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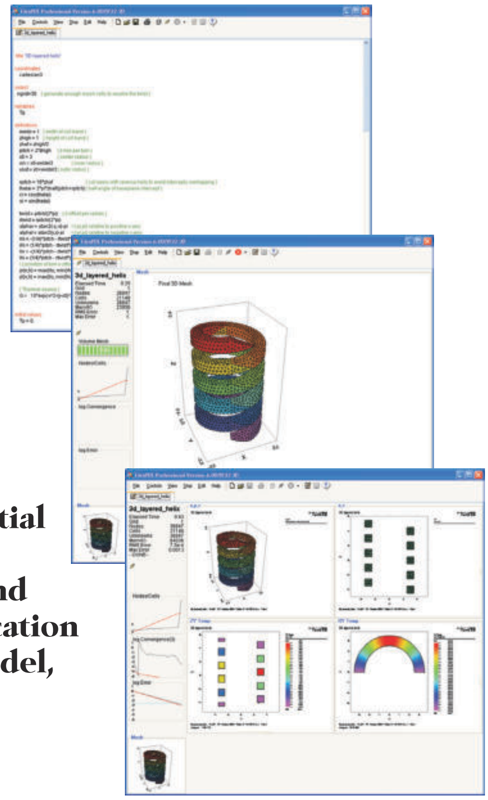

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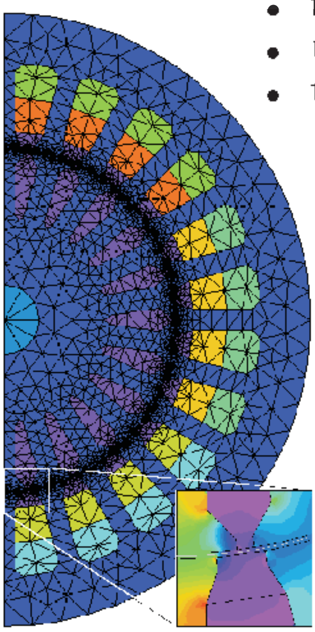

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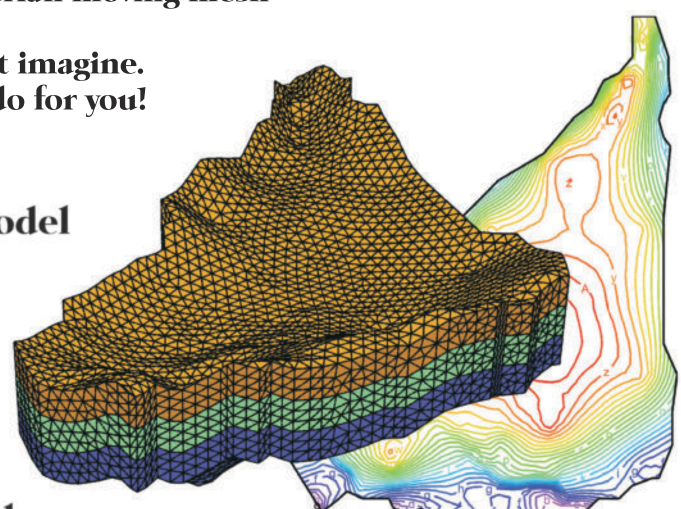

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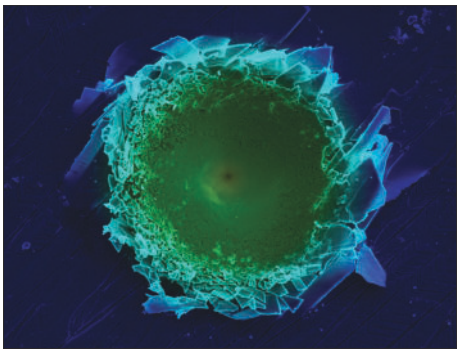

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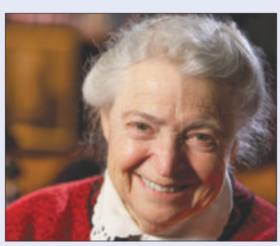

Multimedia

Check out these videos in the digital version of *Physics World* this month:
- What is a gravitational wave? (p6)
- The pitch drop that dripped (p26)
- Mildred Dresselhaus interview (p50)

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For the record

We have an open-door policy, and would love to work with the best scientists in the world – wherever they are based

Wu Ji, *director-general of the Chinese Academy of Science's National Space Science Center in Beijing, quoted in* Nature

China is looking for more international collaboration given the high cost of space missions.

This is definitely a race

Li Zhong, *a physicist at the Chinese Academy of Science's Shanghai Advanced Research Institute, quoted in the* South China Morning Post

China is trying to accelerate research into thorium-based nuclear reactors that could see the opening of such a facility by 2024.

We need to rethink what the 21st-century success story looks like

University of Cambridge physicist **Athene Donald** *quoted in the* Guardian

Donald says that we need to broaden our definition of professional success for men and women and take into account the fact that the default professor is not necessarily male.

I see more and more scientists making huge effort to translate – to not use weird weirdo words

Christiana Figueres, *executive secretary of the United Nations Framework Convention on Climate Change, quoted in the* Independent

Figueres says that we need to put a "human face" on climate change, adding that we also need to communicate it better.

