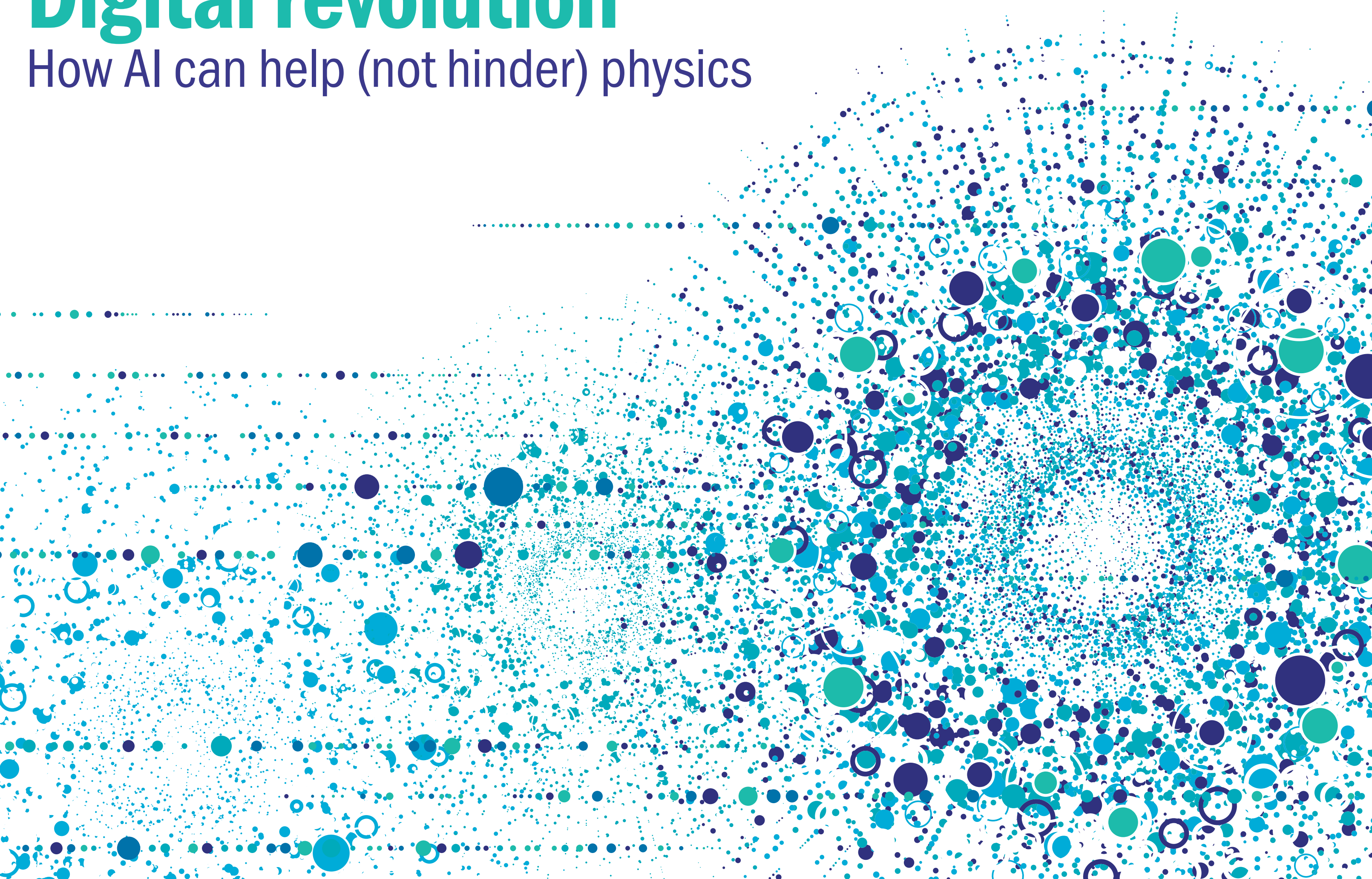
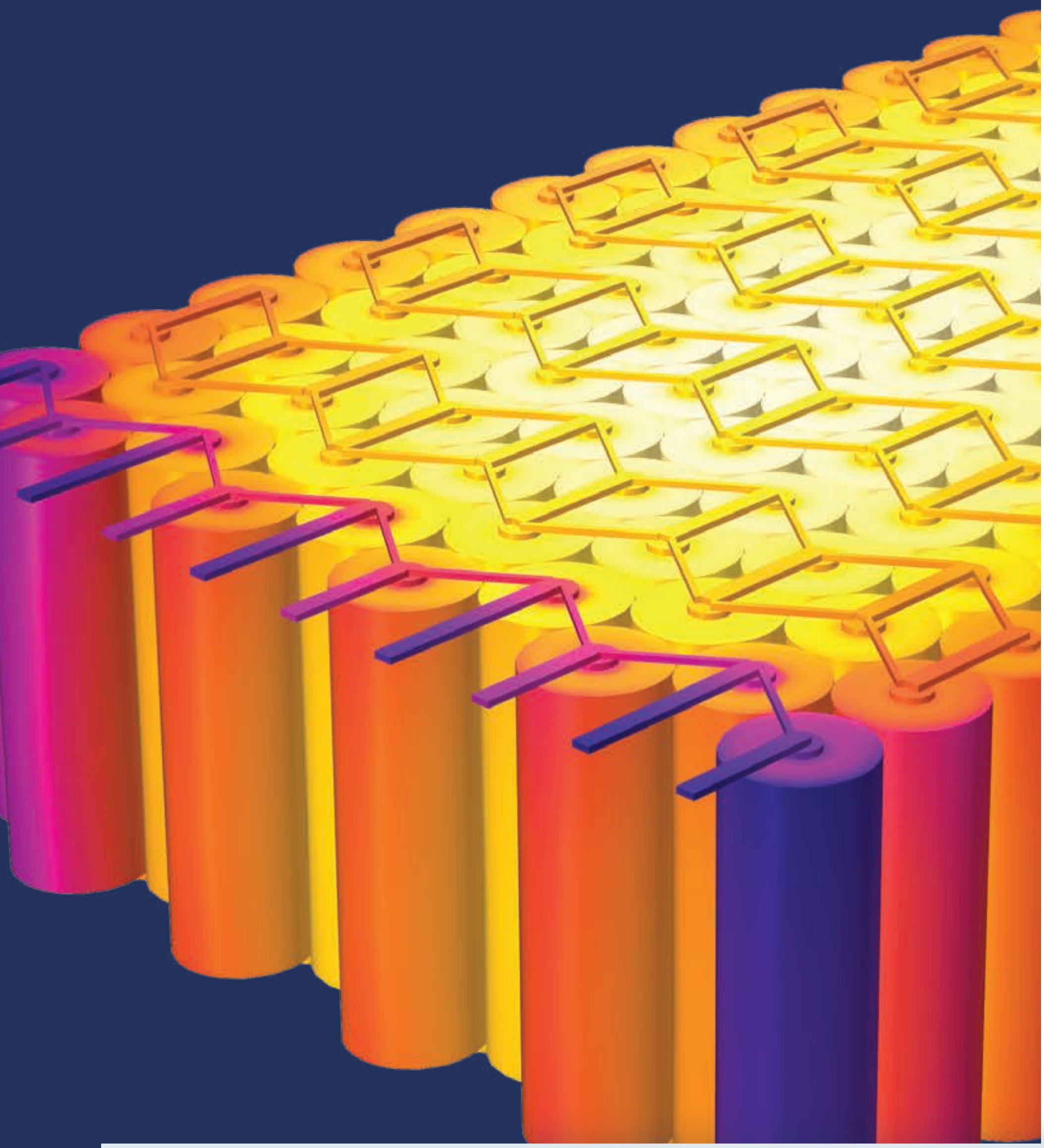
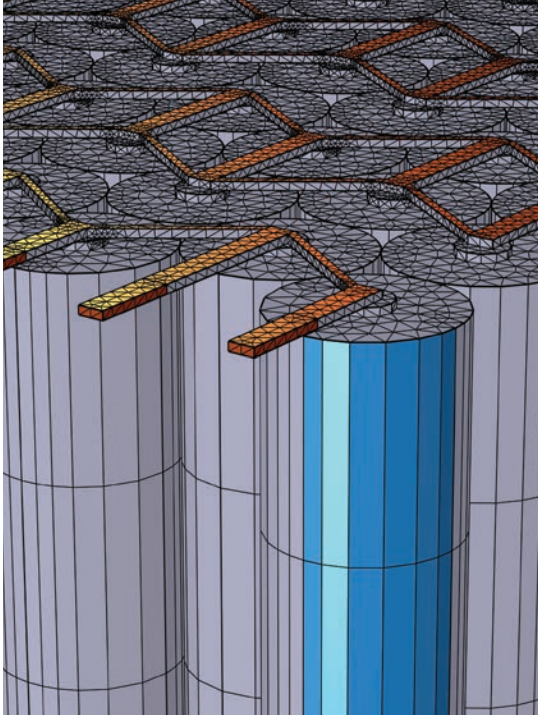
physicsworld
September 2025

**Cosmic clashes** The fight between dark matter and MOND
**Outreach journey** How Big Manny makes science go boom
**Perceptive thinking** Your favourite physics metaphors

# Digital revolution
## How AI can help (not hinder) physics

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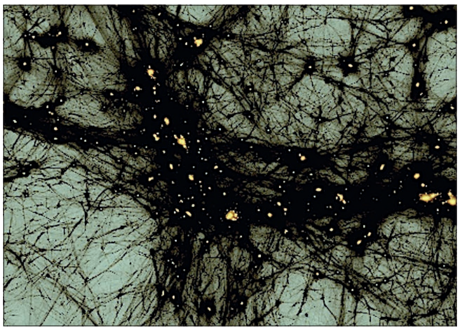
physicsworld
Volume 38 No 9

*Physics World* editors discuss their highlights of the September issue



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*Physics World* is published monthly as 12 issues per annual volume by IOP Publishing Ltd, No.2 The Distillery, Glassfields, Avon Street, Bristol, BS2 0GR, UK

# News & Analysis

## Einstein Telescope set for site decision

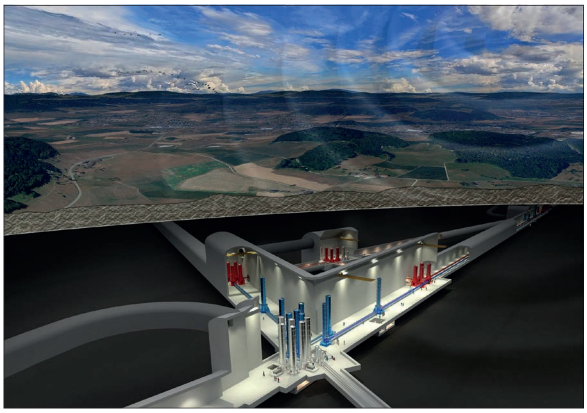
**Ten years after the first gravitational waves were detected, members of the €2bn Einstein Telescope collaboration are narrowing down the location and design for what would be a third-generation gravitational-wave detector. Senne Starckx reports on progress**

A decade ago, on 14 September 2015, the twin detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Hanford, Washington, and Livingston, Louisiana, finally detected a gravitational wave. The LIGO detectors – two L-shaped laser interferometers with 4 km-long arms – had measured tiny differences in laser beams bouncing off mirrors at the end of each arm. The variations in the length of the arms, caused by the presence of a gravitational wave, were converted into the now famous audible "chirp signal", which indicated the final approach between two merging black holes.

Since that historic detection, which led to the 2017 Nobel Prize for Physics, the LIGO detectors, together with VIRGO in Italy, have measured several hundred gravitational waves – from mergers of black holes to neutron-star collisions. More recently, they have been joined by the KAGRA detector in Japan, which is located some 200 m underground, shielding it from vibrations and environmental noise.

Yet the current number of gravitational waves could be dwarfed by what the planned Einstein Telescope (ET) would measure. This European-led, third-generation gravitational-wave detector would be built several hundred metres underground and be at least 10 times more sensitive than its second-generation counterparts including KAGRA. Capable of "listening" to a thousand times larger volume of the universe, the new detector would be able to spot many more sources of gravitational waves. In fact, the ET will be able to gather in a day what took LIGO and VIRGO took a decade to collect.

The ET is designed to operate in two frequency domains. The low-frequency regime – 2–40 Hz – is below current detectors' capabilities and will let the ET pick up waves from more massive black holes. The high-frequency domain, on the other hand, would operate from 40 Hz to 10 kHz and detect a wide variety of astrophysical sources, including merging black holes and other high-energy events. The detected signals from waves would also be much longer with the ET, lasting for hours. This would allow physicists to "tune in" much earlier as black holes or neutron stars approach each other.




**Deep underground** One design for the Einstein Telescope calls for twin "L" detectors, where both arms are 15 km long and the detectors are located far from each other, to provide a way to locate the source of gravitational waves.

### Location, location, location

But all that is still a pipe dream, because the ET, which has a price tag of €2bn, is not yet fully funded and is unlikely to be ready until 2035 at the earliest. The precise costs will depend on the final location of the experiment, which is still up for grabs.

Three regions are vying to host the facility: the Italian island of Sardinia, the Belgian-German-Dutch border region and the German state of Saxony. Each candidate is currently investigating the suitability of its preferred site (see box), the results of which will be published in a "bid book" by the end of 2026. The winning site will be picked in 2027 with construction beginning shortly after.

Other factors that will dictate where the ET is built include logistics in the host region, the presence of companies and research institutes (to build and exploit the facility) and government support. With the ET offering high-quality jobs, economic return, scientific appeal and prestige, that could give the German-Belgian-Dutch candidacy the edge given the three nations could share the cost.

Another major factor is the design of the ET. One proposal is to build it as an equilateral triangle with each side being 10 km. The other is a twin L-shaped design where both arms are 15 km long and each detector located far from each other. The latter design is similar to the two LIGO over-ground detectors, which are 3000 km apart. If the "2L design" is chosen, the detector would then be built at two of the three competing sites.

The 2L design is being investigated by all three sites, but those behind the Sardinia proposal strongly favour this approach. "With the detectors properly oriented relative to each other, this design could outperform the triangular design across all key scientific objectives," claims Domenico D'Urso, scientific director of the Italian candidacy. He points to a study by the ET collaboration in 2023 that investigated the impact of the ET design on its scientific goals. "The 2L design enables, for example, more precise localization of gravitational wave sources, enhancing sky-position reconstruction," he says. "And it provides superior overall sensitivity."

Localization is important for multimessenger astronomy. In other words, if a gravitational-wave source can be located quickly and precisely in the sky, other telescopes can be pointed towards it to observe any eventual light or other electromagnetic (EM) signals. This is what happened after LIGO detected a gravitational wave on 17 August 2017, originating from a neutron star collision. Dozens of ground- and space-based satellites were able to pick up a gamma-ray burst and the subsequent EM afterglow.

The triangle design, however, is

### Where could the next-generation Einstein Telescope be built?

Three sites are vying to host the Einstein Telescope (ET), with each offering various geological advantages. Lausitz in Saxony benefits from being a former coal-mining area. "Because of this mining past, the subsurface was mapped in great detail decades ago," says Günther Hasinger, founding director of the German Center for Astrophysics, which is currently being built in Lausitz and would house the ET if picked. The granite formation in Lausitz is also suitable for a tunnel complex because the rock is relatively dry. Not much water would need to be pumped away, causing less vibration.

Thanks to the former lead, zinc and silver mine of Sos Enattos, meanwhile, the subsurface near Nuoro in Sardinia – another potential location for the ET – is also well known. The island is on a very stable, tectonic microplate, making it seismically quiet. Above ground, the area is undeveloped and sparsely populated, further shielding the experiment from noise.

The third ET candidate, lying near the point where Belgium, Germany and the Netherlands meet, also has a hard subsurface, which is needed for the tunnels. It is topped by a softer, clay-like layer that would dampen vibrations from traffic and industry. "We are busy investigating the suitability of the subsurface and the damping capacity of the top layer," says Wim Walk of the Dutch Center for Subatomic Physics (Nikhef), which is co-ordinating the candidacy for this location. "That research requires a lot of work, because the subsurface here has not yet been properly mapped."

favoured by the Belgian-German-Dutch consortium. It would be the Earth equivalent to the European Space Agency's planned LISA space-based gravitational-waves detector, which will consist of three spacecraft in a triangle configuration that is set for launch in 2035, the same year that the ET could open. LISA would detect gravitational waves with even much lower frequency, coming, for example, from mergers of supermassive black holes.

While the Earth-based triangle design would not be able to locate the source as precisely, it would – unlike the 2L design – be able to do "null stream" measurements. These would yield a clearer picture of the noise from the environment and the detector itself, including "glitches", which are bursts of noise that overlap with gravitational-wave signals. "With a non-stop influx of gravitational waves but also of noise and glitches, we need some form of automatic clean-up of the data," says Jan Harms, a physicist at the Gran Sasso Science Institute in Italy and member of the scientific ET collaboration. "The null stream could provide that."

However, it is not clear if that null stream would be a fundamental advantage for data analysis, with Harms and colleagues thinking more work is needed. "For example, different forms of noise could be connected to each other, which would compromise the null stream," he says. The problem is also that a detector with a null stream has not yet been realized. And that applies to the triangle design in general. "While the 2L design is well established in the scientific community," adds D'Urso.

Backers of the triangle design see the ET as being part of a wider, global network of third-generation detectors, where the localization argument no longer matters. Indeed, the US already has plans for an above-ground successor to LIGO. Known as the Cosmic Explorer, it would feature two L-shaped detectors with arm lengths of up to 40 km. But with US politics in turmoil, it is questionable how realistic these plans are.

Matthew Evans, a physicist at the Massachusetts Institute of Technology and member of the LIGO collaboration, recognizes the "network argument". "I think that the global gravitational waves community are double counting in some sense," he says. Yet for Evans it is all about the exciting discoveries that could be made with a next-generation gravitational-wave detector. "The best science will be done with ET as 2Ls," he says.

**Senne Starckx** is a freelance science writer based in Belgium/Flanders

**Space**

# TRACERS 'magnetic cusp' mission launches

**NASA has successfully launched a mission to explore the interactions between the Sun's and Earth's magnetic fields. The Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) craft was sent into low-Earth orbit on 23 July from Vandenberg Space Force Base in California by a SpaceX Falcon 9 rocket. Following a month of calibration, the twin-satellite mission is expected to operate for a year.**

**The spacecraft will observe particles and electromagnetic fields in the Earth's northern magnetic "cusp region", which encircles the North Pole where the Earth's magnetic field lines curve down toward Earth. This unique vantage point allows researchers to study how magnetic reconnection – when field lines connect and explosively reconfigure – affects the space environment. Such observations will help researchers understand how processes change over both space and time.**

SpaceX

**Practical impact** The TRACERS mission will observe particles and electromagnetic fields in the Earth's northern magnetic "cusp region" to shine a light on space weather.

