to create a network of triangles stretching north, with each point visible from the two next to it. But they also needed one straight line of known length to complete their calculations. With his local knowledge, Celsius knew that this could only be achieved on the frozen surface of the Torne river – and that it would involve several weeks of living on the ice, working largely in the dark and the intense

Courtesy: Museum Gustavianum, photograph by Mikael Wallerstedt

Man of scale Anders Celsius, painted by Magnus Bratt. Copy of Olof Arenius's portrait of Celsius, which is at the Astronomical Observatory in Uppsala, Sweden.

cold, and sleeping in tents.

After months of hardship, the calculations were complete and showed that the length of one degree of latitude in the Arctic was almost 1.5 km longer than the equivalent value in France. The spheroid shape of the Earth had been established.

Of course, not everybody accepted the result. Politics and personalities got in the way. Hembrow uses this as the starting point for a polemic about aspects of modern science and climate change with which he ends his fine book. He argues that the painstaking work carried out by an international team, willing to share ideas and learn from each other, provides us with a template by which modern problems must be addressed.

Considering how often we use his name, most of us know little about Celsius. This book helps to address that deficit. It is a very enjoyable and accessible read and would appeal, I think, to anybody with an interest in the history of science.

Tom Tierney is a physics teacher and writer, based near Dublin, Ireland, e-mail tttierney@yahoo.com

Careers

From blackboard to boardroom

iStock/Drazen Zigic

Level up Most physics students aren't thinking about starting a business, but university can be the perfect time to take advantage of additional training and funding opportunities for entrepreneurs.

Got a great idea for a new technology but don't know how to turn it into a product? Want a career in industry but find the world of business confusing? **Robert Phillips** shares his key tips and tricks for developing entrepreneurship skills

What does an idea need to change the world? Physics drives scientific advancements in healthcare, green energy, sustainable materials and many other applications. However, to bridge the gap between research and real-world applications, physicists need to be equipped with entrepreneurship skills.

Many students dream of using their knowledge and passion for physics to change the world, but when it comes to developing your own product, it can be hard to know where to start. That's where my job comes in – I have been teaching scientists and engineers entrepreneurship for more than 20 years.

Several of the world's most successful companies, including Sony, Texas Instruments, Intel and Tesla Motors, were founded by physicists, and there are many contemporary examples too. For example, Unitary, an AI company that identifies misinformation and deepfakes, was founded by Sasha Haco, who has a PhD in theoretical physics. In materials science, Aruna Zhuma is the co-founder of Global Graphene Group, which manufactures single layers of graphene oxide for use in electronics. Zhuma has nearly 500 patents, the second largest number of any inventor in the field.

In the last decade quantum technology, which encompasses computing, sensing and communications, has spawned hundreds of start-ups, often spun out from university research. This includes cybersecurity firm ID Quantique, super sensitive detectors from Single Quantum, and quantum computing from D-Wave. Overall, about 8–9% of students in the UK start businesses straight after they graduate, with just over half (58%) of these graduate entrepreneurs founding firms in their subject area.

However, even if you aren't planning to set up your own business, entrepreneurship skills will be important no matter what you do with your degree. If you work in industry you will need to spot trends, understand customers' needs and contribute to products and services. In universities, promotion often requires candidates to demonstrate "knowledge transfer", which means working with partners outside academia.

Taking your ideas to the next level

The first step of kick-starting your entrepreneurship journey is to evaluate your existing experience and goals. Do you already have an idea that you want to take forward, or just want to develop skills that will broaden your career options?

If you're exploring the possibilities of


Robert Phillips

Science meets business Researchers at the University of Manchester participating in an entrepreneurship training event.

entrepreneurship you should look for curricular modules at your university. These are normally tailored to those with no previous experience and cover topics such as opportunity spotting, market research, basic finance, team building and intellectual property. In addition, in the UK at least, many postgraduate centres for doctoral training (CDTs) now offer modules in business and entrepreneurship as part of their training programmes. These courses sometimes give students the opportunity to take part in live company projects, which are a great way to gain skills.