I don't want it to be about me or my funny name

Omar Hurricane *from the Lawrence Livermore National Laboratory quoted in the* New York Times

Hurricane tries unsuccessfully to deflect credit from himself to his group at the National Ignition Facility for a recent breakthrough where more energy was produced from the fusion reactions than was deposited in the fuel.

It was relentless

Stand-up mathematician **Matt Parker** *quoted in* New Scientist

Parker together with physics graduate Helen Arney and comedian Steve Mould have just completed a 10-week tour of Full Frontal Nerdity, which featured 29 shows in the UK.

Seen and heard

Shutterstock/Darrenp

Strike a light

Golfers who have had a good round might claim – metaphorically at least – to have set the course on fire. But James Earthman, a materials scientist at the University of California, Irvine, has now found that golfers can literally create sparks if they strike their clubs too fast against a rock. Earthman came to the conclusion after being asked by the Orange County Fire Authority to see how two fires could have started at local golf courses back in 2010. Both incidents were apparently caused by golfers swinging their titanium-headed golf clubs in "arid rough areas", which usually contain rocks and other debris. Earthman and his team used a high-speed camera to see what happened when three titanium clubs and three made from stainless steel – a more common club-head material – were put through their paces, finding that sparks flew with the steel-headed clubs, but not from those made from titanium. Earthman, who says he "tries to play golf" with a handicap around 20, found that the glints could last for a second, reaching a searing 1500 °C – enough to cause dry vegetation to ignite – and could travel more than a metre. Clubs in California are now asking golfers to take a penalty drop away from the stones, although they might do better not shunting their balls into the rough in the first place.

Model behaviour

Here's a thought for anyone planning a scientific meeting. Organizers of this year's annual conference of the Middle European Cooperation in Statistical Physics, held at the Coventry University in the UK last month, asked all registered participants to guess how many people they thought would attend the meeting. Their aim was to test a model that says that the final number of participants at any conference is three times the value calculated from an extrapolation of the initial registration frequency (*Nature Phys.* **3** 746). Masayuki Hase from the University of São Paulo in Brazil and Michael Moore from the UK's University of Manchester were the only attendees to guess the final figure of 110 correctly and can now look forward to their prize, which was a selection of traditional English craft ales. The real loser was the model itself, which predicted an attendance of 270. "The wisdom of the crowd is still ahead of any of these models," says Coventry's Martin Weigel.

Celebrity physicists

This column has long featured celebrities venting their love of physics – a trend that looks set to continue after Fred Durst told *Kerrang!* magazine that he is "obsessed" with physics. The frontman for the US heavy-metal group Limp Bizkit (admit it, you'd never heard of him) adds that he is a big fan of Albert Einstein and Stephen Hawking. "I read a lot – the only books I've read in the past 10 years are physics books," Durst told readers. Not to be outdone, UK pop star Charlotte Church has also expressed her interest in physics, saying she is now considering taking a degree in the subject. Church adds that the opening track on her latest EP – entitled "Entanglement" – is inspired by quantum physics and even says she is a fan of science magazines, including *New Scientist*. "I buy that instead of those gossip magazines or the other s*** you get," she told *Metro*. Perhaps she should try *Physics World* instead.

Who's the fool?

We were feeling pretty pleased with ourselves last month after posting an April Fool's joke on the *Physics World* blog about a call by astronomers at Jodrell Bank Observatory in the UK for a one-day, global microwave-oven ban. We claimed they wanted to prohibit the kitchen gadgets to give scientists more chance of finding gravitational waves from the early universe imprinted on the cosmic microwave background (see pp6–7). On a filming trip to the Cheshire observatory the following day, however, we found that truth can be stranger than fiction as Jodrell Bank staff had actually built a Faraday cage around the microwave in their tearoom (see image) to block electric fields from exiting the oven and creating unwanted noise in their radio-telescope observations. It was a case of microwaved egg on our faces.

Frontiers

In brief

‘Seismic invisibility cloak’ put to the test
Vulnerable buildings could be shielded from damaging earthquakes by surrounding them with “seismic invisibility cloaks”. An early prototype of such a cloak has been tested experimentally by researchers in France, and it involves modifying the ground around a building to divert seismic waves. The team buried a source vibrating at 50 Hz below the surface of a sedimentary basin. They then bored 5 m-deep holes at a distance to modify the density and elastic modulus of the soil. The team found some regions on the other side of the boreholes recorded less than 20% of the oscillation amplitude, showing that the modified soil had stopped much of the wave energy. In principle, the concept could be extended to create protective barriers around sensitive facilities such as nuclear power plants (*Phys. Rev. Lett.* **112** 133901).

Towards a cosmic barometer
Certain carbon-based molecules could be used to trace extreme pressure and temperature environments in the universe that are caused by supernovae or colliding planets, thanks to new research carried out by scientists in the UK. According to the team, studying aromatic hydrocarbons – molecules with certain benzene rings – that are often found in meteorites could allow us to investigate imprints left on the hydrocarbons by violent events in our universe’s past (*ApJ* **784** 98). The researchers conducted laboratory tests using dimethylnaphthalenes that have already been shown to exist in carbonaceous dust in the interstellar medium. The team subjected them to pressures of 0.5–21 GPa, and found that the dominant spectroscopic features of the isomers characteristically shifted to bluer wavelengths with increasing pressure.