**The two satellites will collect data from over 3000 cusp crossings during the year, with the information being used to understand space-weather phenomena, which can disrupt satellite operations, communications and power grids on Earth. Each nearly identical octagonal satellite – weighing less than 200 kg each – features six instruments including magnetomers, electric-field instruments and devices to measure the energy of ions and electrons in plasma around the spacecraft. It will operate in a Sun-synchronous orbit about 590 km above ground, with the satellites following one behind the other in close separation, passing through regions of space at least 10 seconds apart.**

**"TRACERS is an exciting mission," says Stephen Fuselier from the Southwest Research Institute in Texas, who is the mission's deputy principal investigator. "The data from that single pass through the cusp were amazing. We can't wait to get the data from thousands of cusp passes."**

**Michael Banks**

People

# Michele Dougherty named next Astronomer Royal

**The space scientist Michele Dougherty from Imperial College London has been appointed the next Astronomer Royal – the first woman to hold the position. She will succeed the University of Cambridge cosmologist Martin Rees, who has held the role for the past three decades.**

**The title of Astronomer Royal dates back to the creation of the Royal Observatory in Greenwich in 1675, when it mostly involved advising King Charles II on using the stars to improve navigation at sea. John Flamsteed from Derby was the first Astronomer Royal and Dougherty becomes the 16th person to hold the role.**

**Acting as the official adviser to King Charles III on astronomical matters, Dougherty will still continue with her Imperial job as well as being executive chair of the Science and Technology Facilities Council. She is also the next president of the Institute of Physics, a two-year position she will take up in October.**


**Leading light** Michele Dougherty succeeds Martin Rees as Astronomer Royal.

**After gaining a PhD in 1988 from the University of Natal in South Africa, Dougherty moved to Imperial in 1991, where she was head of physics from 2018 until 2024. She has been principal investigator of the magnetometer on the Cassini-Huygens mission to Saturn and its moons and also for the magnetometer for the JUICE craft, which is currently travelling to Jupiter to study its three icy moons.**

**Dougherty was made Commander of the Order of the British Empire in the 2018 New Year Honours for "services to UK physical science research". She is also a Fellow of the Royal Society, who won its Hughes medal in 2008 for studying Saturn's moons and had a Royal Society Research Professorship from 2014 to 2019.**

**"I am absolutely delighted to be taking on the important role of Astronomer Royal," says Dougherty. "I look forward to engaging the general public in how exciting astronomy is, and how important it and its outcomes are to our everyday life."**

**Tom Grinyer, IOP group chief executive officer, offered his "warmest congratulations" to Dougherty. "As incoming president of the IOP and the first woman to hold this historic role [of Astronomer Royal], Dougherty is an inspirational ambassador for science and a role model for every young person who has gazed up at the stars and imagined a future in physics or astronomy."**

**Michael Banks**

Environment

# Scientists decry lack of climate data in developing regions

A shortage of data is hampering efforts to establish the role of climate change in extreme-weather events in the tropics and global south. That's the view of an international team of scientists, which claims the current situation is a "scientific injustice" and wants more investment in climate science and weather monitoring in poorer countries.

The researchers, who are part of World Weather Attribution, have made the call after analysing the role of climate change in an episode of torrential rain in June that triggered a landslide in Colombia. It killed 27 people and led to devastating floods in Venezuela that displaced thousands.

Their study reported that the Colombian Andes were unusually wet from April to June, while the part of Venezuela where the floods occurred experienced its five wettest days of the year. In the current climate, such weather events would be expected every 10 years in Colombia and every three years in Venezuela.


**Climate concerns** Torrential rain in late June triggered a landslide in Colombia that killed 27 people, while devastating floods in Venezuela displaced thousands.

According to the researchers, there is a high level of uncertainty in the study due to a lack of long-term observational data in the region and high uncertainties in global climate models when assessing the tropics. Colombia and Venezuela have complex tropical climates that are under-researched, with some data even suggesting that rainfall in the region is becoming less intense.

But the group says that the possibility of heavier rainfall linked to climate change should not be ruled out in the region, particularly on shorter, sub-daily timescales, which they could not investigate. They add that Colombia and Venezuela are almost certainly facing increased heatwave, drought and wildfire risk.

Mariam Zachariah at the Centre for Environmental Policy at Imperial College London, who was involved with the work, says that the combination of mountains, coasts, rainforests and complex-weather systems in many tropical countries means "rainfall is varied, intense and challenging to capture in climate models".

"Many countries with tropical climates have limited capacity to do climate science, meaning we don't have a good understanding of how they are being affected by climate change," says Zachariah. "Our recent study on the deadly floods in the Democratic Republic of Congo in May is another example. Once again, our results were inconclusive."

**Michael Allen**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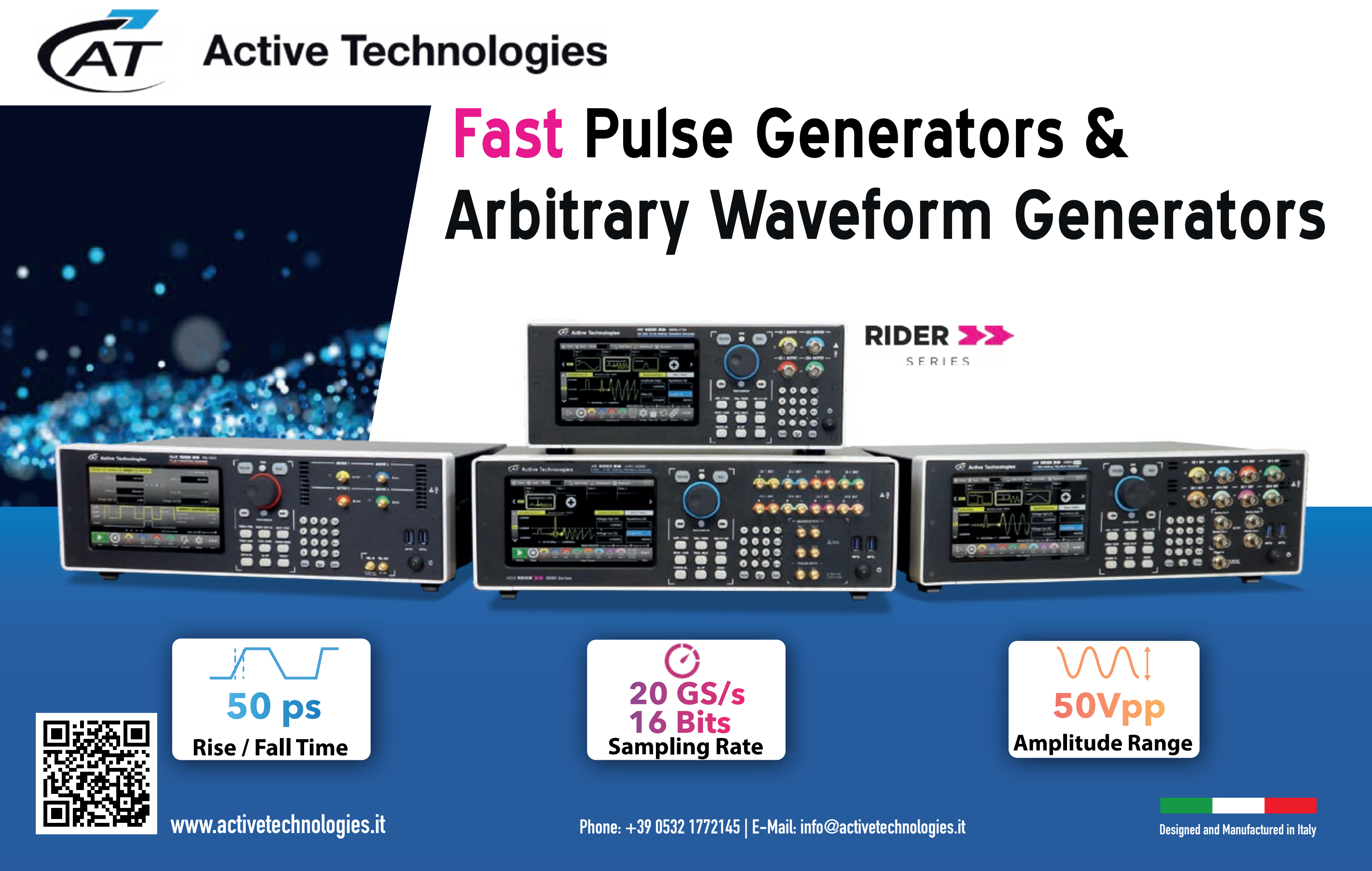
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# Research updates

# Baryon CP violation measured

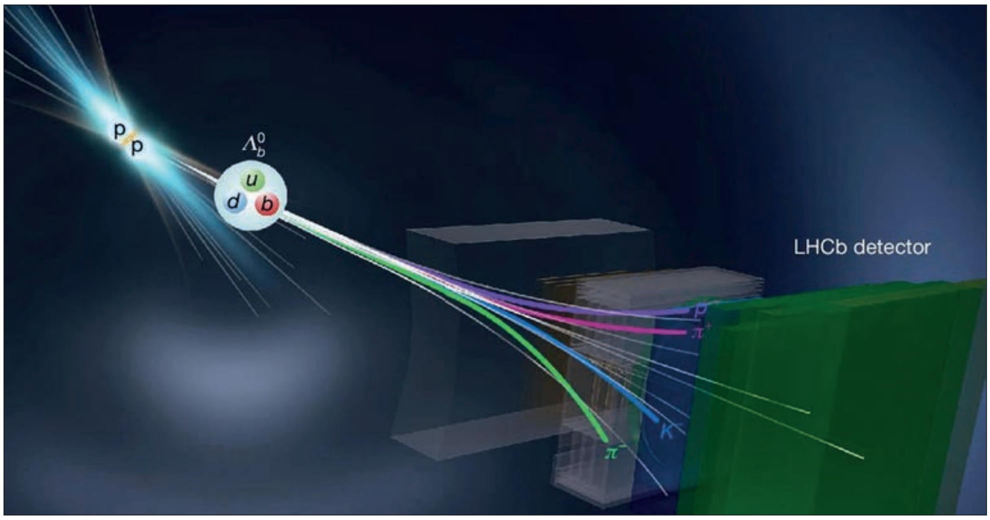
Result at CERN's LHCb experiment is consistent with the Standard Model, but could provide a path to new physics, as **Tim Wogan** reports

The first experimental evidence of charge–parity (CP) symmetry violation in baryons has been obtained by CERN's LHCb Collaboration. The result is consistent with the Standard Model of particle physics but could lead to constraints on theoretical attempts to extend the Standard Model to explain the excess of matter over antimatter in the universe (*Nature* **643** 1223).

Current models of cosmology say that the Big Bang produced a giant burst of matter and antimatter, the vast majority of which recombined and annihilated shortly afterwards. Today however, the universe appears to be made almost exclusively of matter with very little antimatter in evidence. This excess of matter is not explained by the Standard Model and its existence is an important mystery in physics.

In 1964, physicists in the US showed that the weak interaction violated CP symmetry, indicating that matter and antimatter could behave differently and it was suggested that, if amplified at very high mass scales in the early universe, CP violation could have induced the matter–antimatter asymmetry shortly after the Big Bang. Numerous observations of CP violation have subsequently been made in other mesonic systems and the phenomenon is now an accepted part of the Standard Model parametrized by the Cabibbo–Kobayashi–Maskawa (CKM) matrix. This describes the various probabilities of quarks of different generations changing into each other through the weak interaction – a process called mixing.

However, the CP violation produced through the CKM mechanism is a much smaller effect than would have been required to create the matter left over by the Big Bang. What is more, CP violation had never been observed in baryons (mostly





**Smashing result** Researchers at CERN's LHCb looked at the decays of beauty (or bottom) baryons and antibaryons that were produced in proton–proton collisions at the Large Hadron Collider during 2011–2018.

protons and neutrons). "Theoretically the prediction for baryon decay is very imprecise," says Xueting Yang of China's Peking University, who is a member of the LHCb collaboration. "It's much more difficult to calculate than the meson decays because there's some interaction with the strong force."

Given that baryons make up almost all the hadronic matter in the universe, it leaves open the slight possibility that the explanation might lie in some inconsistency between baryonic CP violation and the Standard Model prediction. In the new work, Yang and colleagues at LHCb looked at the decays of beauty (or bottom) baryons and antibaryons. These heavy cousins of neutrons contain an up quark, a down quark and a beauty quark and were produced in proton–proton collisions at the Large Hadron Collider in 2011–2018. The baryons and antibaryons can decay via multiple channels. In one, a baryon decays to a proton, a positive K-meson and a pair of pions – or, conversely, an antibaryon decays to an antiproton, a negative K-meson and a pair of pions.

CP violation should create an asymmetry between these processes, and the researchers looked for evidence of this asymmetry in the numbers of particles detected at different energies from all the collisions. The team found that the CP violation seen was consistent with the Standard Model and inconsistent with zero by 5.2σ. "The experimental result is more precise than what we can get from theory," says Yang. Other LHCb researchers scrutinized alternative decay channels of the beauty baryon: "Their measurement results are still consistent with CP symmetry…There should be CP violation also in their decay channels, but we don't have enough statistics to claim that the deviation is more than 5σ."

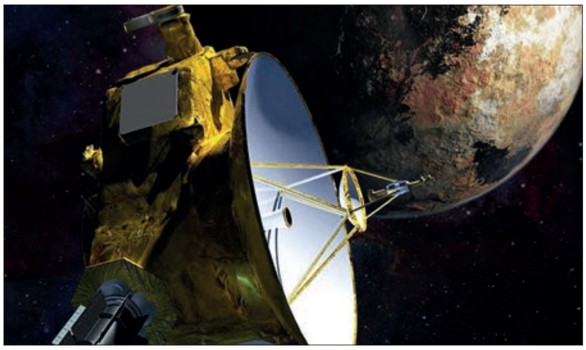
The current data do not rule out any extensions to the current Standard Model, adds Yang, simply because none of those extensions make precise predictions about the overall degree of CP violation expected in baryons. However, the LHC is now in its third run, and the researchers hope to acquire information on, for example, the intermediate particles involved in the decay: "We may be able to provide some measurements that are more comparable for theories and which can provide some constraints on the Standard Model predictions for CP violation," says Yang.

Astronomy

# Spacecraft can navigate using light from just two stars

An international team of researchers have shown that NASA's New Horizons spacecraft can navigate by measuring the parallax of just two stars. Using the new technique, they were able to determine the location and heading of the spacecraft using observations made from space and the Earth. The technique could one day be used by other spacecraft exploring the outermost regions of the solar system or even provide navigation for the first truly interstellar missions (*AJ* **170** 22).

New Horizons visited the Pluto system in 2015 and has now passed through the Kuiper Belt in the outermost solar system. Now, Tod Lauer from NOIRLab in the US and colleagues, who include legendary Queen guitarist Brian May, have created a navigation technique for the spacecraft by choosing two of the nearest stars for parallax measurements. These are Proxima Centauri, which is just 4.2 light–years away, and Wolf 359 at 7.9 light–years. On 23 April 2020, New Horizons imaged star-fields containing the two stars, while on Earth astronomers did the same.



Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

**Stars in their eyes** An international team determined the location and heading of NASA's New Horizons spacecraft using observations from space and the Earth.

At that time, New Horizons was 47.1 AU (seven billion kilometres) from Earth, as measured by NASA's Deep Space Network, but the intention was to replicate that distance determination using parallax. The 47.1 AU separation between Earth and New Horizons meant that each vantage point observed Proxima and Wolf 359 in a slightly different position relative to the background stars. This displacement is the parallax angle, which the observations showed to be 32.4 arcseconds for Proxima and 15.7 arcseconds for Wolf 359 at the time of measurement.

Edward Gomez, from the University of Cardiff, was able to image Proxima with Las Cumbres' telescope at Siding Spring in Australia. Meanwhile, Wolf 359 was observed by the University of Louisville's Manner Telescope at Mount Lemmon Observatory in Arizona. At the same time, New Horizons' Long Range Reconnaissance Imager (LORRI) took pictures of both stars, and all three observations were analysed using a 3D model of the stellar neighbourhood based on data from the European Space Agency's star-measuring Gaia mission.

By applying simple trigonometry using the parallax angle and the known distance to the stars, New Horizons position was calculated to within 0.27 AU, which is not especially useful for navigating towards a trans-Neptunian object, however, the project was more a proof-of-concept than an accurate determination of New Horizons' position and heading. The measurements were also able to ascertain New Horizon's heading to an accuracy of 0.4°, relative to the precise value derived from Deep Space Network signals.