You should also look out for extracurricular opportunities, from speaker events and workshops to more intensive bootcamps, competitions and start-up weekends. There is no mark or grade for these events, so they allow students to take risks and experiment.

Like any kind of research, commercializing physics requires resources such as equipment and laboratory space. For early-stage founders, access to business incubators – organizations that provide shared facilities – is invaluable. You would use an incubator at a relatively early stage to finalize your product, and they can be found in many universities.

Accelerator programmes, which aim to fast-track your idea once you have a product ready and usually run for a defined length of time, can also be beneficial. For example, the University of Southampton has the Future Worlds Programme based in the physical sciences faculty. Outside academia, the European Space Agency has incubators for space technology ideas at locations throughout Europe, and the Institute of Physics also has workspace and an accelerator programme for recently graduated physicists and especially welcomes quantum technology businesses. The Science and Technology Facilities Council (STFC) CERN Business Incubation Centre focuses on high-energy physics ideas and grants access to equipment that would be otherwise unaffordable for a new start-up.

More accelerator programmes supporting physics ideas include Duality, which is a Chicago-based 12-month accelerator programme for quantum ideas; Quantum Delta NL, based in the Netherlands, which provides programmes and shared facilities for quantum research; and Techstars Industries of the Future, which has locations worldwide.

Securing your future

It's the multimillion-pound deals that make headlines but to get to that stage you will need to gain investors' confidence, securing smaller funds to take your idea forward step-by-step. For example, to protect your intellectual property with a patent, make a prototype or road test your technology.

Since early-stage businesses are high risk, this money is likely to come from grants and awards, with commercial investors such as venture capital or banks holding back until they see the idea can succeed. Funding can come from government agencies like the STFC in the UK, or US government scheme America's Seed Fund. These grants are for encouraging innovation, applied research and for finding disruptive new technology, and no return is expected. Early-stage commercial funding might come from organizations such as Seedcamp, and some accelerator programmes offer funding, or at least organize a "demo day" on completion where you can showcase your venture to potential investors.

While you're a student, you can take advantage of the venture competitions that run at many universities, where students pitch an idea to a panel of judges. The prizes can be significant, ranging from £10k to £100k, and often come with extra support such as lab space, mentoring and help filing patents. Some of these programmes are physics-specific, for example the Eli and Britt Harari Enterprise Award at the University of Manchester, which is sponsored by physics graduate Eli Harari (founder of SanDisc) awards funding for graphene-related ideas.

Finally, remember that physics innovations don't always happen in the lab. Theoretical physicist Stephen Wolfram founded Wolfram Research in 1988, which makes computational technology including the answer engine Wolfram Alpha.

Making the grade

There are many examples of students and recent graduates making a success from entrepreneurship. Wai Lau is a Manchester physics graduate who also has a master's of enterprise degree. He started a business focused on digital energy management, identifying energy waste, while learning about entrepreneurship. His business Cloud Enterprise has now branched out to a wider range of digital products and services.

Computational physics graduate Gregory Mead at Imperial College London started Musicmetric, which uses complex data analytics to keep track of and rank music artists and is used by music labels and artists. He was able to get funding from Imperial Innovations after making a prototype and Musicmetric was eventually bought by Apple.

AssestCool Thermal Metaphotonics technology cools overhead power lines – reducing power losses – using novel coatings. It entered the Venture Further competition at the University of Manchester and has now had a £2.25m investment from Gritstone Capital.

Entrepreneurship skills are being increasingly recognized as necessary for physics graduates. In the UK, the IOP Degree Accreditation Framework, the standard for physics degrees, expects students to have "business awareness, intellectual property, digital media and entrepreneurship skills".

Thinking about taking the leap into business can be daunting, but university is the ideal time to think about entrepreneurship. You have nothing to lose and plenty of support available.

Robert Phillips is a senior lecturer at the University of Manchester, UK. He has a PhD in biochemistry and now teaches entrepreneurship modules to scientists and engineers

Ask me anything: Dave Smith


DSIT

Dave Smith is the UK government's national technology adviser based in the Department for Science, Innovation and Technology (DSIT). In this role, he advises the government on technology policy and builds links with industry and academia. After completing a PhD in physics at the University of Warwick, Smith worked in several roles in the technology industry. Before being appointed to his current post, he was the director of central technology at Rolls-Royce.