Four-molecule mechanical resonator
Researchers in Austria have made the smallest ever nanomechanical resonator from just four molecules of α,γ-bisdiphenylene-β-phenylallyl (BDPA). The researchers imaged BDPA molecules by moving a scanning tunnelling microscope tip across the chain and measuring the small electrical current between the tip and the gold surface. They found that at a temperature of 5 K, the chain appears as a thin line of molecules. However, when the temperature is increased to 20 K or higher, the molecules in the chain look wider the further the tip is moved along, indicating that the chain is vibrating. The oscillating cantilever could be used to detect single atoms or molecules (*Phys. Rev. Lett.* **112** 117201).

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Single-atom gates get quantum


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Lightly massive Atomic and photonic qubits interact.

A quantum-information analogue of the transistor has been unveiled by two independent groups in Germany and the US. Both devices – which comprise a single atom that can switch the quantum state of a single photon – are a major step towards the development of practical quantum computers. Such computers store information in qubits, which are a superposition of both 0 and 1. When qubits are entangled, any change in one immediately affects the others, allowing certain complex problems to be solved much faster than with a classical computer.

Qubits can be created from either light or matter, but many researchers believe that practical quantum computers of the future will have to rely on interactions between the two. Unfortunately, it is extremely challenging to make a single photon and a single atom interact, as the two are much more likely to pass straight through each other. The two new devices, however, manage that feat using a scheme involving an optical cavity, which was first proposed in 2004 by physicists in the US.

If a photon incident on the cavity has just the right wavelength to make the cavity resonate, it will be absorbed, reflect off one of the mirrors and come back out again, with the departing photon experiencing a phase shift in the process. The trick is that the resonance of the cavity depends on the state of the atom – if the atom is in a different state, the cavity does not resonate and the photon does not receive a phase shift. The state of the atom therefore controls the phase-state of the transmitted photon, like the gate voltage controlling the current in an ordinary transistor.

In the new work, Stephan Ritter and colleagues at the Max-Planck-Institute of Quantum Optics in Garching have used an optical Fabry–Perót cavity, consisting of two curved mirrors roughly half a millimetre apart (*Nature* **508** 237). Meanwhile, at Harvard University and the Massachusetts Institute of Technology, Mikhail Lukin and colleagues used a silicon chip with a cavity measuring just a few microns in size (*Nature* **508** 241). In both demonstrations, it is the spin of the trapped atom that controls the resonance of the cavity.

Both groups can prepare the atom in a superposition of up and down spins – therefore allowing quantum logic operations to be performed – and are now trying to link several atoms in optical cavities to build a prototype quantum network computer.

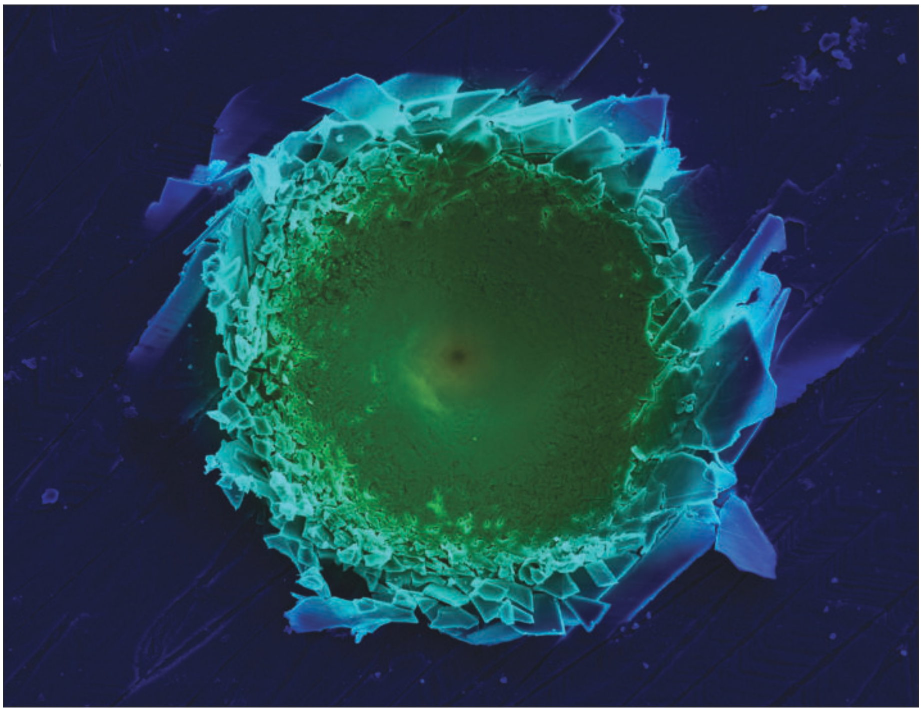
Stamping 2D with ease

Picking up a tiny flake of material just one atom thick and placing it with precision onto a substrate is no easy task. But now that job has become a bit easier, thanks to researchers at the Kavli Institute of Nanoscience in the Netherlands who have come up with the first all-dry technique for transferring 2D materials such as graphene and molybdenum sulphide onto other materials. The method could help researchers make real devices from 2D materials by stacking 2D layers on top of one another.