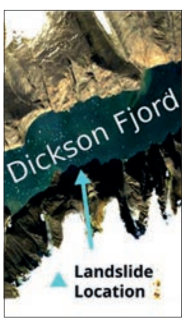
**Keith Cooper**

Geophysics

# Earth-shaking waves tracked back to Greenland mega-tsunamis

**Engineers at the University of Oxford, UK, have confirmed that a mysterious signal in 2023 that caused the Earth to shake every 90 seconds was caused by standing waves, or seiches, that formed after landslides triggered huge tsunamis in a narrow waterway off the coast of Greenland. Using satellite altimetry data from the Surface Water Ocean Topography (SWOT) mission, the team constructed the first images of the seiches, demonstrating that they originated from landslide-triggered mega-tsunamis in Dickson Fjord, Greenland. While events of this magnitude are rare, the team say that climate change is likely to increase their frequency (*Nat. Comms.* 16 4777).**

**In September and October 2023, seismic detectors around the world began picking up a mysterious signal that a year later was explained by seiches. Yet experimental evidence was lacking. To fill this gap, researchers used SWOT, which provides 2D measurements of sea surface height down to the centimetre across the entire globe, including hard-to-reach areas like fjords, rivers and estuaries. "By capturing such high-resolution images of sea-surface height at different time points following the two tsunamis, we could estimate how the water surface tilted during the wave – in other words, gauge the 'slope' of the seiche," says team co-leader Thomas Monahan. "It gave us an unprecedented view into the Dickson Fjord during the seiche events in September and October 2023."**




Thomas Monahan

**Shaky conclusion** Landslide-triggered mega-tsunamis in Dickson Fjord, Greenland, in 2023 caused the Earth to shake.

**The maps revealed clear cross-channel slopes with height differences of up to 2 m. Importantly, these slopes pointed in opposite directions, showing that water was moving backwards as well as forwards across the channel. To prove it was a seiche, they connected the slope measurements with ground-based seismic data that captured how the Earth's crust moved as the wave passed through it. "By combining these two very different kinds of observations, we were able to estimate the size of the seiches and their characteristics even during periods in which the satellite was not overhead," Monahan says.**

**The Oxford team's estimates suggest that the September seiche was initially 7.9 m tall, while the October one measured about 3.9 m. "That amount of water sloshing back and forth over a 10 km-section of fjord walls creates an enormous force," Monahan says. The September seiche, he adds, produced a force equivalent to 14 Saturn V rockets launching at once, around 500 GN. "[It] was literally enough to shake the entire Earth for days," he adds.**

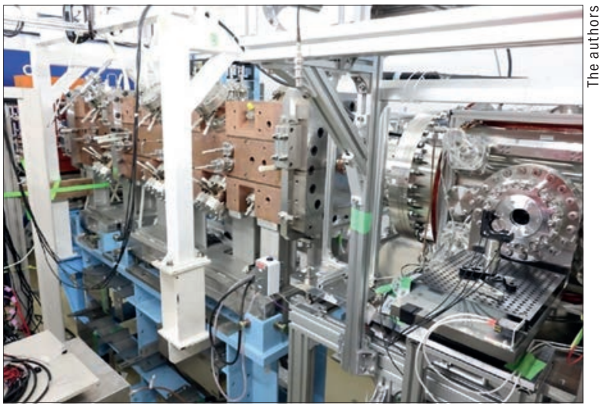
**Isabelle Dumé**

Particle physics

# High-quality muon beam holds promise for proposed collider

**Researchers in Japan have accelerated muons into the most precise, high-intensity beam to date, reaching energies as high as 100 keV. The achievement could enable next-generation experiments such as better measurements of the muon's anomalous magnetic moment, which could in turn potentially point to physics beyond the Standard Model (*Phys. Rev. Lett.* 134 245001).**

**Muons are around 200 times heavier than electrons and so radiate less energy as they travel in circles – meaning that a muon accelerator could, in principle, produce more energetic collisions than a conventional electron machine for a given energy input. However, working with muons comes with challenges. Although scientists can produce high-intensity muon beams from the decay of other sub-atomic particles known as pions, these beams must then be cooled to make the velocities of their constituent particles more uniform before they can be accelerated to collider speeds. And while this cooling process is relatively straightforward for electrons, for muons it is complicated by the particles' short lifetime of just 2 ms. Traditional cooling techniques (such as synchrotron radiation cooling or laser cooling) do not work.**


The authors

**One for the future** A muon accelerator could, in principle, produce more energetic collisions than a conventional electron machine for a given energy input.

**To overcome this problem, researchers at the MUon Science Facility (MUSE) in the Japan Proton Accelerator Research Complex have been developing a method that involves cooling positively-charged muons, or antimuons, down to thermal energies of 25 meV and then accelerating them using radio-frequency cavities.**

**In the new work, a team led by particle and nuclear physicist Shusei Kamioka directed antimuons (μ+) into a target made from a silica aerogel. This material has a unique property: a muon that stops inside gets re-emitted as a muonium atom (an exotic atom consisting of an antimuon and an electron) with very low thermal energy. The researchers then fired a laser beam at these muonium atoms to remove their electrons, thereby producing antimuons with much lower – and, crucially, far more uniform – velocities than was the case for the starting beam. Finally, they guided the slowed particles into a rf cavity, where an electric field accelerated them to an energy of 100 keV.**

**The final beam has an intensity of $2 \times 10^{-3}$ μ+ per pulse, and a measured emittance that is much lower (by a factor of 200 in the horizontal direction and about 400 vertically) than the starting beam. This represents a two-orders-of-magnitude reduction in the spread of positions and momenta in the beam and makes accelerating the muons more efficient, says Kamioka. According to the researchers, these improvements are important steps on the road to a muon collider.**

**Isabelle Dumé**

Biophysics

# Squid use Bragg reflectors in their skin to change colour

The mystery of how squid can change the colour of their skin has been solved. Using a microscopy technique known as holotomography, scientists at the Marine Biological Laboratory in Woods Hole, Massachusetts, have found that the tuneable optical properties of squid skin stem from winding columns of platelets in certain cells. These columns have sinusoidal-wave refractive index profiles, functioning as Bragg reflectors, that can selectively transmit and reflect light at specific wavelengths (*Science* **388** 1389).

The researchers examined the iridescent cells (iridophores) and cell clusters (splotches) responsible for producing colours in longfin inshore squids (*Doryteuthis pealeii*). To do this, they used holotomography, which creates 3D images of individual cells and cell clusters by measuring subtle changes in a light beam as it passes through a sample of tissue. The team could then map out changes in the sample's refractive index across different structures.


Shutterstock/MorphoBio

**Animal magic** How squid can change from transparent to colourful, while maintaining their spectral purity, is now clear.

The holotomography images revealed that the iridophores comprise stacked and winding columns of platelets made from a protein known as reflectin, which has a high refractive index, alternating with a low-refractive-index extracellular space. These Bragg-reflector-like structures allow tissue in the squid's mantle to switch from nearly transparent to vibrantly coloured and back again.

After using computer modelling to capture the optical properties of the squid cells, the researchers designed artificial nanomaterials inspired by the natural structures they discovered. While the squid iridophores only change their visible appearance in response to neurophysiological stimuli, the researchers' elastomeric composite materials (which contain both nanocolumnar metal oxide Bragg reflectors and nanostructured metal films) also change at infrared wavelengths.

Composite materials like these could have applications in adaptive camouflage or fabrics that adjust to hot and cold temperatures.

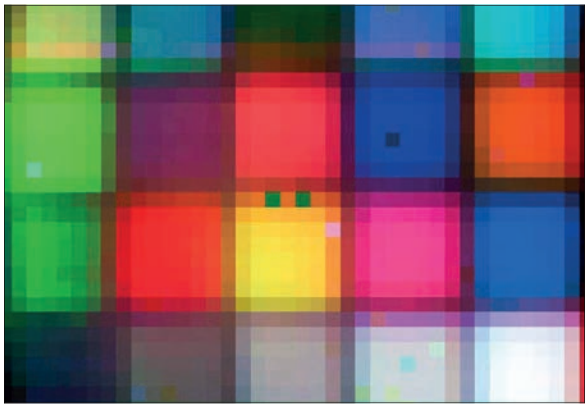
**Isabelle Dumé**

Optics

# Stacked perovskites outperform conventional silicon image sensors

A new photodetector made up of vertically stacked perovskite-based light absorbers can produce real photographic images, potentially challenging the dominance of silicon-based technologies. The detector is the first to exploit the concept of active optical filtering, and its developers at ETH Zurich and Empa in Switzerland say it could be used to produce highly sensitive, artefact-free images with much improved colour fidelity compared to conventional sensors (*Nature* **642** 592).

The human eye uses individual cone cells in the retina to distinguish between red, green and blue (RGB) colours. Imaging devices such as those found in smartphones and digital cameras are designed to mimic this capability. However, because their silicon-based sensors absorb light over the entire visible spectrum, they must split the light into its RGB components. Usually, they do this using colour-filter arrays (CFAs) positioned on top of a monochrome light sensor. Then, once the device has collected the raw data, algorithms are used to reconstruct a colour image.


Empa / ETH Zurich

**Seeing is believing** A new perovskite-based photodetector could be used in consumer-grade colour cameras, machine vision and hyperspectral imaging.

One drawback is the presence of "de-mosaicing" artefacts from the reconstruction process while another is large optical losses, as pixels for red light contain filters that block green and blue light, while those for green block red and blue, and so on. This means that each pixel in the image sensor only receives about a third of the incident light spectrum, greatly reducing the efficacy of light capture.

A team led by materials scientist Maksym Kovalenko from ETH Zurich has now developed an alternative image sensor based on lead halide perovskites. These crystalline semiconductor materials have the chemical formula $APbX_3$, where A is a formamidinium, methylammonium or caesium cation and X is a halide such as chlorine, bromine or iodine. Crucially, the composition of these materials determines which wavelengths of light they will absorb. For example, when they contain more iodide ions, they absorb red light, while materials containing more bromide or chloride ions absorb green or blue light, respectively. Stacks of these materials can thus be used to absorb these wavelengths selectively without the need for filters, since each material layer remains transparent to the other colours.

To build their sensor, the researchers had to fabricate around 30 functional thin-film layers on top of each other, without damaging prior layers. The team's measurements show that the new, stacked sensors reproduce RGB colours more precisely than conventional silicon technologies. The team say that the most obvious application for this sensor would be in consumer-grade colour cameras, machine vision and in so-called hyperspectral imaging.

**Isabelle Dumé**

Materials

# Scientists image excitons in carbon nanotubes for the first time

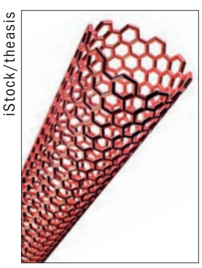
**Researchers in Japan have directly visualized the formation and evolution of quasiparticles known as excitons in carbon nanotubes (CNTs) for the first time. The work could aid the development of nanotube-based nanoelectronic and nanophotonic devices (*Sci. Adv.* 11 eadv9584).**

**CNTs are rolled-up hexagonal lattices of carbon just one atom thick. When exposed to light they generate excitons, which are bound pairs of negatively-charged electrons and positively-charged holes. The behaviour of these excitons governs processes such as light absorption, emission and charge carrier transport that are crucial for CNT-based devices. However, because excitons are confined to extremely small regions and exist for only tens of femtoseconds before annihilating, they are very difficult to observe directly with conventional imaging techniques.**

**In the new work, the researchers developed a technique for imaging excitons in CNTs, known as ultrafast infrared scattering-type scanning near-field optical microscopy (IR s-SNOM). The method first illuminates the CNTs with a short visible laser pulse to create excitons and then uses a time-delayed mid-infrared pulse to probe how these excitons behave.**

**"By scanning a sharp gold-coated atomic force microscope tip across the surface and detecting the scattered infrared signal with high sensitivity, we can measure local changes in the optical response of the CNTs with 130 nm spatial resolution and around 150 fs precision," explains Takashi Kumagai at the Institute for Molecular Science (IMS)/SOKENDAI. "These changes correspond to where and how excitons are formed and annihilated."**

**According to the researchers,**


iStock/theasis

**Clear vision** Excitons in carbon nanotubes have been directly imaged thanks to ultrafast infrared scattering-type scanning near-field optical microscopy.

**the main challenge was to develop a measurement that was ultrafast and highly sensitive while also having a spatial resolution high enough to detect a signal from as few as around 10 excitons. "This required not only technical innovations in the pump-probe scheme in IR s-SNOM, but also a theoretical framework to interpret the near-field response from such small systems," Kumagai says.**

**The measurements reveal that local strain and interactions between CNTs (especially in complex, bundled nanotube structures) govern how excitons are created and annihilated. The researchers say that being able to visualize this behaviour in real time and real space makes the new technique a "powerful platform" for investigating nanoscale ultrafast quantum dynamics and applications in device engineering.**

**Isabelle Dumé**

# Opinion

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Bibliographic codes ISSN 0953-8585 (print)
ISSN 2058-7058 (online) CODEN PHWOEW

Printed in the UK by Warners (Midlands) plc, The Maltings, West Street, Bourne, Lincolnshire PE10 9PH

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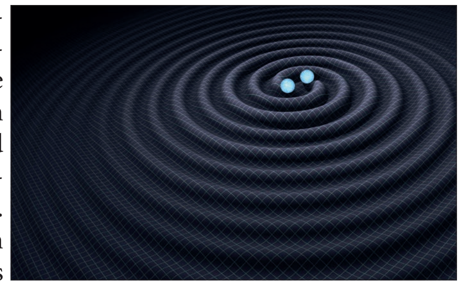
# Bright future

**The Einstein Telescope could usher in a new age of gravitational-wave astronomy**

It was early in the morning of Monday 14 September 2015, exactly 10 years ago, when gravitational waves created from the collision of two black holes 1.3 billion light-years away hit the LIGO detectors in the US. The detections took place just as the two giant interferometers – one in Washington and the other in Louisiana – were being calibrated before the first observational run was due to begin four days later.



R Hurt (Caltech-IPAC)

In one of those curious accidents of history, staff on duty at the Louisiana detector had gone to bed a few hours before the waves rolled in. If they hadn't packed in their calibrations for the night, it would have prevented LIGO from making its historic measurement, dubbed GW150914. Of course, it would surely only have been a matter of time until LIGO had spotted its first signal, with more than 200 gravitational-wave events so far detected.

Observing these "ripples in space–time", which had long been on many physicists' bucket lists, has over the last decade become almost routine. Most gravitational-wave detections have been binary black-hole mergers, though there have also been a few neutron-star/black-hole collisions and some binary neutron-star mergers too. Gravitational-wave astronomy is now a well-established field not just thanks to LIGO but also Virgo in Italy and KAGRA in Japan.

In fact, physicists are already planning what would be a third-generation gravitational-wave detector (see pp3–4). The Einstein Telescope, which could do in a day what took LIGO a decade, could be open by 2035, with three locations vying to host the facility. The Italian island of Sardinia is one option. Saxony in Germany is another, with the third being a site near where Germany, Belgium and the Netherlands meet.

A decision is expected to be made in two years' time, but whichever site is picked – and assuming the €2bn construction costs can be found – Europe would be installed firmly at the forefront of gravitational-wave research. That's because the European Space Agency is also planning a space-based gravitational-wave detector called LISA. It is set to start in 2035 – the same year as the Einstein Telescope.

The US has its own third-generation design, dubbed the Cosmic Explorer. But given the turmoil in US science under Donald Trump, it's far from certain if it'll ever be built. However, if other nations step in and build a network of such facilities around the world, as researchers hope, we could well be in for a new golden age for gravitational-wave astronomy. That bucket list just got longer.

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

# Daring to ask

**Sarika Joshi** says it is important to create an environment where students are never afraid to ask questions – no matter how simple they might seem


Prof. Shobha Shukla, WOPI 2024/IIT Bombay

**Meeting point** The Women in Optics and Photonics in India conference held in Mumbai in December 2024 saw hundreds of attendees discuss the latest developments in the field. This group photo features panellists and members of the organizing team from the NeMO Lab at IIT Bombay.

It was a crisp, chilly morning in Bombay (Mumbai) on 4 December 2024 as delegates made their way to the Indian Institute of Technology, Bombay (IITB) for the opening day of the Women in Optics and Photonics in India-Asia (WOPI) conference. The cool, air-conditioned auditorium was soon packed with almost 300 people – mostly female postgraduate students and researchers – with notepads in hand and lanyards around their necks, eager to learn from the talks ahead.

The three-day event was organized by the IITB and sponsored by institutions, companies and publishers, including IOP Publishing, which publishes *Physics World*. Aimed at highlighting female voices that often go unheard, the meeting brought together scientists and experts from all over the world.

Yet not everything went according to plan. Although the room was full of curious students, each time the floor opened for questions, nervous glances were exchanged. A few moments of silence lingered as though everyone was waiting for a "better" question to come along. The silence rung of missed opportunities.

This kind of reticence is not new. From classrooms and labs to meetings, we see hesitance by students, and especially female students, everywhere. Growing up, I was told to look up the basics first and only ask so-called "high-level" questions. Good advice in theory but not if you're already unsure of your place in the room. Add to that a dismissive answer such as "You should have known this by now" and the urge to speak up is nipped right in the bud.

Perhaps the hesitation is understandable. We live in a world where every answer is an Internet search away. Why ask a "silly" question when everyone else probably already knows better – or at least looks like they do? Yet asking questions is a fundamental part of learning. Science doesn't move forward because people stay quiet until they have the perfect question, it moves because someone dares to ask – even when they aren't sure.

Another contributing factor to such silence is imposter syndrome – the feeling that you don't deserve to be there and aren't good at your work. Multiple studies have shown that women consistently score higher on measures of imposter syndrome than men. Women in technical fields such as engineering, science and maths also report lower self-efficacy than men, regardless of actual performance or ability – so not only do we question whether we belong but we also underestimate ourselves.

All of this means women are less likely to ask questions or speak up when uncertain. But for a scientist, uncertainty is the norm. We spend most of our time sitting with the unknown and with it the need to ask questions and chip away at it. Yet the very process of scientific inquiry can feel to women like a trap.

## A new way

So what can we do differently? Events like WOPI create time and space not just for presenting research and innovation, but for mentorship, for insight into the real-world machinery of science. It's not just about "What are you working on?" but also "Where are you heading, and who's with you?"

WOPI 2024 modelled a new approach to inclusivity by running panel sessions that included the families of successful leaders to showcase the kind of support that is necessary to "make it". Women were invited who fearlessly shared their stories of pivoted careers and/or failures, while acknowledging the challenges that they encountered along the way. It reminded us that you don't just grow by knowing but by asking, exploring and doing.

But we need to do more. Encouraging young female scientists today means accounting for the weight of cultural expectations, social atmosphere and gender-based tendencies. Events and conferences need to go beyond formal settings to highlight not just the science but the scaffolding that holds it all together – networking, informal mentorship, vulnerability and visibility. This must be integrated into the very fabric of all scientific events, not just those for women.

The real pulse of the WOPI conference was in the moments after the talks – students lining up to talk to speakers. Nervous, curious and determined to ask their questions anyway. That moment stayed with me. It was steadfast curiosity that had survived immense self-doubt and fear of speaking in front of an audience.

Hopefully at the next WOPI meeting to be held in India in 2026, students will be much more confident in asking questions. So, to every student: don't wait for the perfect moment. Ask the question that's been sitting at the edge of your mind, making you wonder. After all, that is where discovery starts.

**Sarika Joshi** is studying for a PhD in materials engineering at IIT Bombay and Monash University, e-mail sarika.joshi@monash.edu

# Transactions The joy of networking

Scientific meetings and conferences are all about mixing with other people, but networking isn't easy. **Honor Powrie** gives her tips if you're either attending or organizing such events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Dear *Physics World* readers, I'm going to let you in on a secret. I get anxious every time I see the word "networking" on a meeting or conference agenda. I'm nervous whether anyone will talk to me and – if they do – what I'll say in reply. Will I end up stuck in a corner fiddling on my phone to make it seem like I want to join in but have something more important to do?

If you feel this way – or even if you don't – please read on because I have some something important to say for anyone who attends or organizes scientific events.

Now, we all know there are many benefits to networking. It's a good way to meet like-minded people, tell others about what you're doing, and build a foundation for collaboration. Networking can also boost your professional and personal development – for example, by identifying new perspectives and challenges, finding a mentor, connecting with other organizations, or developing a tailor-made support system.

However, doing this effectively and efficiently is not necessarily easy. Networking can also soak up valuable time. It can create connections that lead nowhere. It can even be a hugely exploitative and one-sided affair where you find yourself under pressure to share personal and/or professional information that you didn't intend to.

## Top tips

Like most things in life, what you get from networking depends on what you put in. To make the most of such events, try to think about how others are feeling in the same situation. Chances are that they will be a bit nervous and apprehensive about opening the conversation. So there's no harm in you going first.