What skills do you use every day in your job?

Being sociable may sound trivial, but collaboration has been vital in all the roles I have had, especially now that I work in such a large and complex organization. No single person has the answer to the challenges we face (although occasionally you meet people who think they do). By working together, humans accomplish amazing things.

A key feature of seniority – managerial seniority anyway – is juggling multiple topics each day; from the bogs and bike sheds; to finance; to investment decisions; to technical review; to people – it has few limits. With the fast pace of our work, especially with a new government coming in, we need to quickly adapt and reprioritize. I have several teams reporting to me at any one time, so it's important to allocate time and focus effectively – this is a core skill I'm constantly working on.

What do you like best and least about your job?

Even though I am officially part of the Department for Science, Innovation and Technology (DSIT), as the national technology adviser, I love that my work spans all government departments. We have a fantastic network of departmental chief scientific advisers (CSAs), led by Dame Angela McLean, the government's chief scientific adviser. This network lets me see the amazing work my colleagues are doing. Anyone who has worked in government knows how tricky it can sometimes be to work through the barriers between departments. But the CSA network is open, allowing us to have honest and productive conversations, which is crucial for effective collaboration.

I'm also incredibly lucky to have a wonderful, efficient and supportive private office. They help me connect with the right people across government to push our key projects forward.

> Do the right things to make yourself useful in the first half of your career, then the second half will look after itself

What do you know today, that you wish you knew when you were starting out in your career?

I don't spend time on regrets, but I do try to learn. Learning is part of the journey and the joy, so I am not sure that I would give my younger self any advice. There have been big highs and deep lows but it has turned out ok so far. I have had three career plans in my life; they made me feel secure, but I didn't complete any of them because something more interesting cropped up. Since then, I have stopped having plans.

I would say two things to others, however. The first is advice that was given to me, which is to do the right things to make yourself useful in the first half of your career, then the second half will look after itself – don't chase glory, just get good. The second is that whilst some might dismiss diversity as a buzzword, I see it as crucial to success, so value a wide range of views and skills when forming teams.

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Pasta, chimps and squirting plants

Michael Banks picks his favourite stories and quotes from the weird and wonderful world of physics

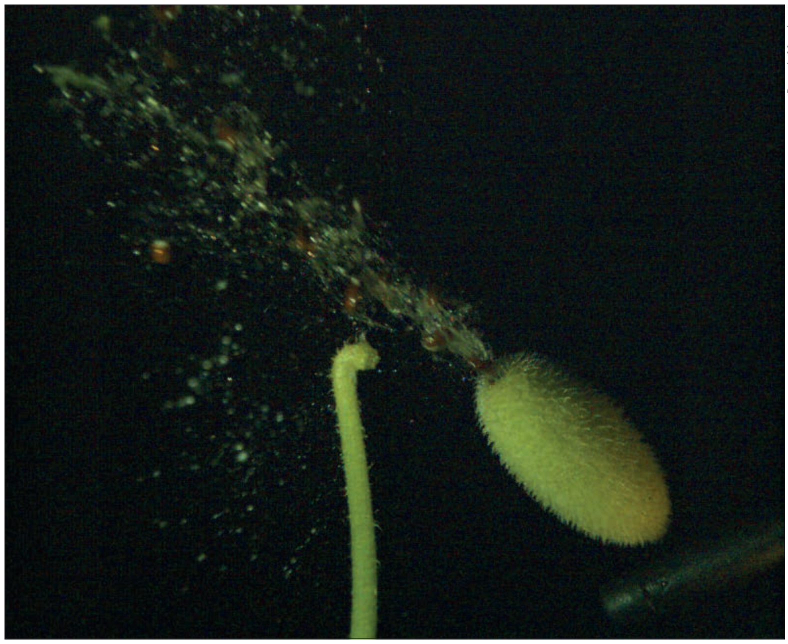
The world's thinnest known pasta is said to be *su filindeu* – or "threads of God". Barely 0.4 mm in diameter, it's hand-made on the Italian island of Sardinia. But researchers in the UK have now smashed that record by creating spaghetti just 372 nm across (*Nanoscale Adv.* 10.1039/D4NA00601A). The "nanopasta", as it's dubbed, is made by pulling threads of flour through the tip of a needle using an electric charge. "To make spaghetti, you push a mixture of water and flour through metal holes," says Adam Clancy from University College London (UCL). "We did the same except we pulled our flour mixture through with an electrical charge." While each individual strand is too thin to see directly, the researchers used the threads to create a mat of nanofibres about 2 cm across. The team is now investigating how the starch-based nanofibres could be used for medical purposes such as wound dressing, for scaffolds in tissue regrowth and even in drug delivery. But don't expect to see nanopasta hitting the supermarket shelves anytime soon. "I don't think it's useful as pasta, sadly, as it would overcook in less than a second, before you could take it out of the pan," says UCL materials scientist Gareth Williams.