Most techniques for making such heterostructures involve wet chemistry, and use chemicals that often contaminate the 2D materials, adversely affecting their pristine electronic and physical properties. Moreover, the capillary forces between the chemicals and the material being transferred can cause their 2D structure to collapse.

The new all-dry technique – developed by a team led by Herre van der Zant and Gary Steele – involves peeling off 2D flakes from a parent 3D crystal using adhesive film (*2D Materials* **1** 011002). These layers are then attached to a thin layer of a commercially available viscoelastic material, which acts as a stamp. “To transfer the flake, we press the stamp against the sample surface and peel it off very slowly,” says team member Andres Castellanos-Gomez. The whole process takes no more than 15 minutes.

The team used the technique to transfer graphene flakes onto a 2D hexagonal boron nitride. Using an optical microscope, the researchers confirmed that nearly half of the graphene flakes lie flat on the boron nitride without any bubbles or wrinkles. The team has also succeeded in transferring a single-layer molybdenum disulphide crystal onto a silicon oxide/silicon substrate pre-patterned with holes of different diameters.



Ling Li and James C Weaver

Scientists crack oyster's secret of strength

The blue hues of this colourized, scanning electron micrograph show localized damage on the shell of a windowpane oyster (*Placuna placenta*). The image was taken by Christine Ortiz and Ling Li at the Massachusetts Institute of Technology, who uncovered a series of nanoscale mechanisms that make such transparent oyster shells resistant to the piercing teeth of predators. Living in waters off the Philippines and other parts of the tropical central Indo-Pacific region, the windowpane oyster's shell might be the toughest see-through material in nature, with the studies revealing that the shell's toughness is due to how its very thin calcite layers respond to being hit. These layers make up about 99% of the mass of the shell and have an average thickness of 300 nm, consisting of elongated, diamond-shaped tiles that are arranged like a mosaic, between which lie much thinner layers of organic material. Attempts to break through the shell using a hammer with a micron-sized diamond tip caused narrow bands of atoms within individual calcite crystals to shift into new orientations, a phenomenon known as deformation "twinning". These bands absorbed much of the energy of impact without the crystal cracking, while also triggering other inelastic mechanisms that helped dissipate energy (*Nature Mat.* 10.1038/nmat3920).

Saliva-powered fuel cell

A micron-sized microbial fuel cell that contains multilayer graphene and works using saliva or other waste liquids has been created by an international team of researchers. The device, which can produce nearly 1 μW of power, has been made by a team of researchers led by Muhammad Hussain at the King Abdullah University of Science and Technology in Saudi Arabia together with colleagues in the US.

Microbial fuel cells, which rely on bacteria to generate electricity from waste, usually contain two chambers in which the cathode and anode are separated by a semi-permeable membrane. The new device consists of multilayer graphene foil for the anode and uses – for the first time in such a micron-sized cell – air as the cathode. More importantly, the researchers have avoided using a membrane altogether, which greatly simplifies the device and removes the internal resistance associated with this structure that otherwise reduces current output from a fuel cell (*NPG Asia Mat.* **6** e89).

The team found that its device produces higher current densities than any such cell to date. Moreover, the graphene anode generates 40 times more power than is possible using an ordinary carbon-cloth anode.

One unexpected application of the cell is that it could be used to predict ovulation because saliva's conductivity decreases sharply about five days beforehand, mostly due to a peak in oestrogen levels. The new cell could measure this change in conductivity and so identify when a woman is most fertile. The power generated by the device could also perhaps be harnessed to send the data to a smartphone. Such an application could therefore help in better family planning in a non-invasive, easy-to-use way.

Innovation

Graphene gains thermal vision

The first room-temperature, high-sensitivity infrared photodetector has been designed by a team in the US. The device is based on graphene – a layer of carbon just one atom thick – and works across the full infrared spectrum.

Zhaohui Zhong, Ted Norris and colleagues from the University of Michigan developed photodetectors that can take advantage of graphene's unique properties, including its ability as a semi-metal to absorb light over a wide range of frequencies. Conventional photodetectors, which are made from semiconductors, can only absorb light at specific wavelengths.

Used in night-vision goggles, infrared detectors can also detect heat leaks, monitor blood flow and identify certain chemicals in the environment. However, they require a combination of technologies to accurately detect the whole of the infrared spectrum. Indeed, detecting mid-infrared and far-infrared radiation requires the sensors to operate at very low temperatures.

While graphene has been used previously to make photodetectors, these have been limited by their poor sensitivity. Being just one-atom thick, graphene absorbs only about 2.3% of the light incident on it, meaning that its sensitivity is up to 1000 times lower than the level a commercial device would require. Zhong's design has hugely improved upon this sensitivity by creating the device from two graphene sheets with a thin tunnelling-barrier layer between them. When light hits the top layer of graphene, it creates "hot" electrons and holes with high energy.