A good opening gambit is to briefly introduce yourself, say who you are, where you work and what you do, and seek similar information from the other person. Preparing a short "elevator pitch" about yourself makes it easier to start a conversation and reduces the need to think on the spot. (Fun fact: elevator pitch gets its name from US inventor Elisha Otis, who needed a concise way of explaining his device to catch a plummeting elevator.)

Make an effort to remember other people's names. I am not brilliant at this and have found that double checking and using people's names in conversation is a good way to commit them to memory. Some advance preparation also helps. If possible, study the attendee list, so you know who else might be there and where they're from. Be yourself and try to be an active listener – listen to what others are saying and ask thoughtful questions.

Don't feel the need to stick with one person or group of people for the whole the time. Five minutes or so is polite and then you can move on and mingle further. Obviously, if you are making a good connection then it's worth spending a bit more time. But if you are genuinely engaged, making plans to follow up post event should be straightforward.

Decide the best way to share your contact details. It could be an iPhone air drop, taking a photo of someone's name badge, sending an e-mail, or swapping business cards (seems a bit unecological these days). If there are people you want to meet, don't be afraid to seek them out. It's always a nice compliment to approach someone and say: "Ah, I was hoping to speak to you today; I've heard a lot about you."

On the flip side, avoid hanging out with your cronies, by which I mean colleagues from the same company or organization or people you already know well. Set yourself a challenge to meet people you've never met before. Remember few of us like being left out so try to involve others in a conversation. That's especially true if someone's listening but not getting the chance to speak; think of a question to bring that person into the discussion.

Of course, if someone you meet doesn't seem to be relevant to you, don't be afraid to admit it. I'm sure they won't be offended if you don't follow up after the meeting. And to those who are already comfortable with networking, remember not to hog all the limelight and to encourage others to participate.

Let me end with a message to organizers, which – I'll be honest – is the main reason I'm writing this article. I have recently attended conferences and events where the music is so loud that people, myself included, have gone with the smokers to the perishing cold outside simply so we can hear each other speak. Am I getting old or is this defeating the object of networking? Please, no more loud music!

I also urge event organizers to have places where people can connect, including tables and seating areas where you can put your plates and drinks down. There's nothing worse than trying to talk while juggling cutlery to avoid a quiche collapsing down the front of your shirt. Buffets are always better than formal sit-down dinners as it provides more opportunity for people to mix. But remember that long queues for food can arise.

So what has networking ever done for me? Over the years the benefits have changed, but most recently I have met some great peer mentors, people whom I can share cross-industry experience and best practice with. And, if I hadn't been at a certain Institute of Physics networking event last year and met Matin Durrani, the editor of *Physics World,* then I wouldn't be writing this article for you today.

I'll let you, though, be the judge of whether that was a success. [Editor's note: it certainly was…]

**Honor Powrie** is an engineer who is now senior director for data science and analytics at GE in Southampton, UK. She is writing here in a personal capacity

# Critical Point Verifiable metaphors

When **Robert P Crease** asked for your experimentally testable physics metaphors, he received dozens of examples – here are the highlights

Physics metaphors don't work, or so I recently claimed. Metaphors always fail; they cut corners in reshaping our perception. But are certain physics metaphors defective simply because they cannot be experimentally confirmed? To illustrate this idea, I mentioned the famous metaphor for how the Higgs field gives particles mass, which is likened to fans mobbing – and slowing – celebrities as they walk across a room.

I know from actual experience that this is false. Having been within metres of film-maker Spike Lee, composer Stephen Sondheim, and actors Mia Farrow and Denzel Washington, I've seen fans have many different reactions to the presence of nearby celebrities in motion. If the image were strictly true, I'd have to check which celebrities were about each morning to know what the hadronic mass would be that day.

I therefore invited *Physics World* readers to propose other potentially empirically defective physics metaphors, and received dozens of candidates. Technically, many are similes rather than metaphors, but most readers, and myself, use the two terms interchangeably. Some of these metaphors/similes were empirically confirmable and others not.


**Lively idea** Atoms, according to Irish novelist Flann O'Brien's book *The Third Policeman*, are likened to "leprechauns doing a jig on top of a tombstone" – but testing the notion might be tricky.

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### Shoes and socks

Michael Elliott, a retired physics lecturer from Oxford Polytechnic, mentioned a metaphor from Jakob Schwichtenberg's book *No-Nonsense Quantum Mechanics* that used shoes and socks to explain the meaning of "commutation". It makes no difference, Schwichtenberg wrote, if you put your left sock on first and then your right sock; in technical language the two operations are said to commute. However, it does make a difference which order you put your sock and shoe on.

"The ordering of the operations 'putting shoes on' and 'putting socks on' therefore matters," Schwichtenberg had written, meaning that "the two operations do not commute." Empirically verifiable, Elliott concluded triumphantly.

A metaphor that was used back in 1981 by CERN physicist John Bell in a paper addressed to colleagues requires more footgear and imagination. Bell's friend and colleague Reinhold Bertlmann from the University of Vienna was a physicist who always wore mismatched socks, and in the essay "Bertlmann's socks and the nature of reality" Bell explained the Einstein–Podolsky–Rosen (EPR) paradox and Bell's theorem in terms of those socks.

If Bertlmann stepped into a room and an observer noticed that the sock on his first foot was pink, one could be sure the other was not-pink, illustrating the point of the EPR paper. Bell then suggested that, when put in the wash, pairs of socks and washing temperatures could behave analogously to particle pairs and magnet angles in a way that conveyed the significance of his theorem. Bell bolstered this conclusion with a scenario involving correlations between spikes of heart attacks in Lille and Lyon. I am fairly sure, however, that Bell never empirically tested this metaphor, and I wonder what the result would be.

Out in space, the favourite cosmology metaphor of astronomer and astrophysicist Michael Rowan-Robinson is the "standard candle" that's used to describe astronomical objects of roughly fixed luminosity. Standard candles can be used to determine astronomical distances and are thus part of the "cosmological distance ladder" – Rowan-Robinson's own metaphor – towards measuring the Hubble constant.

Retired computer programmer Ian Wadham, meanwhile, likes Einstein's metaphor of being in a windowless spacecraft towed by an invisible being who gives the ship a constant acceleration. "It is impossible for you to tell whether you are standing in a gravitational field or being accelerated," Wadham writes. Einstein used the metaphor effectively – even though, as an atheist, he was convinced that he would be unable to test it.

I was also intrigued by a comment from Dilwyn Jones, a consultant in materials science and engineering, who cited a metaphor from the 1939 book *The Third Policeman* by Irish novelist Flann O'Brien. Jones first came across O'Brien's metaphor in Walter J Moore's 1962 textbook *Physical Chemistry*. *Atoms*, says a character in O'Brien's novel, are "never standing still or resting but spinning away and darting hither and thither and back again, all the time on the go", adding that "they are as lively as twenty leprechauns doing a jig on top of a tombstone".

But as Jones pointed out, the metaphor "can only be tested on the Emerald Isle".

Often metaphors entertain as much as inform. Clare Byrne, who teaches at a high school in St Albans in the UK, tells her students that delocalized electrons are like stray dogs – "hanging around the atoms, but never belonging to any one in particular". They could, however, she concedes "be easily persuaded to move fast in the direction of a nice steak".

### Giving metaphors legs

I ended my earlier column on metaphors by referring to poet Matthew Arnold's fastidious correction of a description in his 1849 poem "The Forsaken Merman". After it was published, a friend pointed out to Arnold his mistaken use of the word "shuttle" rather than "spindle" when describing "the king of the sea's forlorn wife at her spinning-wheel" as she lets the thing slip in her grief.

The next time the poem was published, Arnold went out of his way to correct this. Poets, evidently, find it imperative to be factual in metaphors, and I wondered, why shouldn't scientists? The poet Kevin Pennington was outraged by my remark.

"Metaphors in poetry are not the same as metaphors used in science," he insisted. "Science has one possible meaning for a metaphor. Poetry does not." Poetic metaphors, he added are "modal", having many possible interpretations at the same time – "kinda like particles can be in a superposition".

I was dubious. "Superposition" suggests that poetic meanings are probabilistic, even arbitrary. But Arnold, I thought, was aiming at something specific when the king's wife drops the spindle in "The Forsaken Merman". After all, wouldn't I be misreading the poem to imagine his wife thinking, "I'm having fun and in my excitement the thing slipped out of my hand!"

My Stony Brook colleague Elyse Graham, who is a professor of English, adapted a metaphor used by her former Yale professor Paul Fry. "A scientific image has four legs", she said, "a poetic image three". A scientific metaphor, in other words, is as stable as a four-legged table, structured to evoke a specific, shared understanding between author and reader.

A poetic metaphor, by contrast, is unstable, seeking to evoke a meaning that connects with the reader's experiences and imagination, which can be different from the author's within a certain domain of meaning. Graham pointed out, too, that the true metaphor in Arnold's poem is not really the spinning wheel, the wife and the dropped spindle but the entirety of the poem itself, which is what Arnold used to evoke meaning in the reader.

That's also the case with O'Brien's atom-leprechaun metaphor. It shows up in the novel not to educate the reader about atomic theory but to invite a certain impression of the worldview of the science-happy character who speaks it.

### The critical point

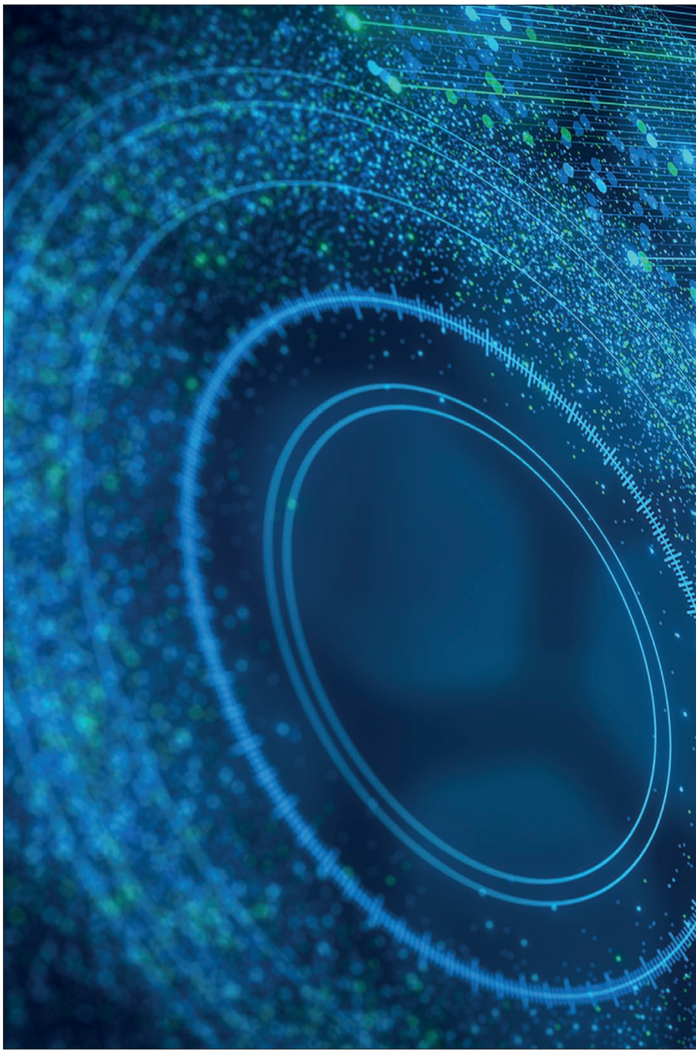
In his 2024 book *Waves in an Impossible Sea: How Everyday Life Emerges from the Cosmic Ocean*, physicist Matt Strassler coined the term "physics fib" or "phib". It refers to an attempted "short, memorable tale" that a physicist tells an interested non-physicist that amounts to "a compromise between giving no answer at all and giving a correct but incomprehensible one".

The criterion for whether a metaphor succeeds or fails does not depend on whether it can pass empirical test, but on the interaction between speaker or author and audience; how much the former has to compromise depends on the audience's interest and understanding of the subject.

Metaphors are interactions. Byrne was addressing high-school students; Schwichtenberg was aiming at interested non-physicists; Bell was speaking to physics experts. Their effectiveness, to use one final metaphor, does not depend on empirical grounding but impedance matching; that is, they step down the "load" so that the "signal" will not be lost.

**Robert P Crease** is a professor in the Department of Philosophy, Stony Brook University, US; e-mail robert.crease@stonybrook.edu; www.robertpcrease.com; his latest book is *The Leak* (2022 MIT Press)

# How AI can help (and not hinder) physics



The use of artificial intelligence is already commonplace in physics, but could physics also help AI? **Tara Shears** examines the relationship between the two fields following a survey and report by the Institute of Physics

**Tara Shears** is a professor of particle physics at the University of Liverpool, UK

To paraphrase Jane Austen, it is a truth universally acknowledged that a research project in possession of large datasets must be in want of artificial intelligence (AI).

CDF was a large international collaboration, involving around 60 institutions from 15 countries. One of the groups involved was at the University of Karlsruhe (now the Karlsruhe Institute of Technology) in Germany, and they were trying to identify the matter and antimatter versions of a beauty quark from the collider's data. This was notoriously difficult – backgrounds were high, signals were small, and data volumes were massive. It was also the sort of dataset where for many variables, there was only a small difference between signal and background.

In the face of such data, Michael Feindt, a professor in the group, developed a neural-network algorithm to tackle the problem. This type of algorithm is modelled on the way the brain learns by combining information from many neurons, and it can be trained to recognize patterns in data. Feindt's neural network, trained on suitable samples of signal and background, was able to more easily distinguish between the two for the data's variables, and combine them in the most effective way to identify matter and antimatter beauty quarks.

At the time, this work was interesting simply because it was a new way of trying to extract a small signal from a very large background. But the neural network turned out to be a key development that underpinned many of CDF's physics results, including the landmark observation of a $B_s$ meson (a particle formed of an antimatter beauty quark and a strange quark) oscillating between its matter and antimatter forms.

Versions of the algorithm have since been used elsewhere, including by physicists on three of the four main experiments at CERN's Large Hadron Collider (LHC). In every case, the approach allowed researchers to extract more information from less data, and in doing so, accelerated the pace of scientific advancement.

What was even more interesting is that the neural-network approach didn't just benefit particle physics. There was a brief foray applying the network to hedge fund management and predicting car insurance rates. A company Phi-T (later renamed Blue Yonder) was spun out from the University of Karlsruhe and applied the algorithm to optimizing supply-chain logistics. After a few acquisitions, the company is now award-winning and global. The neural network, however, remained free for particle physicists to use.

## From lab to living room

Many types of neural networks and other AI approaches are now routinely used to acquire and analyse particle physics data. In fact, our datasets are so large that we absolutely need their computational help, and their deployment has moved from novelty to necessity.

To give you a sense of just how much information we are talking about, during the next run period of the LHC, its experiments are expected to produce about 2000 petabytes ($2 \times 10^{18}$ bytes) of real and simulated data per year that researchers will need to analyse. This dataset is almost 10 times larger than a year's worth of videos uploaded to YouTube, 30 times larger than Google's annual webpage datasets, and over a third as big as a year's worth of Outlook e-mail traffic. These are dataset sizes very much in want of AI to analyse.

Particle physics may have been an early adopter, but AI has now spread throughout physics. This shouldn't be too surprising. Physics is data-heavy and computationally intensive, so it benefits from the step up in speed and


**Two-way street**
Machine-learning algorithms can be invaluable for analysing the extremely large datasets generated by big physics experiments. But physics has also helped drive many advances in AI techniques.

computational complexity to analyse datasets, simulate physical systems, and automate the control of complicated experiments.

For example, AI has been used to classify gravitational-lensing images in astronomical surveys. It has helped researchers interpret the resulting distributions of matter they infer to be there in terms of different models of dark energy. Indeed, in 2024 it improved Dark Energy Survey results equivalent to quadrupling their data sample (see box "An AI universe" on p22).

AI has even helped design new materials. In 2023 Google DeepMind discovered millions of new crystals that could power future technologies, a feat estimated to be equivalent to 800 years of research. And there are many other advances – AI is a formidable tool for accelerating scientific progress.

But AI is not limited to complex experiments. In fact, we all use it every day. AI powers our Internet searches, helps us understand concepts, and even leads us to misunderstand things by feeding us false facts. Nowadays, AI pervades every aspect of our lives and presents us with challenges and opportunities whenever it appears.

### Physicists have their say

It's this mix of challenge and opportunity that makes now the right time to examine the relationship between physics and AI, and what each can do for the other. In fact, the Institute of Physics (IOP) has recently published a "pathfinder" study on this very subject, on which I acted as an adviser. Pathfinder studies explore the landscape of a topic, identifying the directions that a subsequent, deeper and more detailed "impact" study should explore.

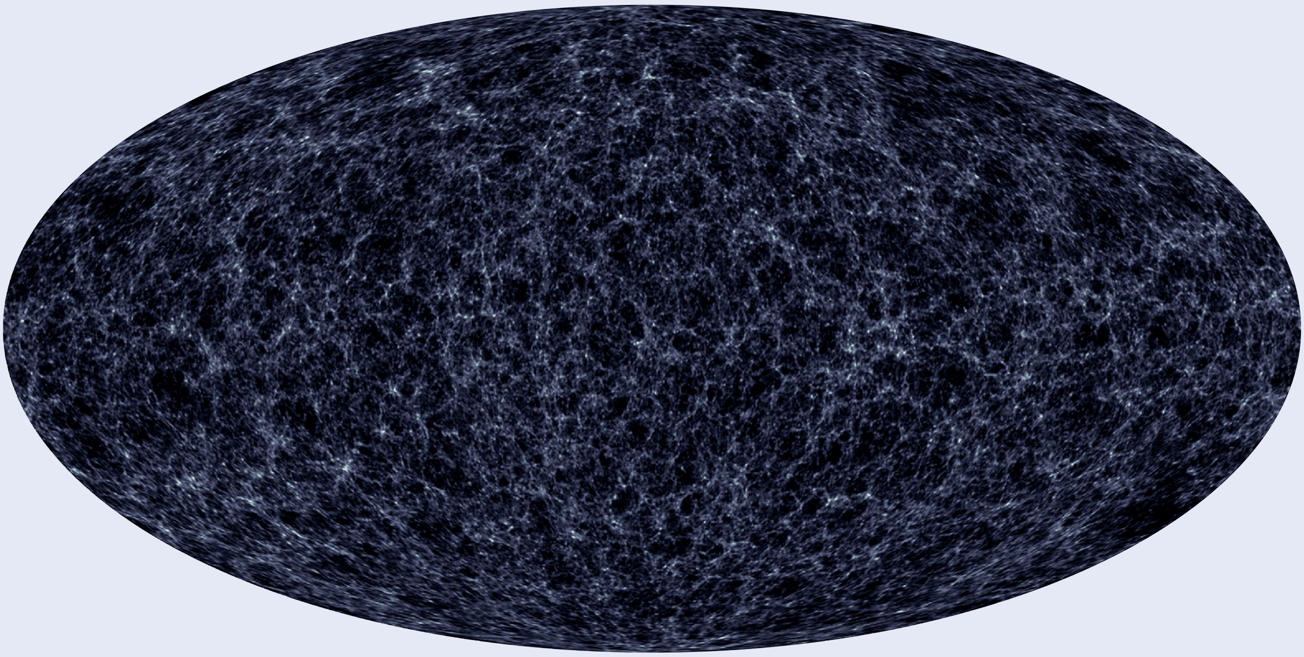
This current pathfinder study – *Physics and AI: a Physics Community Perspective* – is based on an IOP member survey that examined attitudes towards AI and its uses, and an expert workshop that discussed future potential for innovation. The resulting report, which came out in April 2025, revealed just how widespread the use of AI is in physics.