Chimp Shakespeare

According to the infinite monkeys theorem, a monkey randomly pressing keys on a typewriter for an infinite amount of time would eventually type out the complete works of William Shakespeare purely by chance. Yet analysis by two mathematicians in Australia has found that even a troop might not have time to do so within the supposed timeframe of the universe (*Franklin Open* **9** 100171). The researchers came to their conclusion after creating a computational model that assumed a constant chimpanzee population of 200 000, each typing at one key per second until the end of the universe in about 10^{100} years. If that is true, there'd be only a 5% chance a single monkey would type "bananas" within its own lifetime of just over 30 years. But even all the chimps feverishly typing away couldn't produce Shakespeare's entire works (coming in at over 850 000 words) before the universe ends. "It is not plausible that, even with improved typing speeds or an increase in chimpanzee populations, monkey labour will ever be a viable tool for developing non-trivial written works," the authors conclude, adding that while the infinite monkeys theorem is true, it is also "somewhat misleading", or in reality it's "not to be".

Squirting cucumbers

The plant kingdom is full of intriguing ways to distribute seeds such as the dandelion pappus effortlessly drifting on air currents. Not to be outdone, the squirting cucumber (*Ecballium elaterium*), which is native to the Mediterranean and is often regarded as a weed, has its own unique way of ejecting seeds. When ripe, the ovoid-shaped fruits detach from the stem and as it does so explosively ejects seeds in a high-pressure jet of mucilage. The process, which lasts just 30 ms, launches the seeds at more than 20 m/s with some landing 10 m away. Researchers in the UK have, for the first time, revealed the mechanism behind the squirt by using high-speed imaging and mathematical modelling (*Proc. Natl Acad. Sci.* **121** e2410420121). The researchers found that in the weeks leading up to the ejection, fluid builds up inside the fruits so they become pressurized. Then just before seed dispersal, some of this fluid moves from the fruit to the stem, making it longer and stiffer. This process crucially causes the fruit to rotate from being vertical to close to an angle of 45°, improving the launch angle for the seeds. During the first milliseconds of ejection, the tip of the stem holding the fruit then recoils away causing the pod to counter-rotate and detach. As it does so, the pressure inside the fruit causes the seeds to eject at high speed. By changing parameters in the model, such as the stiffness of the stem, reveals that the mechanism has been fine-tuned to ensure optimal seed dispersal.



Derek Moulton

Quick fire round Just before launch, the fruit of the squirting cucumber rotates from being vertical to close to an angle of 45°, improving the launch angle for the seeds.

Whoever did move Skynet-1A did us few favours

Space consultant **Stuart Eves** outlines how the UK's oldest satellite, which was launched in 1969, was recently moved from its original location above Africa to a new position some 36 000 km above the Americas, but no-one knows who did it, when it was done or why. (Source: BBC News)

I don't think space travel, or space generally, should be for the elites

British astronaut **Rosemary Coogan**, who is set to be deployed on a six-month mission to the International Space Station before 2030, says she doesn't "envisage a future where we have permanent colonies" on other planets. (Source: *Guardian*)

Michael Banks is news editor of *Physics World*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