"By designing the material interfaces properly, the hot electrons will tunnel through the barrier layer into the bottom graphene layer, while leaving behind positively charged holes on the top graphene layer," explains Zhong. "The positively charged holes can produce an electrostatic gating effect and this affects the current readout of the bottom graphene layer." Measuring the change in current allows the team to detect the brightness of the light incident on the detector.

Rather than trying to directly measure the freed electrons, the team configured the bottom-layer graphene as a field-effect transistor, which provides an intrinsic gain to amplify the tiny current and so overcomes graphene's natural low sensitivity. "We can make the entire design super-thin," says Zhong. "It can be stacked on a contact lens or integrated with a mobile phone." The team is currently working on making an infrared camera from an array of the detectors, the prototype of which will be ready in a few years (*Nature Nanotech.* **9** 278).

News & Analysis

Sifting the first evidence for inflation

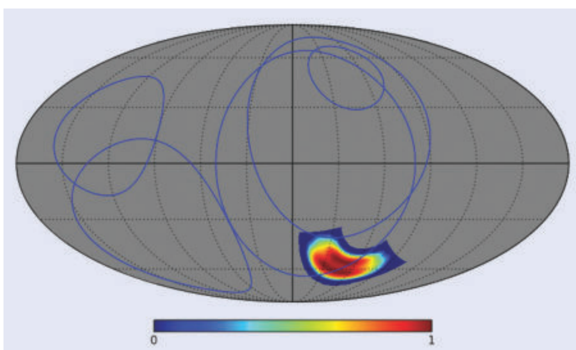
Does BICEP2's measurement of primordial B-mode polarization open a window on the early universe or has it fallen foul of an unexpected signal from galactic radio loops? **Tushna Commissariat** investigates

Trying to decipher what happened to our nascent universe when it was a mere fraction of a second old is no easy task. So when astronomers from the Background Imaging of Cosmic Extragalactic Polarization (BICEP2) telescope at the South Pole claimed in March that they had detected the primordial "B-mode polarization" of the cosmic microwave background (CMB) for the first time, the news hit headlines around the world. This polarization signal is related to primordial gravitational waves that are thought to have abounded in the early universe. If confirmed, the signal could be the first tentative evidence for "cosmic inflation" – the extremely rapid expansion that cosmologists believe our universe underwent a mere 10^{-35} s after the Big Bang.

First proposed in 1980 by Alan Guth and later expanded on by Andrei Linde, the theory of inflation is currently the best explanation to resolve some key cosmological conundrums. We know from measurements of the CMB – the thermal remnant of the Big Bang, which came into being some 380 000 years after it – that the universe is homogeneous, flat and isotropic, whereas the physics of the Big Bang suggests that it should be highly curved and heterogeneous. Inflation solves these problems by suggesting that the entire observable universe originated in a small, causally connected region that expanded at an exponential rate, with the volume of the universe growing by a factor of up to 10^{80} within a tiny fraction of a second, such that the horizon of the universe became much larger and space could be flat.

The theory also irons out any anisotropies or curvature of space, putting the universe into a rather simple state that is only mildly pertubated by quantum fluctuations. These fluctuations are thought to have occurred in a microscopic inflationary region that eventually magnified to cosmic size, becoming the seeds for stars, galaxies and other structures we see in the universe today. The CMB is also important to cosmologists in that it has some variations in temperature of about 100 μK – over and above its otherwise uniform temperature of 3 K – that reveal density fluctuations in the early universe.

Keith Vanderlinde



Philipp Mertsch

Radio loops killed the waves data? Has the BICEP2 telescope (top) seen B-mode polarization of the cosmic microwave background (CMB)? The grey oblate (below) is the universe as seen from Earth. The blue lines trace out galactic loops that have been identified in the CMB by Subir Sarkar and colleagues in the WMAP data. The BICEP2 data appear as the colourful patch on the bottom right of the map.

Gravitational aftershocks

Theorists think extreme gravitational conditions prevailed in the early universe, when space–time would have resonated with the aftershocks of inflation. Gargantuan primordial gravitational waves are thought to have propagated through the entire universe, producing a cosmic gravitational-wave background, which would have left its own imprint on the polarization of the CMB – a sort of "curl" component or rotation, which is the primordial B-mode polarization.

But there is another type of polarization signal – known as the E-mode – which describes how the magnitude of polarization varies across the CMB. Unfortunately, scientists cannot distinguish between the B-mode polarization caused by gravitational waves, which has a tensor component, and the E-mode polarization, which is caused by density waves and has a scalar component, by simply looking at the CMB temperature variations (see image opposite). Moreover, the B-mode is thought to be much weaker than its counterpart, making the task of detection that much more onerous.

But on 17 March members of the BICEP2 team announced that they had been able to differentiate between the tensor and scalar components by taking certain measurements of the polarization angles that can be detected at each point on the sky, which provide extra information. The team measured the resulting "tensor-to-scalar" ratio to be 0.20 with a statistical significance of about 3σ, ruling out the possibility that the ratio is zero at 7σ. "This has been like looking for a needle in a haystack, but instead we found a crowbar," said BICEP2 co-leader Clem Pryke from the University of Minnesota. The collaboration claimed that "the long search for tensor B-modes is apparently over, and a new era of B-mode cosmology has begun".