About two thirds of the 700 people who replied to the survey said they had used AI to some degree, and every physics area contained a good fraction of respondents who had at least some level of familiarity with it. Most often this experience involved different machine-learning approaches or generative AI, but respondents had also worked with AI ethics and policy, computer vision and natural language processing. This is a testament to the many uses we can find for AI, from very specific pattern recognition and image classification tasks, to understanding its wider implications and regulatory needs.

### Proceed with caution

Although it is clear that AI can really accelerate our research, we have to be careful. As many respondents to the survey pointed out, AI is a powerful aid, but simply using it as a black box and imagining it does the right

## An AI universe




**Deep learning the dark sky** An example of a simulated map of dark matter created using an AI tool called Gower Street.

AI approaches have been used by the Dark Energy Survey (DES) collaboration to investigate dark energy, the mysterious phenomenon thought to drive the expansion of the universe.

DES researchers had previously mapped the distribution of matter in the universe by relating distortions in light from galaxies to the gravitational attraction of matter the light passes through before being measured. The distribution depends on visible and dark matter (which draws galaxies closer), and dark energy (which drives galaxies apart).

In a 2024 study researchers used AI techniques to simulate a series of matter distributions – each based on a different value for variables describing dark matter, dark energy and other cosmological parameters that describe the universe. They then compared these simulated findings with the real matter distribution. By determining which simulated distributions were consistent with the data, values for the corresponding dark energy parameters could be extracted.

Because the AI techniques allowed more information to be used to make the comparison than would otherwise be possible, the results are more precise. Researchers were able to improve the precision by a factor of two, a feat equivalent to using four times as much data with previous methods.

thing is dangerous. AI tools and the challenges we put them to are complex – we need to ensure we understand what they are doing and how well they are doing it to have confidence in their answers.

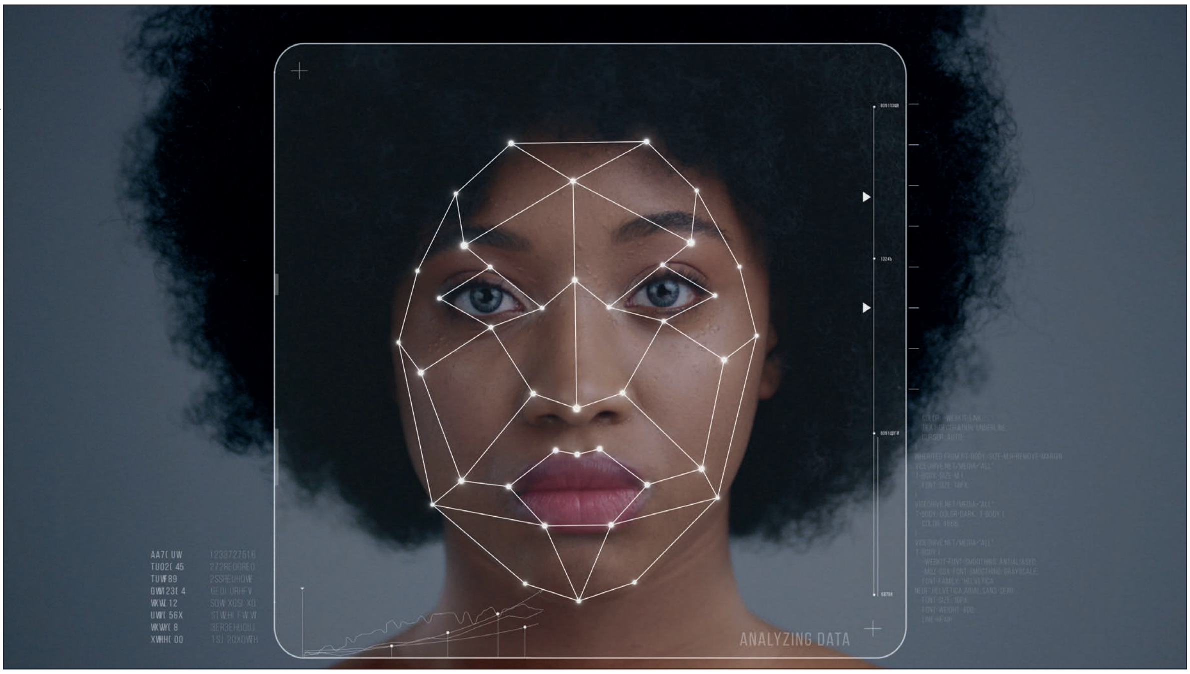
There are any number of cautionary tales about the consequences of using AI badly and obtaining a distorted outcome. A 2017 master's thesis by Joy Adowaa Buolamwini from Massachusetts Institute of Technology (MIT) famously analysed three commercially available facial-recognition technologies, and uncovered gender and racial bias by the algorithms due to incomplete training sets. The programmes had been trained on images predominantly consisting of white men, which led to women of colour being misidentified nearly 35% of the time, while white men were correctly classified 99% of the time. Buolamwini's findings prompted IBM and Microsoft to revise and correct their algorithms.

Even estimating the uncertainty associated with the use of machine learning is fraught with complication. Training data are never perfect. For instance, simulated data may not perfectly describe equipment response in an experiment, or – as with the example above – crucial processes occurring in real data may be missed if the training dataset is incomplete. And the performance of an algorithm is never perfect; there may be uncertainties associated with the way the algorithm was trained and its parameters chosen.

Indeed, 69% of respondents to the pathfinder survey felt that AI poses multiple risks to physics, and one of the main concerns was inaccuracy due to poor or bad training data (figure 1). It's bad enough getting a physics result wrong and discovering a particle that isn't really there, or missing a new particle that is. Imagine the risks if poorly understood AI approaches are applied to healthcare decisions when interpreting medical images, or in finance where investments are made on the back of AI-driven model suggestions. Yet despite the potential consequences, the AI approaches in these real-world cases are not always well calibrated and can have ill-defined uncertainties.

New approaches are being considered in physics that try to separate out the uncertainties associated with simulated training data from those related to the performance of the algorithm. However, even this is not straightforward. A 2022 paper by Aishik Ghosh and Benjamin Nachman from Lawrence Berkeley National Laboratory in the US (*Eur. Phys. J. C* **82** 46) notes that devising a procedure to be insensitive to the uncertainties you think are present in training data is not the same as having a procedure that is insensitive to the actual uncertainties that are really there.

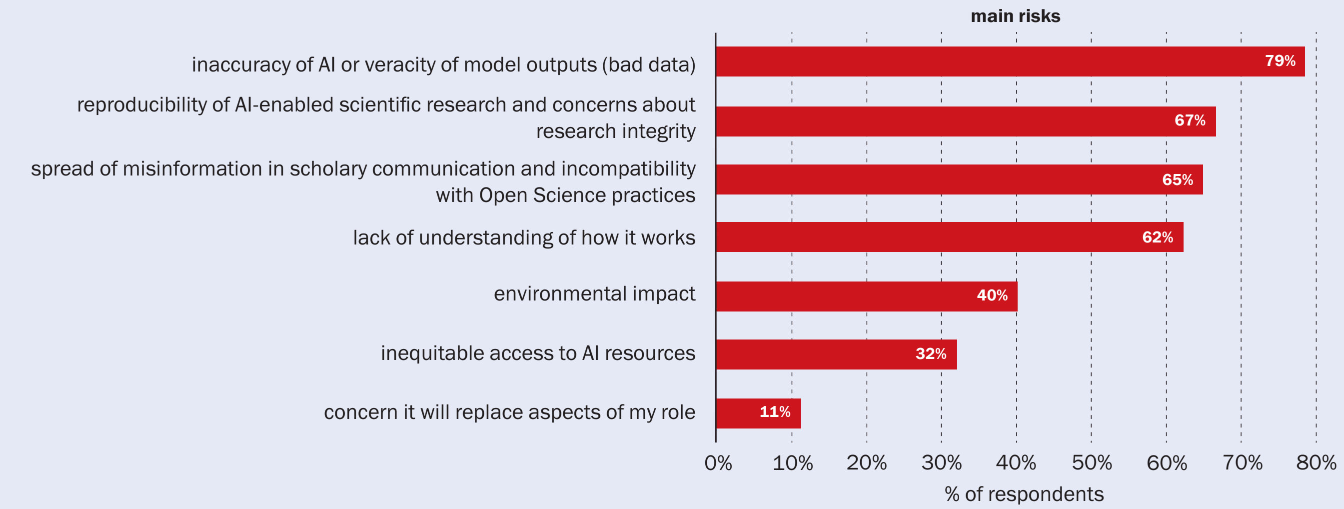
Shutterstock/Fractal Pictures




**Cause for caution** AI-based facial-recognition technology works less well with Black women than any other demographic group. This can have real-world negative consequences. The cause is training datasets heavily skewed to white men.

Institute of Physics, *Physics and AI: a Physics Community Perspective*

## 1 Uncertain about uncertainties




The Institute of Physics pathfinder survey asked its members, "Which are your potential greatest concerns regarding AI in physics research and innovation?" Respondents were allowed to select multiple answers, and the prevailing worry was about the inaccuracy of AI.

If that's true, not only is measurement uncertainty underestimated but, depending on the differences between training data and reality, false results can be obtained.

The moral is that AI can and does advance physics, but we need to invest the time to use it well so that our results are robust. And if we do that, others can benefit from our work too.

### How physics can help AI

Physics is a field where accuracy is crucial, and we are as rigorous as we can be about understanding bias and uncertainty in our results. In fact, the pathfinder report highlights that our methodologies to quantify uncertainty can be used to advance and strengthen AI methods too. This is critical for future innovation and to improve trust in AI use.

Advances are already under way. One development, first introduced in 2017, is physics-informed neural networks. These impose consistency with physical laws in addition to using training data relevant to their particular applications. Imposing physical laws can help compensate for limited training data and prevents unphysical solutions, which in turn improves accuracy. Although relatively new, it's a rapidly developing field, finding applications in sectors as diverse as computational fluid dynamics, heat transfer, structural mechanics, option pricing and blood pressure estimation.

Another development is in the use of Bayesian neural networks, which incorporate uncertainty estimates into their predictions to make results more robust and meaningful. The approach is being trialled in decision-critical fields such as medical diagnosis and stock market prediction.

But this is not new to physics. The neural network devel-

## AI terms and conditions

Definitions of some key terms in the AI space.

**Artificial intelligence (AI)**
Intelligent behaviour exhibited by machines. But the definition of intelligence is controversial so a more general description of AI that would satisfy most is: the behaviour of a system that adapts its actions in response to its environment and prior experience.

**Machine learning**
As a group of approaches to endow a machine with artificial intelligence, machine learning is itself a broad category. In essence, it is the process by which a system learns from a training set so that it can deliver autonomously an appropriate response to new data.

**Training data**
A set of real or simulated data used to train a machine-learning algorithm to recognize patterns in data indicative of signal or background.

**Artificial neural networks**
A subset of machine learning in which the learning mechanism is modelled on the behaviour of a biological brain. Input signals are modified as they pass through networked layers of neurons before emerging as an output. Experience is encoded by varying the strength of interactions between neurons in the network.

**Generative AI**
A type of machine-learning algorithm that creates new content, such as images or text, based on the data the algorithm was trained on.

**Computer vision**
A branch of AI that analyses, interprets and extracts meaningful data from images to identify and classify objects and patterns.

**Natural language processing**
A branch of AI that analyses, interprets and generates human language.

oped at CDF in the 2000s was an early Bayesian neural network, developed to be robust against outliers in data, avoid issues in training caused by statistical fluctuations, and to have a sound probabilistic basis to interpret results. All the features, in fact, that make the approach invaluable for analysing many other systems outside physics.

So physics benefits from AI and can drive advances in it too. This is a unique relationship that needs wider recognition, and this is a good moment to bring it to the fore. The UK government has said it sees AI as "the defining opportunity of our generation", driving growth and innovation, and that it wants the UK to become a global AI superpower. Action plans and strategies are already being implemented. Physics has a unique perspective to offer help and make this happen. It's time for us to include it in the conversation.

In the words of the pathfinder report, we need to articulate and showcase what AI can do for physics and what physics can do for AI. Let's make this the start of putting physics on the AI map for everyone. ■

# The clash for cosmology's soul

Will modified gravity be the solution to our cosmological conundrums as dark matter wimps out, or will new experiments and telescopes finally spot the elusive particle once and for all? In the third and final part of this series, **Keith Cooper** speaks to scientists on both sides of this stellar showdown

**Keith Cooper** is a science writer based in the UK

The clash between dark matter and modified Newtonian dynamics (MOND) can get a little heated at times. On one side is the vast majority of astronomers who vigorously support the concept of dark matter and its foundational place in cosmology's standard model. On the other side is the minority – a group of rebels convinced that tweaking the laws of gravity rather than introducing a new particle is the answer to explaining the composition of our universe.

Both sides argue passionately and persuasively, pointing out evidence that supports their view while discrediting the other side. Often it seems to come down to a matter of perspective – both sides use the same results as evidence for their cause. For the rest of us, how can we tell who is correct?

As long as we still haven't identified what dark matter is made of, there will remain some ambiguity, leaving a door ajar for MOND. However, it's a door that dark-matter researchers hope will be slammed shut in the not-too-distant future.

### Crunch time for WIMPs

In part two of this series, where I looked at the latest proposals from dark-matter scientists, we met University College London's Chamkaur Ghag, who is the spokesperson for Lux-ZEPLIN. This experiment is searching for "weakly interacting massive particles" or WIMPs – the leading dark-matter candidate – down a former gold mine in South Dakota, US. A huge seven-tonne tank of liquid xenon, surrounded by an array of photomultiplier tubes, watches patiently for the flashes of light that may occur when a passing WIMP interacts with a xenon atom.

I think none of us are ever going to fully believe it completely until we've found a WIMP and can reproduce it in a lab

Running since 2021, the experiment just released the results of its most recent search through 280 days of data, which uncovered no evidence of WIMPs above a mass of 9 GeV/$c^2$ (*Phys. Rev. Lett.* **135** 011802). These results help to narrow the range of possible dark-matter theories, as the new limits impose constraints on WIMP parameters that are almost five times more rigorous than the previous best. Another experiment at the INFN Laboratori Nazionali del Gran Sasso in Italy, called XENONnT, is also hoping to spot the elusive WIMPs – in its case by looking for rare nuclear recoil interactions in a liquid xenon target chamber.

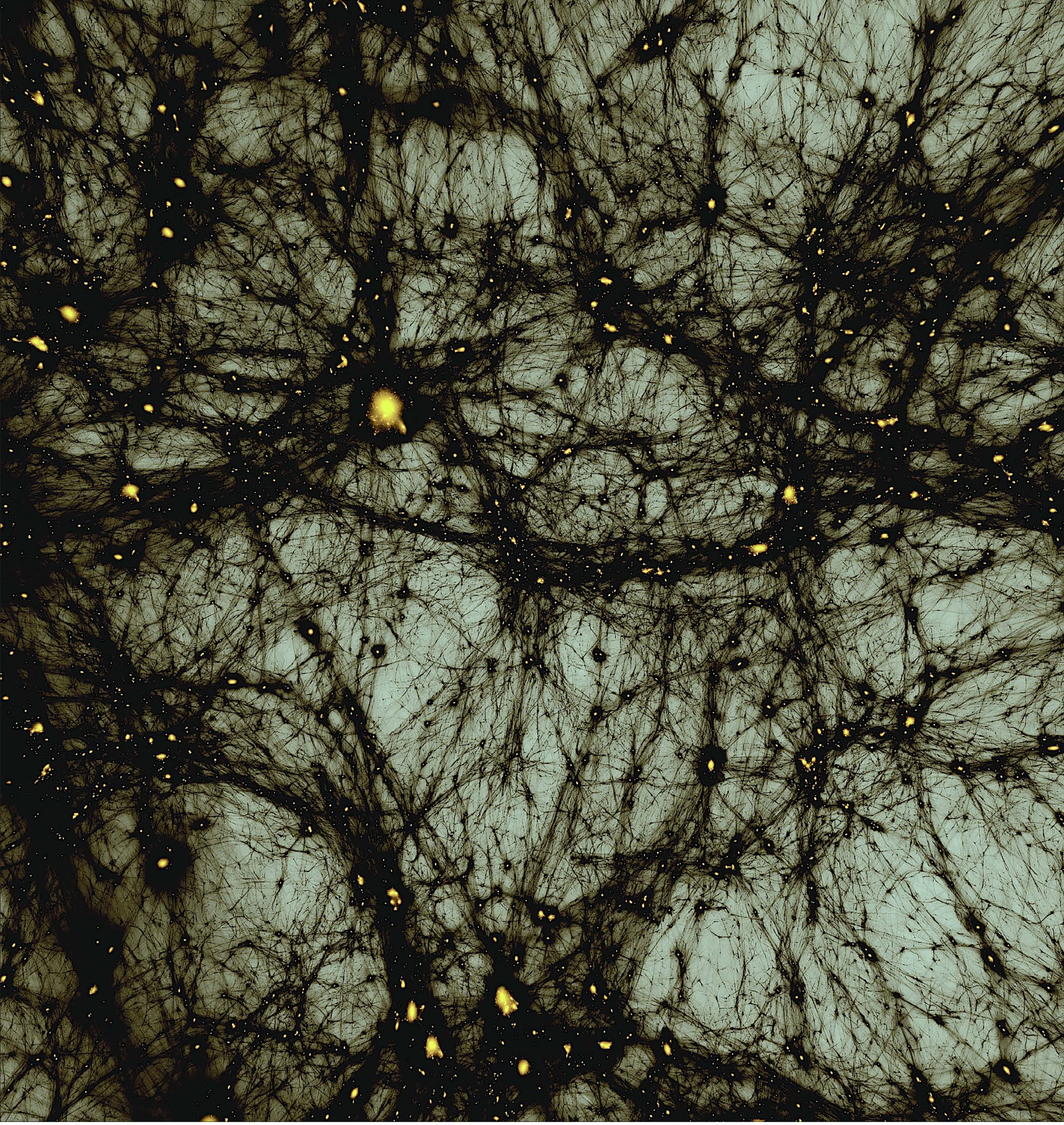
Lux-ZEPLIN and XENONnT will cover half the parameter space of masses and energies that WIMPs could in theory have, but Ghag is more excited about a forthcoming, next-generation xenon-based WIMP detector dubbed XLZD that might settle the matter. XLZD brings together both the Lux-ZEPLIN and XENONnT collaborations, to design and build a single, common multi-tonne experiment that will hopefully leave WIMPs with no place to hide. "XLZD will probably be the final experiment of this type," says Ghag. "It's designed to be much larger and more sensitive, and is effectively the definitive experiment."