Many physicists quickly hailed the results as the first evidence for inflation. "If it's confirmed, it is truly profound – the first direct evidence not only for inflation, but of a quantum behaviour of space and time," said Craig Hogan, director of the Fermilab Center for Particle Astrophysics. Indeed, a video of the BICEP2 collaboration informing Linde of its discovery showed him overcome with emotion. "I always live with this feeling…what if I am tricked?" he said. "What if I believe in [inflation] just because it is beautiful? So this is really helpful to have events like this. Really, really helpful. Thank you so much."

But not everyone is convinced that BICEP2 has truly detected a

B-mode. Neil Turok, director of the Perimeter Institute for Theoretical Physics in Canada, who worked on an inflationary model of his own with Stephen Hawking in the 1990s, soon urged caution, saying that extensive experimental confirmation will be necessary before BICEP2's results can be cemented. While agreeing that the observations seem to be in keeping with inflation, he was worried by a discrepancy with previous CMB data. Indeed, the ratio of 0.20 that BICEP2 measured is much larger than expected from earlier analyses carried out by the European Space Agency's Planck spacecraft and NASA's WMAP mission.

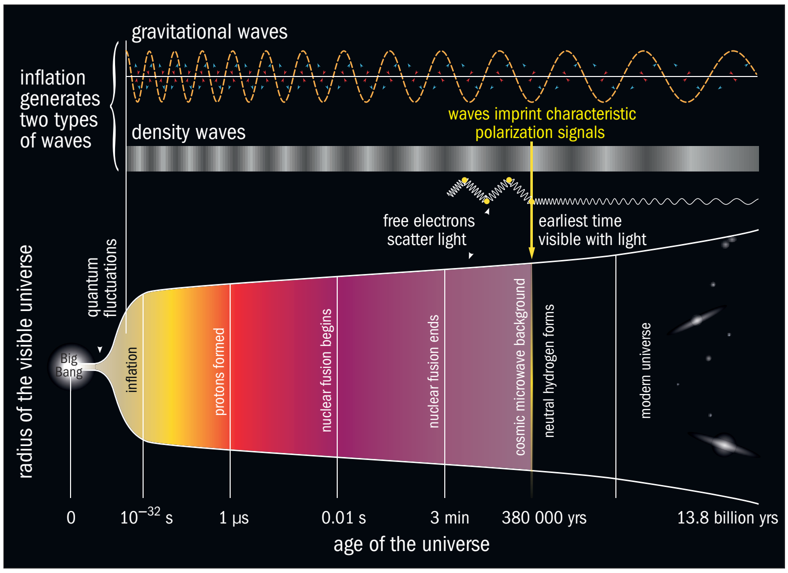
Ugly tweaks

Although the BICEP2 team says that the two results could be made to agree by adjusting an extension of the most common Big Bang cosmological model known as ΛCDM, Turok thinks those tweaks would be "tremendously ugly". In fact, he believes that if both Planck and the new results agree, then together they would give substantial evidence against inflation. "I will quote Carl Sagan and say 'extraordinary claims require extraordinary evidence', and they don't have extraordinary evidence just yet."

Others have been equally cautious about BICEP2's data interpretations, preferring to reserve their judgement until the results are confirmed by other experiments. Indeed, the dust had barely settled on BICEP2's disclosure when a trio of cosmologists, led by Subir Sarkar at the University of Oxford, claimed to have found evidence that emissions from local structures in our galaxy – known as "radio loops" – could generate a previously unknown polarized signal, thus casting doubt on the BICEP2 finding.

Radio loops are thought to be caused by the remnants of ancient supernovae, in the form of shells of gas and dust that have grown to colossal sizes of 100–300 parsecs, after being accelerated by the supernova's shock waves. These loops emit synchrotron radiation when charged particles from cosmic rays gyrate inside their shells' magnetic fields. Researchers need to account for such radiation – including the synchrotron radiation and polarized emission from dust – while carrying out large-scale surveys of the CMB.

A long time ago The illustration shows how, in the early universe, gravitational waves would "curl" the CMB polarization, causing the B-modes, while the density waves create the E-mode polarization.



National Science Foundation/BICEP2

Using WMAP data, Sarkar and colleagues found that the signal from the loops forms a new "foreground" that has evaded the usual "cleaning" methods used by WMAP and Planck scientists on their data, meaning that it could be misinterpreted as a B-mode polarization. A foreground is made up of any emissions that could be confused with primordial CMB photons since they were last scattered at the "epoch of recombination", when neutral atoms first formed and the decoupling of matter and radiation allowed photons to travel freely across the universe.

Star dust

Sarkar, who has been studying radio loops since the 1980s, thinks that if the supernova shells also trap dust enriched with metallic iron or ferrimagnetic molecules, they might produce shorter-wavelength radiation that is polarized, thanks to the grains aligning with the galactic magnetic field. Indeed, Sarkar and colleagues have found evidence for this radiation not only at radio frequencies, but also at microwave frequencies, resulting in a possible contamination of BICEP2's signal, especially as the region of the sky studied by the telescope is crossed by these loops.

The BICEP2 researchers claim to have ruled out known contamination from synchrotron radiation and dust at a statistical significance of about 2.3σ by cross-correlating what they see with the best available models of the same. However, these models do not include the possible new source of foreground Sarkar has identified. But as BICEP2 has not made its sky maps public, he "cannot check if what BICEP2 has seen correlates with these foreground structures".

Another astrophysicist urging caution over BICEP2's claims is Peter Coles from the University of Sussex. "My greatest worry about the BICEP2 results is that the measurement is made at a single frequency, 150 GHz," he says." In order to be convinced that the signal is cosmological, rather than arising from a foreground source, I would need to see it confirmed by other measurements at different frequencies." Coles thinks that a truly cosmological signal would look the same irrespective of frequency, while a foreground emission would vary.

David Spergel, a theoretical astrophysicist at Princeton University, thinks that the radio-loop emission is weak enough to not be a "significant contaminant" in the WMAP and Planck temperature maps. But, as the polarization signal is less than a 100th of the temperature signal, these subtle effects will be much more important for the polarization data.

All eyes are now on the upcoming polarization data from the Planck satellite, which should clarify the situation within the year. "Planck has polarization measurements across the whole sky at multiple frequencies, so it will provide both a detailed characterization of galactic emission," says Spergel. He hopes that the Planck data will confirm the BICEP2 results and show convincingly that the emission is cosmological.

To quote Carl Sagan, 'extraordinary claims require extraordinary evidence', and BICEP2 doesn't have extraordinary evidence just yet

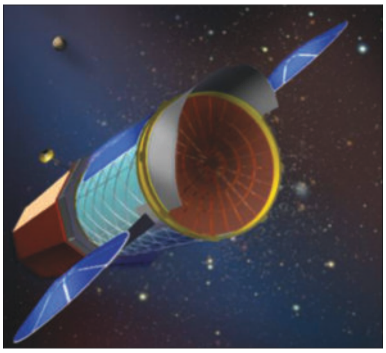
Space

Report warns of rising costs of NASA telescope

NASA's astrophysics programme could be threatened by the rising costs of building the agency's Wide-Field Infrared Survey Telescope (WFIRST) – an instrument to study the nature of dark energy and search for exoplanets. That is a key conclusion of a report by the National Academy of Sciences' National Research Council (NRC), which, while applauding the scientific value of the instrument, warns that the cost hike of building the craft could make the astrophysics programme "challenging" to manage.

First proposed in 1998 after the discovery that the expansion of the universe is accelerating, the concept of a wide-field survey to study dark energy – thought to be the cause of the expansion – has undergone several iterations. By 2010 it had amalgamated with a microlensing survey intended to detect Earth-like exoplanets and in 2011 the mission came top of NASA's decadal survey of planned space-based instruments. WFIRST then became the next big space telescope project after the James Webb Space Telescope, which is scheduled for launch in 2018.

Initial designs for the instrument called for a 1.3 m aperture. But in 2012 the National Reconnaissance Office (NRO) gave NASA two 2.4 m telescopes for which it had no further use. The space agency then asked the NRC to study the scientific and economic implications of refurbishing one of these telescopes into WFIRST as well as the cost value for adding a coronagraph, which blocks out starlight.



JPL/NASA

Cost concerns A report by the National Research Council warns of price hikes in building the Wide-Field Infrared Survey Telescope.

The report concludes that adapting the NRO satellite for WFIRST would "significantly enhance the scientific power", allowing it to meet or even in some cases "significantly" exceed its scientific goals. However, the report warns that the upgrade will result in a "greater likelihood that costs will increase beyond current estimates". The study estimates that WFIRST without the coronagraph would cost around $2.1bn – up from the original $1.8bn price tag.

Yet the report does not say how much WFIRST would cost if it included a coronagraph, noting that the instrument's design is immature and that studies of accommodating it to the mission have been limited. "NASA needs to mature [the design] rapidly, and remove it from the mission if it looks as if it will cause significantly increased risk for cost," says Fiona Harrison, an astronomer at the California Institute of Technology, who chaired the NRC committee. She points out that such extra increases could cut into funds for other smaller missions. "The decadal survey chose WFIRST because it had relatively low cost and low cost risk," she adds. "If properly managed with a budget allocation properly sized and emphasis on the rest of the programme, then it's all great."

Scientists on WFIRST are already working to address the NRC's concerns, according to Dominic Benford, the mission's programme scientist. "We are increasing risk-reduction activities to try to mitigate this concern and lower risk," Benford told *Physics World*, adding that NASA will nominate its key strategic mission for the following decade in 2020. "We're preparing WFIRST to be that mission," he says.

Peter Gwynne
Boston, MA

Europe launches first Sentinel mission

The European Space Agency (ESA) has launched the first satellite belonging to a dedicated programme that will monitor the Earth in unprecedented detail. Launched on a Soyuz rocket from the Guiana Space Centre, Europe's spaceport near Kourou in French Guiana, Sentinel-1 will, among other things, study sea ice in the Arctic and map land surfaces, including forests, water and soil. It is the first part of the Copernicus programme – a fleet of satellites that will be launched in the coming decade.