If WIMPs do exist, then this detector will find them, and it could happen on UK shores. Several locations around the world are in the running to host the experiment, including Boulby Mine Underground Laboratory near Whitby Bay on the north-east coast of England. If everything goes to plan, XLZD – which will contain between 40 and 100 tonnes of xenon – will be up and running and providing answers by the 2030s. It will be a huge moment for dark matter, and a nervous one for its researchers.

"I think none of us are ever going to fully believe it completely until we've found [a WIMP] and can reproduce it in a lab and show that it's not just some abstract stuff that we call dark matter, but that it is a particular particle that we can identify," says astronomer Richard Massey of the University of Durham, UK.

But if WIMPs are in fact a dead-end, then it's not a complete death-blow for dark matter – there are other dark-matter candidates and other dark-matter experiments. For example, the Forward Search Experiment (FASER) at CERN's Large Hadron Collider is looking for less massive

Tom Abel and Ralf Kaehler, SLAC National Accelerator Laboratory and Kavli Institute for Particle Astrophysics and Cosmology



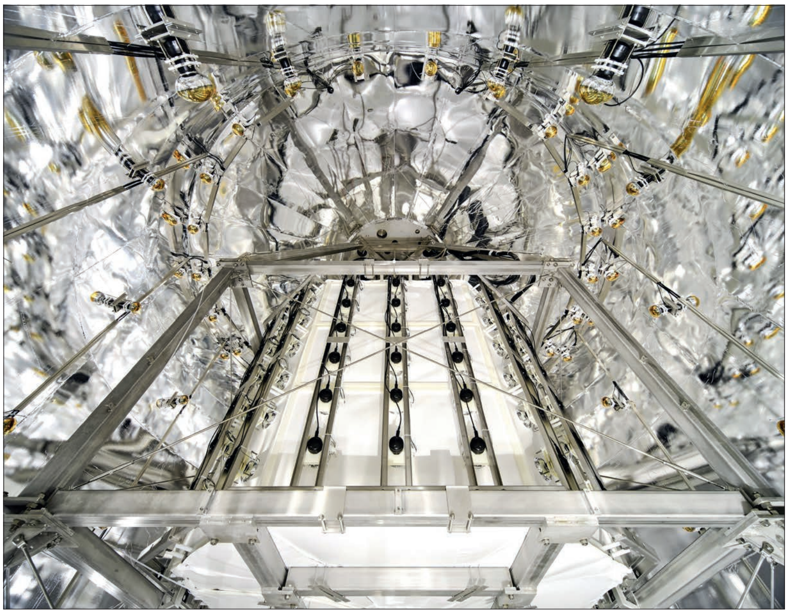
dark-matter particles such as axions. However, WIMPs have been a mainstay of dark-matter models since the 1980s. If the xenon-based experiments turn up empty-handed it will be a huge blow, and the door will creak open just a little bit more for MOND.

## Galactic frontier

MOND's battleground isn't in particle detectors – it's in the outskirts of galaxies and galaxy clusters, and its proof lies in the history of how our universe formed. This is dark matter's playground too, with the popular models for how galaxies grow being based on a universe in which dark matter forms 85% of all matter. So it's out in the depths of space where the two models clash.

The current standard model of cosmology describes how the growth of the large-scale structure of the universe, over the past 13.8 billion years of cosmic history since the Big Bang, is influenced by a combination of dark matter and dark energy (responsible for the accelerated expansion of the universe). Essentially, density fluctuations in the cosmic microwave background (CMB) radiation reflect the clumping of dark matter in the very early

**Dark web**
Simulation of the formation of dark-matter structures from the early universe until today.




**Deep underground** The XENON Dark Matter Project is hosted by the INFN Gran Sasso National Laboratory in Italy. The latest detector in this programme is the XENONnT (pictured) which uses liquid xenon to search for dark-matter particles.

universe. As the cosmos aged, these clumps thinned out into the cosmic web of matter. This web is a universe-spanning network of dark-matter filaments, where all the matter lies, between which are voids that are comparatively less densely packed with matter than the filaments. Galaxies can form inside "dark matter haloes", and at the densest points in the dark-matter filaments, galaxy clusters coalesce.

Simulations in this paradigm – known as lambda cold dark matter (ΛCDM) – suggest that galaxy and galaxy-cluster formation should be a slow process, with small galaxies forming first and gradually merging over billions of years to build up into the more massive galaxies that we see in the universe today. And it works – kind of. Recently, the James Webb Space Telescope (JWST) peered back in time to between just 300 and 400 million years after the Big Bang and found the universe to be populated by tiny galaxies perhaps just a thousand or so light-years across (*ApJ* **970** 31). This is as expected, and over time they would grow and merge into larger galaxies.

Yet the deeper we push into the universe, the more we observe challenges to the ΛCDM model, which ultimately threatens the very existence of dark matter. For example, those early galaxies that the JWST has observed, while being quite small, are also surprisingly bright – more so than ΛCDM predicts. This has been attributed to an initial mass function (IMF – the property that determines the average mass of stars that form) that skews more towards higher-mass stars and therefore more luminous stars than today. It does sound reasonable, except that astronomers still don't understand why the IMF is what it is today (favouring the smallest stars; massive stars are rare) never mind what it might have been over 13 billion years ago.

Not everyone is convinced, and this is compounded by slightly later galaxies, seen around a billion years after the Big Bang, which continue the trend of being more luminous and more massive than expected. Indeed, some of these galaxies sport truly enormous black holes hundreds of times more massive than the black hole at the heart of our Milky Way. Just a couple of billion years later and significantly large galaxy clusters are already present, earlier than one would have surmised with ΛCDM.

## The fall of ΛCDM?

Astrophysicist and MOND advocate Pavel Kroupa, from the University of Bonn in Germany, highlights giant elliptical galaxies in the early universe as an example of what he sees as a divergence from ΛCDM.

"We know from observations that the massive elliptical galaxies formed on shorter timescales than the less massive ellipticals," he explains. This phenomenon has been referred to as "downsizing", and Kroupa declares it is "a big problem for ΛCDM" because the model says that "the big galaxies take longer to form, but what we see is exactly the opposite".

To quantify this problem, a 2020 study (*MNRAS* **498** 5581) by Australian astronomer Sabine Bellstedt and colleagues showed that half the mass in present-day elliptical galaxies was in place 11 billion years ago, compared with other galaxy types that only accrued half their mass on average about 6 billion years ago. The smallest galaxies only accrued that mass as recently as 4 billion years ago, in apparent contravention of ΛCDM.

Observations (*ApJ* **905** 40) of a giant elliptical galaxy catalogued as C1-23152, which we see as it existed 12 billion years ago, show that it formed 200 billion solar masses worth of stars in just 450 million years – a huge firestorm of star formation that ΛCDM simulations just can't explain. Perhaps it is an outlier – we've only sampled a few parts of the sky, not conducted a comprehensive census yet. But as astronomers probe these cosmic depths more extensively, such explanations begin to wear thin.

Kroupa argues that by replacing dark matter with MOND, such giant early elliptical galaxies suddenly make sense. Working with Robin Eappen, who is a PhD student at Charles University in Prague, they modelled a giant gas cloud in the very early universe collapsing under gravity according to MOND, rather than if there were dark matter present.

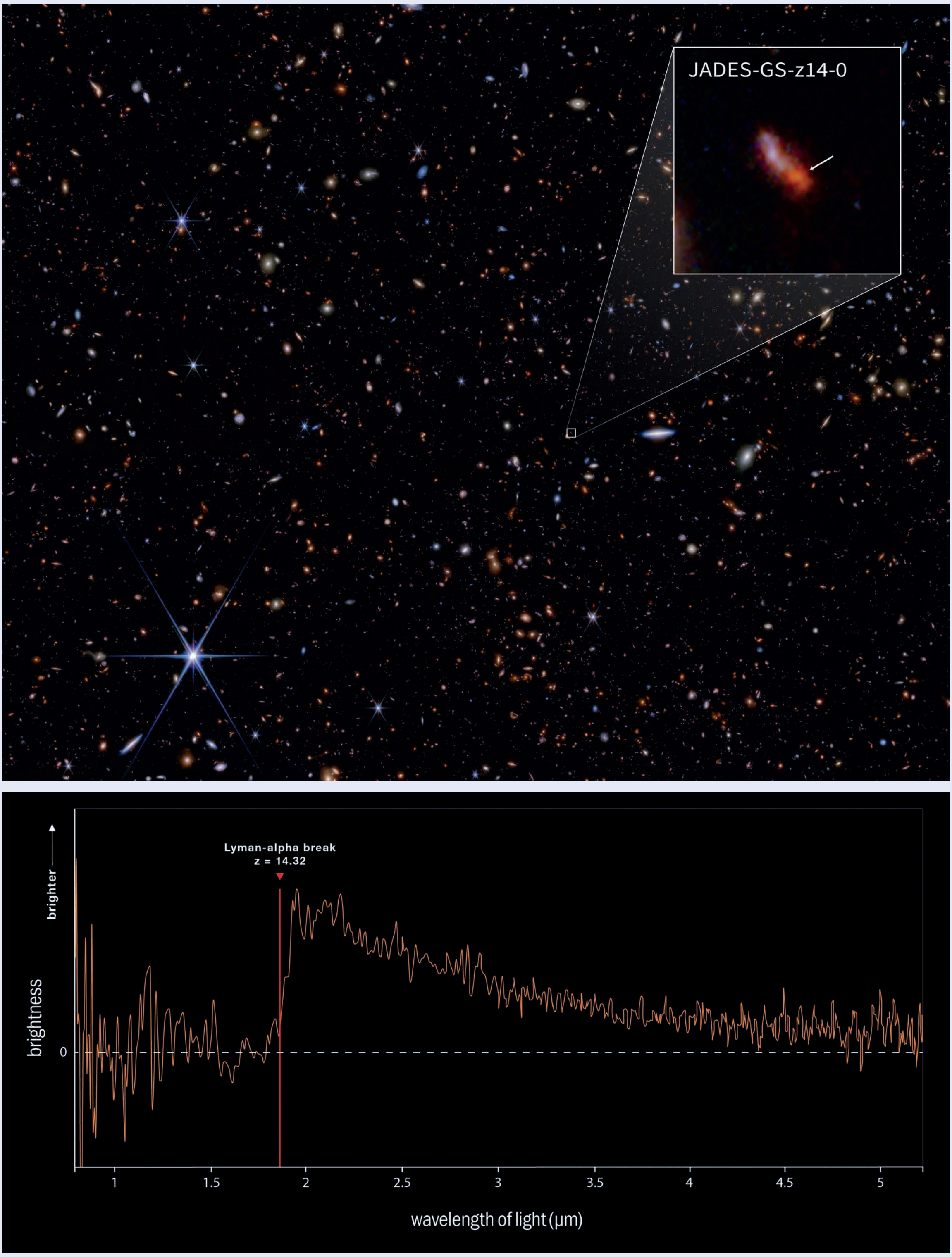
"It is just stunning that the time [of formation of such a large elliptical] comes out exactly right," says Kroupa. "The more massive cloud collapses faster on exactly the correct timescale, compared to the less massive cloud that collapses slower. So when we look at an elliptical galaxy, we know that thing formed from MOND and nothing else."

Elliptical galaxies are not the only thing with a size problem. In 2021 Alexia Lopez, a PhD student at the University of Central Lancashire, UK, discovered a "Giant Arc" of galaxies spanning 3.3 billion light-years, some 9.2 billion light-years away. And in 2023 Lopez spotted another gigantic structure, a "Big Ring" (shaped more like a coil) of galaxies 1.3 billion light-years in diameter, but with a circumference of about 4 billion light-years. The opposite of these giant structures are the massive under-dense voids that take up space between the filaments of the cosmic web. The KBC Void (sometimes called the "Local Hole"), for example, is about two billion light-years across and the Milky Way among a host of other galaxies sits inside it. The trouble is, simulations in ΛCDM, with dark matter at the heart of it, cannot replicate structures and voids this big.

"We live in this huge under-density; we're not at the centre of it but we are within it and such an under-density is completely impossible in ΛCDM," says Kroupa, before declaring, "Honestly, it's not worthwhile to talk about the ΛCDM model anymore."

## 1 Step back in time

a
b




NASA/ESA/CSA/STScI/ Brant Robertson, UC Santa Cruz/ Ben Johnson, CfA/ Sandro Tacchella, University of Cambridge/ Phill Cargile, CfA

NASA/ESA/CSA/ Joseph Olmsted, STScI/ S Carniani, Scuola Normale Superiore/ JADES Collaboration

Data from the James Webb Space Telescope (JWST) form the basis of the JWST Advanced Deep Extragalactic Survey (JADES). (*a*) This infrared image from the JWST's NIRCam highlights galaxy JADES-GS-z14-0. (*b*) The JWST's NIRSpec (Near-Infrared Spectrograph) obtained this spectrum of JADES-GS-z14-0. A galaxy's redshift can be determined from the location of a critical wavelength known as the Lyman-alpha break. For JADES-GS-z14-0 the redshift value is 14.32 (+0.08/–0.20), making it the second most distant galaxy known at less than 300 million years after the Big Bang. The current record holder, as of August 2025, is MoM-z14, which has a redshift of 14.4 (+0.02/–0.02), placing it less than 280 million years after the Big Bang (arXiv:2505.11263). Both galaxies belong to an era referred to as the "cosmic dawn", following the epoch of reionization, when the universe became transparent to light. JADES-GS-z14-0 is particularly interesting to researchers not just because of its distance, but also because it is very bright. Indeed, it is much more intrinsically luminous and massive than expected for a galaxy that formed so soon after the Big Bang, raising more questions on the evolution of stars and galaxies in the early universe.

X-ray: NASA/CXC/SAO; near-infrared: NASA/ESA/CSA/STScI; processing: NASA/STScI/ J DePasquale

**Bullet time and mass** This spectacular new image of the Bullet Cluster was created using NASA's James Webb Space Telescope and Chandra X-ray Observatory. The new data allow for an improved measurement of the thousands of galaxies in the Bullet Cluster. This means astronomers can more accurately "weigh" both the visible and invisible mass in these galaxy clusters. Astronomers also now have an improved idea of how that mass is distributed.

### A bohemian model

Such fighting talk is dismissed by dark-matter astronomers because although there are obviously deficiencies in the ΛCDM model, it does such a good job of explaining so many other things. If we're to kill ΛCDM because it cannot explain a few large ellipticals or some overly large galaxy groups or voids, then there needs to be a new model that can explain not only these anomalies, but also everything else that ΛCDM does explain.

"Ultimately we need to explain all the observations, and some of those MOND does better and some of those ΛCDM does better, so it's how you weigh those different baskets," says Stacy McGaugh, a MOND researcher from Case Western Reserve University in the US.

As it happens, Kroupa and his Bonn colleague Jan Pflamm-Altenburg are working on a new model that they think has what it takes to overthrow dark matter and the broader ΛCDM paradigm. Calling it the Bohemian model (the name has a double meaning – Kroupa is originally from Czechia), it incorporates MOND as its main pillar and Kroupa describes the results they are getting from their simulations in this paradigm as "stunning" (*A&A* **698** A167).

But Kroupa admits that not everybody will be happy to see it published. "If it's published, a lot of experts at Ivy League universities will say it's all completely impossible," he says. "But I know for a fact that there is part of the community, the 'bright part' as I call them, which is just itching to have a completely different model."

Kroupa is staying tight-lipped on the precise details of his new model, but says that according to simulations the puzzle of large-scale structure forming earlier than expected, and growing larger faster than expected, is answered by the Bohemian model. "These structures [such as the Giant Arc and the KBC Void] are so radical that they are not possible in the ΛCDM model," he says. "However, they pop right out of this Bohemian model."

### Binary battle

Whether you believe Kroupa's promises of a better model or whether you see it all as bluster, the fact remains that a dark-matter-dominated universe still has some problems. Maybe they're not serious, and all it will take is a few tweaks to make those problems go away. But maybe they'll persist, and require new physics of some kind, and it's this possibility that continues to leave the door open for MOND. For the rest of us, we're still grasping for a definitive statement one way or another.

For MOND, perhaps that definitive statement could still turn out to be binary stars, as discussed in the first article in this series. Researchers have been particularly interested in so-called "wide binaries" – pairs of stars that are more than 500 AU apart. Thanks to the vast distance between them, the gravitational impact of each star on the other is weak, making it a perfect test for MOND. Idranil Banik, of the University of St Andrews, UK, controversially concluded that there was no evidence for MOND operating on the smaller scales of binary-star systems. However, other researchers such as Kyu-Hyun Chae of Sejong University in South Korea argue that they have found evidence for MOND in binary systems, and have hit out at Banik's findings.

Indeed, after the first part of this series was published, Chae reached out to me, arguing that Banik had analysed the data incorrectly. Chae specifically points out the fraction of wide binaries (pairs that are more than 500 AU apart, meaning that the gravitational impact of each star on the other is weak, making it a perfect test for MOND) with an extra unseen close stellar companion (a factor designated $f_{multi}$) to one or both of the binary stars must be calibrated for when performing the MOND calculations. Often when two stars are extremely close together, their angular separation is so small that we can't resolve them and don't realize that they are binary, he explains. So we might mistake a triple system, with two stars so close together that we can't distinguish them and a third star on a wider circumbinary orbit, for just a wide binary.

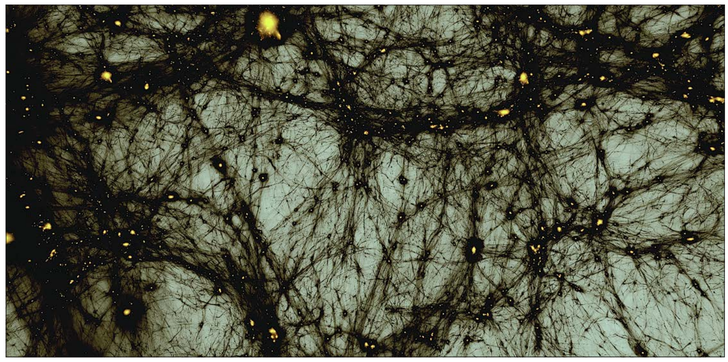
"I initially believed Banik's claim, but because what's at stake is too big and I started feeling suspicious, I chose to do my own investigation," says Chae (*ApJ* **952** 128). "I came to realize the necessity of calibrating $f_{multi}$ due to the intrinsic degeneracy between mass and gravity (one cannot simultaneously determine the gravity boost factor and the amount of hidden mass)."

The probability of a wide binary having an unseen extra stellar companion is the same as for shorter binaries (those that we can resolve). But for shorter binaries the gravitational acceleration is high enough that they obey regular Newtonian gravity – MOND only comes into the picture at wider separations. Therefore, the mass uncertainty in the study of wide binaries in a MOND regime can be calibrated for using those shorter-period binaries. Chae argues that Banik did not do this. “I’m absolutely confident that if the Banik *et al.* analysis is properly carried out, it will reveal MOND’s low-acceleration gravitational anomaly to some degree.”

So perhaps there is hope for MOND in binary systems. Given that dark matter shouldn’t be present on the scale of binary systems, any anomalous gravitational effect could only be explained by MOND. A detection would be pretty definitive, if only everyone could agree upon it.

But let’s not kid ourselves – MOND still has a lot of catching up to do on dark matter, which has become a multi-billion-dollar industry with thousands of researchers working on it and space missions such as the European Space Agency’s Euclid space telescope. Dark matter is still in pole position, and its own definitive answers might not be too far away.

“Finding dark matter is definitely not too much to hope for, and that’s why I’m doing it,” says Richard Massey. He highlights not only Euclid, but also the work of the James Webb Space Telescope in imaging gravitational lensing on smaller scales and the Nancy G Roman Space Telescope, which will launch later this decade on a mission to study weak gravitational lensing – the way in which small clumps of matter, such as individual dark matter haloes around galaxies, subtly warp space.



View this e-magazine online to watch a video of a dark-matter simulation.

“These three particular telescopes give us the opportunity over the next 10 years to catch dark matter doing something, and to be able to observe it when it does,” says Massey. That “something” could be dark-matter particles interacting, perhaps in a cluster merger in deep space, or in a xenon tank here on Earth.

“That’s why I work on dark matter rather than anything else,” concludes Massey. “Because I am optimistic.”

- In the first instalment of this three-part series, Keith Cooper explored the struggles and successes of modified gravity in explaining phenomena at varying galactic scales (March 2024 pp23–27)
- In the second part of the series, Keith Cooper explored competing theories of dark matter (August 2024 pp31–36)

# Making science go boom

**Emanual Wallace**, aka **Big Manny**, is quickly becoming the new face of science outreach. He talks to Sarah Tesh about his journey from making social media videos in his garden, to writing books and appearing on TV, and what he hopes to do next

When lockdown hit, school lab technician Emanual Wallace started posting videos of home science experiments on social media. Now, as Big Manny, he's got over three million followers on Instagram and TikTok; won TikTok's Education Creator of the Year 2024; and has created videos with celebrities like Prince William and Brian Cox. Taking his science communication beyond social media, he's been on CBBC's *Blue Peter* and *Horrible Science*; has made TV appearances on shows like *This Morning* and *BBC Breakfast*; and has even given talks at Buckingham Palace and the Houses of Parliament.

But he's not stopped there. Wallace has also recently published a second book in his *Science is Lit* series, *Awesome Electricity and Mad Magnets*, which is filled with physics experiments that children can do at home. He talks to Sarah Tesh about becoming the new face of science communication, and where he hopes this whirlwind journey will go next.

Charlotte Knee Photography

**Access all areas** Emanual Wallace, better known as Big Manny, is bringing science to new audiences.

## What sparked your interest in science?

I've always been really curious. Ever since I was young, I had a lot of questions. I would, for example, open up my toys just so I could see what was inside and how they worked. Then when I was in year 8 I had a science teacher called Mr Carter, and in every lesson he was doing experiments, like exciting Bunsen burner ones. I would say that's what ignited my passion for science. And naturally, I just gravitated towards science because it answered all the questions that I had.

## Growing up, what were the kind of science shows that you were really interested in?

When I was about 11 the show that I used to love was *How it's Made?* And there's a science creator called Nile Red – he creates chemistry videos, and he inspired me a lot. I used to watch him when I was growing up and then I actually got to meet him as well. He's from Canada so when he came over, he came to my house and we did some experiments. To be inspired by him and then to do experiments with him, that was brilliant. I also used to watch a lot of Brian Cox when I was younger, and David Attenborough – I still watch Attenborough's shows now.

## You worked in a school for a while after your degrees at the University of East London – what made you go down that path rather than, say, staying in academia or going into industry?

Well, my bachelor's and master's degrees are in biomedical science, and my aspiration was to become a biomedical scientist working in a hospital lab, analysing patient samples. When I came out of university, I thought that working as a science technician at a school would be a great stepping stone to working as a biomedical scientist because I needed to gain some experience within a lab setting. So, the school lab was my entry point, then I was going to go into a hospital lab, and then work as a biomedical scientist.

But my plans have changed a bit now. To become a registered biomedical scientist you need to do nine months in a hospital lab, and at the moment, I'm not sure if I can afford to take nine months off from my work doing content creation. I do still want to do it, but maybe in the future, who knows.

## What prompted you to start making the videos on social media?

When I was working in schools, it was around the time of lockdown. There were school closures, so students were missing out on a lot of science – and science is a subject where to gain a full understanding, you can't just read the textbook. You need to actually do the experiments so you can see the reactions in front of you, because then you'll be more likely to retain the information.

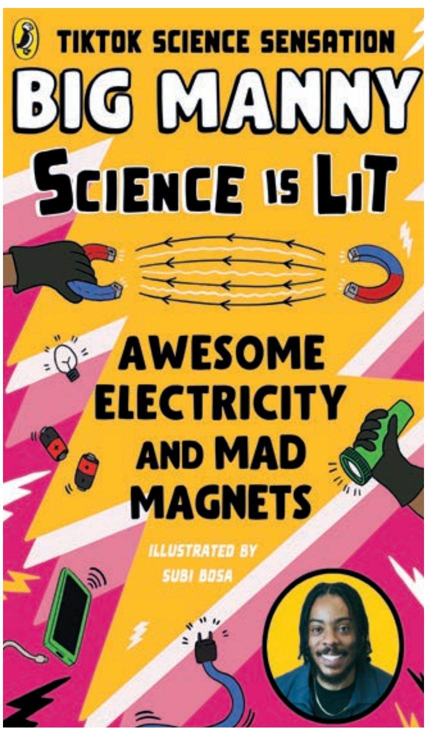
I started to notice that students were struggling because of all the science that they had missed out on. They were doing a lot of Google classrooms and Zoom lessons, but it just wasn't having the full impact. That's when I took it upon myself to create science demonstration videos to help students catch up with everything they'd missed. Then the videos started to take off.

## How do you come up with the experiments you feature in your videos? If you're hoping to help students, do you follow the school curriculum?

I would say right now there's probably three main types of videos that I make. The first includes experiments that pertain to the


Ken McKay/ITV/Shutterstock

**Making science fun** Big Manny (above right) on ITV show *This Morning* with host Alison Hammond and Paddy McGuiness.




Penguin Books

**Sparking interest** Big Manny has now written his own series of children's science books.

national curriculum – the experiments that might come up in, say, the GCSE exams. I focus on those because that's what's going to be most beneficial to young people.

Secondly, I just do fun experiments. I might blow up some fruit or use fire or blow up a hydrogen balloon. Just something fun and visually engaging, something to get people excited and show them the power of science.

And then the third type of video that I make is where I'm trying to promote a certain message. For example, I did a video where I opened up a lithium battery, put it into water and we got an explosion, because I wanted to show people the dangers of not disposing of batteries correctly. I did another one where I showed people the effects of vaping on the lungs, and one where I melted down a knife and I turned it into a heart to persuade people to put down their knives and spread love instead.

## Who would you say is your primary audience?

Well, I would say that my audience is quite broad. I get all ages watching my videos on social media, while my books are focused towards primary school children, aged 8 to 12 years. But I've noticed that those children's parents are also interested in the experiments, and they might be in their 30s. So it's quite a wide age range, and I try to cater for everyone.

## In your videos, which of the sciences would you say is the easiest to demonstrate and which is the hardest?

I'd say that chemistry is definitely the easiest and most exciting because I can work with all the different elements and show how they react and interact with each other. I find that biology can sometimes be a bit tricky to demonstrate because, for example, a lot of biology involves the human body – things like organ systems, the circulatory system and the nervous system are all inside the body, while cells are so small we can't really see them. But there's a lot that I can do with physics because there's forces, electricity, sound and light. So I would say chemistry is the easiest, then physics, and then biology is the hardest.

## Do you have a favourite physics experiment that you do?

I would say my favourite physics experiment is the one with the Van de Graff generator. I love that one – how the static electricity makes your hair stand up and then you get a little electric shock, and you can see the little electric sparks.

## You're becoming a big name in science communication – what does an average day look like for you now?

On an average day, I'm doing content creation. I will research some ideas, find some potential experiments that I might want to try. Then after that I will look at buying the chemicals and equipment that I need. From there, I'll probably do some filming, which I

Big Manny/YouTube

View this e-magazine online to watch a Big Manny video about sound waves coming from a moving train.

Big Manny/YouTube

View this e-magazine online to watch a Big Manny video explaining how oxygen masks on planes provide oxygen in an emergency.

**Science in action** Big Manny's videos on social media have captured the imaginations of viewers of all ages.

normally just do in my garden. Straight after, I will edit all the clips together, add the voiceover, and put out the content on social media. One video can easily take the whole day – say about six or seven hours – especially if the experiment doesn't go as planned and I need to tweak the method or pop out and get extra supplies.

### In your videos you have a load of equipment and chemicals. Have you built up quite a laboratory of kit in your house now?

Yeah, I've got a lot of equipment. And some of it is restricted too, like there's some heavily regulated substances. I had to apply for a licence to obtain certain chemicals because they can be used to make explosives, so I had to get clearance.

### What are you hoping to achieve with your work?

I've got two main goals at the moment. One of them is bringing science to a live audience. Most people, they just see my content online, but I feel like if they see it in person and they see the experiments live, it could have an even bigger impact. I could excite even more people with science and get them interested. So that's one thing that I'm focusing on at the moment.

I also want to do some longer-form videos because my current ones are quite short – they're normally about a minute long. I realize that everyone learns in different ways. Some people like those short, bite-sized videos because they can gain a lot of information in a short space of time. But some people like a bit more detail – they like a more lengthy video where you flesh out scientific concepts. So that's something that I would like to do in the form of a TV science show where I can present the science in more detail.

**Sarah Tesh** is features editor of *Physics World*

Reviews

# A scientific odyssey in pixel form

**Andrew Glester** reviews the computer game *Exographer* developed by SciFunGames


View this e-magazine online to watch a video trailer for the game *Exographer*.

**Exographer**
2024 SciFunGames and Abylight Studios
Nintendo Switch £17.99; PS5 £15.99; Xbox £16.74; PC £16.75

In an era where video games often prioritize fast-paced action and instant gratification, *Exographer* offers a refreshing change. With a contemplative journey that intertwines the realms of particle physics and interactive storytelling, this beautifully pixelated game invites players to explore a decaying alien civilization through the lens of scientific discovery while challenging them with dexterity and intellect.

*Exographer* was developed by particle physicist and science-fiction author Raphaël Granier de Cassagnac and his video-game studio SciFunGames. At its core, it is a puzzle-platformer – where the player's character has to move around an environment using platforms while solving puzzles. The character in question is Ini, an alien explorer who discovers a multifunctional camera in the opening scenes of the game's narrative. Stranded on a seemingly deserted planet, Ini is tasked with unlocking the mystery of the world's fallen civilization.

The camera quickly becomes central to gameplay, allowing for environmental analysis, teleportation to previously visited locations and, most intriguingly, the discovery of subatomic particles through puzzles inspired by Feynman diagrams. These challenges require players to match particle trajectories using various analytical tools, mirroring the investigative processes of real-world physicists.

It is in these games where the particle physics really shines through. Beamlines have to be tracked and redirected to unveil greater understanding of the particles that make up this strange land and, with that, Ini's abilities to understand the world.

As you crack one puzzle, a door opens and off you pootle to another blockage or locked door. Players will doubtless, as I did, find themselves wandering around areas pondering how to unlock it. A tip for those a little stuck: use the camera wherever a background seems a little different. In most circumstances, clues and cues will be waiting there.

The game's environments are meticulously crafted, drawing inspiration from actual laboratories and observatories. I played the game on Nintendo Switch, but it is also available on several other platforms – including PS5, Xbox and Steam – and it looks pretty much identical on each. The pixel art style is not merely a visual choice but a thematic one, symbolizing the fundamental "pixels" of the universe of elementary particles. As players delve deeper, they encounter representations of particles including electrons, gluons and muons, each unlocking new abilities that alter gameplay and exploration.

Meanwhile, the character of Ini moves in a smooth and – for those gamers among us with a love of physics – realistic way. There is even a hint of lighter gravity as you hold down the button to activate a longer jump.

What sets *Exographer* apart is its ability to educate without compromising entertainment. The integration of scientific concepts is seamless, offering players a glimpse into the world of particle physics without overwhelming them. However, it's worth noting that some puzzles may present a steep learning curve, potentially posing challenges for those less familiar with scientific reasoning.

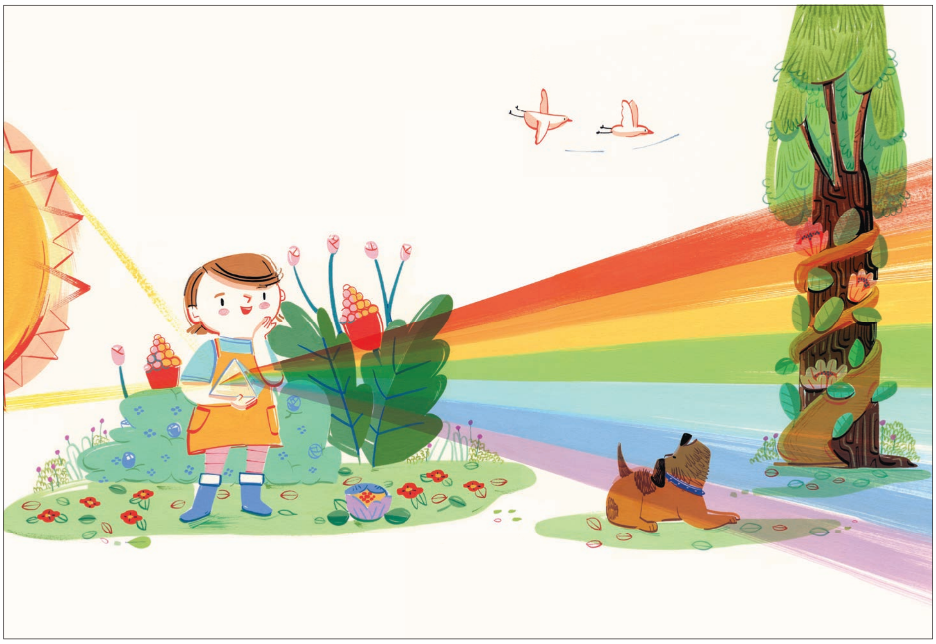
Complementing the game's visual and intellectual appeal is its atmospheric soundtrack, composed by Yann Van Der Cruyssen, known for his work on the game *Stray*. As with *Stray* – where you take the role of a stray cat with a backpack – the music enhances the sense of wonder and discovery, underscoring the game's themes of exploration and scientific inquiry.

*Exographer* is more than just a game; it's an experience that bridges the gap between science and (pixelated) art. It challenges players to think critically, to explore patiently, and to appreciate the intricate beauty of the universe's building blocks. For those willing to engage with its depth, *Exographer* offers a rewarding journey that lingers after the console is turned off.

**Andrew Glester** is a producer and presenter of the *Physics World Stories* podcast. He is also a senior lecturer teaching filmmaking, podcasting, radio and science communication at UWE Bristol, UK

# Illuminating light

**Sarah Tesh** reviews *Light: the Extraordinary Energy That Illuminates Our World* by Jess Wade, illustrated by Ana Sanfelippo






**Colourful science**
*Light* is full of bright pictures and illuminating facts, making the whole spectrum accessible to children.

**Light: the Extraordinary Energy That Illuminates Our World**
*Jess Wade (text) and Ana Sanfelippo (illustrations)*
2025 Walker Books
32pp £12.99hb

As a mother of two, I've read a lot of children's books. While there are some so good that even parents don't mind reading them again and again, it's also very easy for them to miss the mark and end up "accidentally" hidden behind other books. They've not only got to have an exciting story, but also easy wording, a rhythmic pace, flowing language and captivating pictures.

Great non-fiction kids' books are especially hard to find as they need to add in yet another ingredient: facts. As a result, they can often struggle to portray educational topics in an accessible and engaging way without being boring. So when I saw the ever impressive Jess Wade had published her second children's book about physics, *Light: the Extraordinary Energy That Illuminates Our World*, I was intrigued.

Wade is a woman of many talents. She's an accomplished physicist at Imperial College London, a trailblazing advocate for equality in science, and an enthusiastic science communicator. Her first book, *Nano: the Spectacular Science of the Very (Very) Small*, won the 2022 UK Literary Association (UKLA) Book Award for information books (3–14+ years).

And now, with the help of beautiful illustrations by Argentinian artist Ana Sanfelippo, Wade has created a clear, concise explanation of light, how it behaves and how we use it. The book starts by describing where light comes from and why we need it, and goes on to more complex topics like reflection, scattering and dispersion, the electromagnetic spectrum, and technologies that use light.

The language is clear, the sentences are simple, and there is a flow to the narrative that makes up for the lack of a story. Wade makes the science relatable for children by bringing in real-world examples – such as how your shadow changes length during the day, and how apples reflect red light so look red. And throughout, Sanfelippo's gorgeous illustrations fill the pages with colourful images of a girl and her dog exploring the concepts discussed, keeping the content bright and cheerful.

Now obviously I am not the target audience for *Light*. So, as my own children are too young (the age range listed is 7–12 years), I asked my eight-year-old niece, Katie, to take a look.

Instantly, Katie loved the illustrations, which helped keep her engaged with the content as she read – her favourite was one of a cat using a desk lamp to create a shadow. She was intrigued by how fast light is – "you'd have to run seven and a half times around Planet Earth in a single second" – and liked being "let in on a secret" when Wade explains that white light actually contains a rainbow.

But as the book went on, she found some bits confusing, like the section on the electromagnetic spectrum. "It's definitely a book someone Katie's age should read with a grown up, and maybe in two sittings, because it's very information heavy (in a good way)," said her mum, Nicci. Indeed, there are a couple of page spreads that stand out as being particularly busy and wordy, and these dense parts somewhat interrupt the book's flow. "But overall, she found the topic very interesting, and it provoked a lot of questions," Nicci continued. "I enjoyed sharing it with her!"

I think it's safe to say that Wade can add another success to her list of many accomplishments. *Light* is beautiful and educational, and personally, I wouldn't hesitate to give it as a gift or keep it at the front of the bookshelf.

**Sarah Tesh** is a features editor of *Physics World*

# Careers

## Top careers tips from the experts

Physicists have so many career options that it can be hard to know where to start. Careers experts **Crystal Bailey**, **Tamara Clelford**, **Araceli Venegas-Gomez** and **Tushna Commissariat** offer their tips and advice

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**Cornucopia of careers** There are many opportunities out there for you if you have a physics degree. Our experts are here to help you find your way.

Studying physics can so busy and stressful that deciding what you should do after graduating is probably the last thing on any student's mind. Here to help you work out what to do next are four careers experts, who took part in an episode of Physics World Live earlier this year. They all studied physics or engineering – and have thought long and hard about the career opportunities available for physics graduates.

**The four experts are:**

- **Crystal Bailey**, director of programmes and inclusive practices at the American Physical Society (APS);
- **Tamara Clelford**, a physics consultant working in aerospace and currently leading a review of the Chartered Physicist standard at the Institute of Physics, which publishes *Physics World*;
- **Araceli Venegas-Gomez**, chief executive and founder of quantum education company QURECA;
- **Tushna Commissariat**, features editor of *Physics World*, who edits the annual *Physics World Careers* and *APS Careers* guides.

## Our expert panel

**Sound advice** From left to right: Crystal Bailey, Tamara Clelford, Araceli Venegas-Gomez and Tushna Commissariat.

Left to right: APS, T Clelford, Qureca, IOP Publishing

After getting interested in science at high school, **Crystal Bailey** majored in electrical engineering at the University of Arkansas in Fayetteville but soon realized that "physics was the most beautiful thing ever" and did a PhD in nuclear physics at Indiana University in Bloomington. A chance encounter with someone who was in her Morris-dancing group led to Bailey working as career-programme manager at the American Physical Society, where she now serves as its director of programmes and inclusive practices.

Having declared aged five that she wanted to be a nuclear physicist, **Tamara Clelford** studied physics and astrophysics at the University of Sheffield in the UK. She has a PhD in antenna design and simulation from Queen Mary, University of London. After a year teaching physics in secondary schools, Clelford then spent a decade working as an antenna engineer in the defence industry. Following a short spell in a start-up, she now works as a freelance physics consultant in the aerospace sector.

**Araceli Venegas-Gomez** always wanted to work in science or technology and studied aerospace engineering at the Universidad Politécnica de Madrid, before getting a job at Airbus in Germany. However, she always had a passion for physics and in her spare time did a master's in medical physics via distance learning. After taking an online course in quantum physics at the University of Maryland, Venegas-Gomez did a PhD in quantum simulation at the University of Strathclyde, UK. Her experience of business and academia led her to set up QURECA in 2019, which offers resources, careers advice and education to people who want to work in the burgeoning quantum sector.

**Tushna Commissariat** grew up in Mumbai, India, where gazing up at the few stars she could make out in the big-city skies inspired her to study science. While doing a bachelor's degree in physics at Xavier's College, she did a summer astrophysics placement in Pune, where she quickly realized she wasn't cut out for academia. Instead, Commissariat did a master's in science journalism at City, University of London. After an internship at the International Centre for Theoretical Physics in Trieste, Italy, she joined *Physics World* in 2011, where she now works as careers and features editor.

### The career options for physicists are wide but can also seem overwhelming – so what advice do you have for people starting out on their career journey today?

**Crystal Bailey:** Finding a fulfilling career means trying to find something that matches your values. I don't just mean what you're interested in or what you like – but who you are as a person. So the first step always starts with self-assessment and self exploration, exploring what it is you really want from your life.

Do you want a job that has good work-life balance? Do you want something with a flexible schedule? Or do you want to make money? Making money is a very righteous and noble thing to want to do it – there's nothing wrong with that. But when I give careers talks and ask the audience if they've asked themselves those questions, almost nobody raises their hand

So I encourage you to reflect on a time when you've been really happy and fulfilled. I don't just mean were you doing, say, a quantum-mechanics problem, but were you with other people? Were you alone? Were you doing something with your hands, building something? Or was it something theoretical? You need to understand what will be a good match for you.

After you've done that self-assessment and understand what you need, I advise you do "informational interviews", which basically involves getting in touch with somebody – online or in person – to ask them what they do day-to-day. What advice do they have? Where's their sector going?

You'll get real insider knowledge and, more importantly, it'll help you build your network – especially if you follow-up, say, every six months to thank them for advice and update them of your situation. It'll keep that relationship fresh and serve you later when you're actually looking for jobs in a more targeted way.

**Tamara Clelford:** You need to understand what it is you enjoy. Are you a leader or do you like to be managed? Do you prefer to be told what to do? Do you like working in a team or working alone? Are you theoretical or more experimental? Do you prefer research or the real world? Maybe you just want to work with, say, aeroplanes, which is a perfectly valid reason to do so.

You also need to ask yourself where you want to work. Do you want to work in a big company, a medium-sized firm, or a small start up? I began in a large defence company, where I could easily switch jobs if something wasn't the right fit. But in a big firm you often get taken off work as priorities change, so I now work for myself, which is fabulous.

> "Self-assessment – understanding your skills and talents – is really important" Araceli Venegas-Gomez

**Araceli Venegas-Gomez:** The hardest thing is finding out what you like. Your long-term goal might be to get rich or have your own company. Once you work that out, you'll need a short-term plan. It'll probably change but having a plan is a great start. Then ask yourself: are you good at it? That self-assessment – understanding your skills and talents – is really important.

Next, find out what companies are there. Create a LinkedIn profile. Talk to people. Expand your network. Go to careers events. Do mock interviews – maybe not for your dream job but to help you learn how to do them. Learn how to do a CV and apply for jobs. Use all the resources available to you.

**Tushna Commissariat:** My advice is don't leave your job search until just before you graduate. Start looking at internships and summer jobs as early as you can. I recall interviewing one physicist who sent an e-mail to NASA and got an internship at the age of 15. But on the other hand, remember that even if you land your perfect job, it might not work out, and its always okay to change your mind.

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## What is the number one skill – over and above technical knowledge – that physicists have that will help them in their career?

**Crystal Bailey:** Physicists often go into well-paid jobs that have "engineering" in the title, working alongside other STEM graduates. In fact, physicists have many of the same scientific and technical skills that make engineers and computer scientists so attractive to employers. But what sets physicists apart is a confidence that they can teach themselves whatever they need to know to go to the next step.

It's a kind of "intellectual fearlessness" that is part of being a physicist. You're used to marching up to the edge of what is known about the universe and taking that next step over to discover new knowledge. You might not know the answer, but you know you can teach yourself how to find the answer – or find somebody who can help you get there.

> "As physicists, we have the ability to upskill, to improve and to solve whatever problem we want" Tamara Clelford

**Tamara Clelford:** It might not help us narrow down where we want to work, but physicists are capable of solving a huge range of problems. We can root around a problem, look for its fundamental aspects, and use mathematical and experimental skills to solve it. Whether it's a hardware problem, a software problem or the need to derive an equation, we can do all that.

If we're not an expert in a particular area, we know we can go and get the relevant expertise. As physicists, we know where our limits are. We're not going to make stuff up to sound better than we are. We have the ability to upskill, to improve and to solve whatever problem we want.

**Araceli Venegas-Gomez:** As physicists, we have a multidisciplinarity that we often don't realize we have. If you're, say, a marine engineer, you're going to work in marine engineering. But as a physicist, you can work anywhere there's a job for you. What's more, physicists don't only solve problems; we also want to know why they exist. It might take us a bit longer to find a solution, but we look at it in a way that engineers might not.

> "One of the brilliant things about physicists is that they are absolutely confident that they can come in and fix a problem" Tushna Commissariat

**Tushna Commissariat:** One of the brilliant things about physicists is that they're absolutely confident that they can come in and fix a problem. You see physicists going into biology and saying "Oh cancer, I can do that". There are physicists who've gone into politics and into sport. I've even seen physicists improving nappies for babies.

At the same time, there's almost a joy in failure: if something doesn't work or goes wrong, it means something exciting and interesting is about to happen. I remember Rolf-Dieter Heuer, who was then director-general of CERN, saying it'll be more exciting if we don't find the Higgs boson because it would have meant the Standard Model of particle physics is broken – which would open up a wealth of possibilities.

## What do you know today that you wish you'd known at the start of your career?

> Don't doubt yourself. Don't let anybody tell you that you can't do something Crystal Bailey

**Crystal Bailey:** When I went to grad school, I liked physics and thought "I'm good at it and I want to keep doing physics". But I didn't really having a clear reason for staying in academia. I was just doing what I thought was expected of me and didn't even want a career in academia. So I wish I had had more of a sense of ownership and a little more confidence about my career.

The key message is: don't doubt yourself. Don't let anybody tell you that you can't do something. It's your life – and what you want is the most important thing. I just wish I had been given a little more encouragement and a little more confidence to go in new directions.

**Tamara Clelford:** In life, your priorities change and it's very difficult to project into the future. At any particular time, you have certain experience and knowledge, on which you make the best decision you can make. But if, in five or 10 years' time, you realize things aren't working, then change and do something else. Trust your instincts – and change when you need to change.

**Araceli Venegas-Gomez:** I wish I'd known at the start of my career that everything's going to be okay and there's no need to panic. If you're doing a PhD and you don't finish it, that's fine – I don't think I've ever met a single physicist who's ended up jobless. There are millions of options so remind yourself that everything is going to be okay.

**Tushna Commissariat:** When you're studying, it's easy to feel you're in a kind of bubble universe of exams, practicals or labs. Set backs can feel like the end of the world when they really aren't: your marks on a particular test won't determine your entire future. Remember that you gain so many useful skills while studying, whether it's working with other people or doing outreach work, which might seem a waste of time but are great for your CV.

- This article is based on the 9 April 2025 episode of Physics World Live, which you can watch on demand on our website.
- For more information, check out *Physics World Jobs*, the *Physics World Careers* guide, and the careers services offered by the Institute of Physics.

## **Ask me anything:** Tom Driscoll

With a PhD in physics from the University of California, San Diego, Tom Driscoll is the founder and chief technology officer of the Seattle-based firm Echodyne, which uses metamaterials to build radar technology for both commercial and defence applications. He was previously managing director of the Metamaterials Commercialization Center at the technology incubator Intellectual Ventures


Echodyne

### What skills do you use every day in your job?

I'm thankful every day that my physics background helps me quickly understand information – even outside my areas of expertise – and fit it into the larger puzzle of what's valuable and/or critical for our company, business, products, team and technology. I also believe it's under-appreciated how difficult it is to communicate clearly – especially on technical topics or across large teams – and the challenge scales with the size of the team. Crafting clear communication is therefore something that I try to give extra time and attention to myself. I also encourage the wider team to follow that example and do themselves as they develop our technology and products.

### What do you like best and least about your job?

The best thing for me is that every day, every task and action, no matter how small, helps bit-by-bit to build a world that is safer and more secure against the backdrop of dramatic changes in autonomy. What's also great are the remarkable people I work with – on my team and across the company. They're dedicated, intelligent, and each exemplary in their own unique ways. My least favourite part of the job is PowerPoint, which to me is the least effective and most time-consuming means of communicating ever created. In the business world, however, you have to accept and accommodate your customers' preferences – and that means using PowerPoint.

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

I wish I'd known that anyone who believes a hardware start-up will only take three or four years to develop a product has to be kidding. But jokes aside, I believe that learning things is often more valuable than knowing things – and the past 11 years have been an amazing journey of learning. If I had a time machine would I go back and tweak what I did early on? Absolutely! But would I hand myself a cheat-sheet that let me skip all the learning? Absolutely not!

# Recruitment

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# Buzzing all the way

**Colin White** explains how talking to 150 school children about physics proved to be an unnerving but rewarding experience

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After 40 years lecturing on physics and technology, you'd think I'd be ready for any classroom challenge thrown at me. Surely, during that time, I'd have covered all the bases? As an academic with a background in designing military communication systems, I'm used to giving in-depth technical lectures to specialists. I've delivered PowerPoint presentations to a city mayor and council dignitaries (I'm still not sure why, to be honest). And perhaps most terrifying of all, I've even had my mother sit in on one of my classes.

During my retirement, I've taken part in outreach events at festivals, where I've learned how to do science demonstrations to small groups that have included everyone from babies to great-grandparents. I once even gave a talk about noted local engineers to a meeting of the Women's Institute in what was basically a shed in a Devon hamlet. But nothing could have prepared me for a series of three talks I gave earlier this year.

I'd been invited to a school to speak to three classes, each with about 50 children aged between six and 11. The remit from the headteacher was simple: talk about "My career as a physicist". To be honest, most of my working career focused on things like phased-array antennas, ferrite anisotropy and computer modelling of microwave circuits, which isn't exactly easy to adapt for a young audience.

But for a decade or so my research switched to sports physics and I've given talks to more than 200 sports scientists in a single room. I once even wrote a book called *Projectile Dynamics in Sport* (Routledge, 2011). So I turned up at the school armed with a bag full of balls, shuttlecocks, Frisbees and flying rings. I also had a javelin (in the form of a telescopic screen pointer) and a "secret weapon" for my grand finale.

### A question of sport

Our first game was "guess the sport". The pupils did well, correctly discriminating the difference between a basketball, softball and a football, and even between an American football and a rugby ball. We discussed the purposes of dimples on a golf ball, the seam on a cricket ball and the "skirt" on a shuttlecock – the feathers, which are always taken from the right wing of a goose. Unless they are plastic.

As physicists, you're probably wondering why the feathers are taken from its right side – and I'll leave that as an exercise for the reader. But one pupil was more interested in the poor goose, asking me what happens when its feathers are pulled out. Thinking on my feet, I said the feathers grow back and the bird isn't hurt. Truth is I have no idea, but I didn't want to upset her.

Despite the look of abject terror on the teachers' faces, we did not descend into anarchy

Then: the finale. From my bag I took out a genuine Aboriginal boomerang, complete with authentic religious symbols. Not wanting to delve into Indigenous Australian culture or discuss a boomerang's return mechanism in terms of gyroscopy and precession, I instead allowed the class to throw around three foam versions of it. Despite the look of abject terror on the teachers' faces, we did not descend into anarchy but ended each session with five minutes of carefree enjoyment.

There is something uniquely joyful about the energy of children when they engage in learning. At this stage, curiosity is all. They ask questions because they genuinely want to know how the world works. And when I asked them a question, hands shot up so fast and arms were waved around so frantically to attract my attention that some pupils' entire body shook. At one point I picked out an eager firecracker who swiftly realized he didn't know the answer and shrank into a self-aware ball of discomfort.

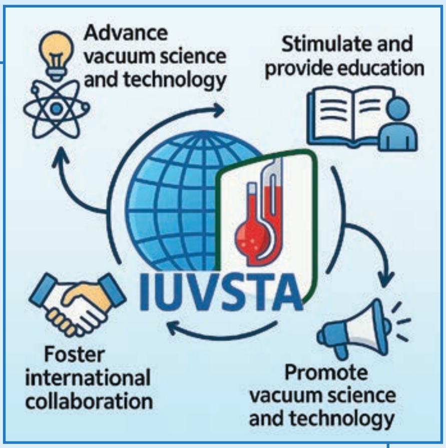
Mostly, though, children's excitement is infectious. I left the school buzzing and on a high. I loved it. In this vibrant environment, learning isn't just about facts or skills; it's about puzzle-solving, discovery, imagination, excitement and a growing sense of independence. The enthusiasm of young learners turns the classroom into a place of shared exploration, where every day brings something new to spark their imagination.

How lucky primary teachers are to work in such a setting, and how lucky I was to be invited into their world.

**Colin White** was a lecturer in physics and sports science at the University of Portsmouth, UK, where he was also the science faculty's education director. Now retired, he is a STEM ambassador

IUVSTA serves to advance Vacuum Science and Technology enabling nanotechnology, surface engineering, quantum science, semiconductor chips and more; Stimulates and provides education through Workshops, Technical Training Courses, Schools, Short Courses and Webinars; Promotes vacuum technology through scholarships and awards aimed at both early-career and established vacuum scientists from multiple disciplines; and fosters international collaborations with organization of 35 different countries of the world.

# A Message from the President of IUVSTA
## **"Vacuum, the Enabling Technology for a Better Life!"**




As the incoming President for the world's vacuum societies union, IUVSTA, I'm excited to share my vision for how vacuum science and technology can be both an engine for our world's innovation economy and build a more robust and resilient society at time where we are collectively facing challenges never seen before.

IUVSTA (International Union for Vacuum Science, Technique and Applications) represents over 100,000 scientists, engineers and technicians comprising 35 members nations. The members of the union do work that is important and critical to emerging technologies including quantum science, advanced computing, semiconductors, biotechnology and advanced manufacturing. IUVSTA's role is to connect and communicate with the member countries, and to organize a number of scientific conferences, including the International Vacuum Congress (IVC-23, Sydney Australia Sept 15-19th, 2025), and to coordinate the organization and funding of Workshops, Technical Training Courses, Schools, and Short Courses and Webinars.

The Union funds and runs awards aimed at both early-career and senior scientists. These IUVSTA awards include the IUVSTA Prize for Science, the IUVSTA Prize for Technology, the IUVSTA Medard W. Welch International Scholarship, the IUVSTA EBARA Award, and IUVSTA Elsevier Student Travel Awards. One of the major goals that I will be working on over the next three years is public outreach to make the connections between the science done by our IUVSTA Divisions of Applied Surface Science, Biointerfaces, Electronic Materials & Processing, Nanometer Structures, Plasma Science & Technologies, Surface Engineering, Surface Science, Thin Film, Vacuum Science and Technology, and the IUVSTA Working Group on Sustainability and its impact on the everyday life for the citizens of the world. These impacts show up in many ways, everything from faster smaller, lighter computer chips to artificial intelligence systems, to self-driving cars, to a more energy efficient and resilient systems needed to address more aggressive weather patterns.

I look forward to working with you!"

Dr. Jay Hendricks, IUVSTA President 2025-2028.
Jay works at National Institute of Standards and Technology (NIST), in Gaithersburg, Maryland, USA, is the Deputy Program Manager for the "NIST on a Chip" Program and has worked at NIST 29 years.