Measuring 2.8 m long, 2.5 m wide, 4 m high and weighing 2300 kg, Sentinel-1 will orbit the earth at an altitude of 693 km. The craft carries a synthetic-aperture radar system that will study the Earth constantly throughout the day and night and in any weather. It is expected to observe the Earth for seven years, by which time the other six Sentinel craft should have launched. These include Sentinel-2, which is expected to take off next year to monitor vegetation, soil and water, and Sentinel-3, which will monitor sea- and land-surface temperatures.

Earth monitor The Sentinel-1 craft will use radar to study sea ice in the Arctic and map land surfaces.

ESA

Copernicus was previously known as the Global Monitoring for Environment and Security programme (GMES). Later missions such as Sentinel 4 and 5 – which will both study the atmosphere – will not be individual satellites but rather instruments that piggy back on weather-monitoring satellites launched by the European Organisation for the Exploitation of Meteorological Satellites.

"Sentinel-1 is unique in its capacity to serve the user community with timely information, unprecedented observation frequency and free open data distribution," Ramón Torres, Sentinel 1's project manager told *Physics World*. "Although [previous missions] have facilitated scientific discoveries by thousands of investigators, no other space-borne radar system has ever been able to satisfy the needs for truly operational use in the areas of timeliness, revisit rate and affordability." Sentinel-1 and its sister satellites build on previous European efforts to monitor the Earth, which were halted when the Envisat satellite, which launched in 2002, failed in orbit in 2012.

Michael Banks

Astronomy

Boss quits budget-threatened Spanish observatory

The director of a leading Spanish observatory has resigned in protest over drastic budget cuts to the facility. José María Quintana, who has stepped down after just a year as head of the German-Spanish Astronomical Center at Calar Alto (CAHA), claims that the "real motivations" behind the cuts may not have been just to save money. He warns that the reductions will not allow the observatory to carry out its mission and will also force staff to be made redundant.

To maintain the observatory's four telescopes – the largest being 3.5 m – and keep most of the observatory's 40 staff, Quintana had requested a budget of €2.7m for 2014, and €2.6m thereafter. However, CAHA will only get €2.2m this year and will have to get by on just €1.6m in subsequent years. CAHA's future is in further doubt from 2018 when the Max Planck Institute for Astronomy in Heidelberg, Germany, is due to pull out of the observatory. "In my opinion it could be very difficult to manage CAHA within the limits imposed by this funding," Quintana told *Physics World*, adding that it was not an easy decision to step down from the post.

Stepping down The head of the German-Spanish Astronomical Center at Calar Alto has resigned due to a falling budget for the facility.

Quintana's disapproval of the decision is echoed by staff at CAHA. "The most puzzling aspect of all of this is that the €1.6m per year figure is given 'as it is' without any technical implementation plan," says David Galadí-Enríquez, who heads CAHA's astronomy department. "The changes derived from this new budget are being implemented on a day-to-day decision basis, through direct improvization and trial and error," he says. "[The observatory is being] managed in a very chaotic way."

Christina Beck, head of science and corporate communication at the Max Planck Society, which has run CAHA jointly with Spain since 2005, says that its budget reductions were agreed four years ago, in preparation for Germany's departure. "Although such decisions had already been taken in 2010, [Quintana] was not willing to go along that way with the CAHA partners," she says, adding that independent experts had assured the CAHA executive committee in 2013 and prior to 2010, that CAHA could be run on a lower budget. However, CAHA astronomer Jesús Aceituno Castro says that CAHA department heads have tried to say this would not be possible, but that their pleas had fallen on deaf ears. "Just this year we are starting some new international collaborations which will fail if we don't have the resources and people needed for them," he says.

Gemma Lavender

Research

UK physics faces 'catastrophic' funding future

A review of the programme at one of the UK's main funding agencies – the Science and Technology Facilities Council (STFC) – has warned that the council faces a "catastrophic" future if its budget does not increase in the coming years. The report was made public following the announcement in February by the UK chancellor George Osborne that support for basic science will be frozen at £4.6bn per year for the next two years – the same level it has been at since 2010.

The STFC distributes government money for astronomy, particle and nuclear physics as well as supporting the UK contributions to large-scale facilities such as CERN and the Diamond synchrotron in Oxfordshire. Carried out by the STFC's science board last year – but only released in late March after the STFC had used it in budget negotiations – the report looked at three scenarios for future spending: the budget staying the same (known as "flat cash"), a 10% increase and a 10% decrease.

Shutterstock/Stanimir G Stoev

Flat cash A report warns that the static budget of the Science and Technology Facilities Council could erode the UK's reputation as a credible international partner.

The report, written by the 16-strong science board, warns that flat cash "would result in a loss of scientific leadership in many areas that the UK has led for many years and an erosion of the UK's reputation as a credible international partner", adding that the consequences of further constraining the programme over a prolonged period of time would be "catastrophic". Although the impact of flat cash on individual programmes was redacted from the final report, it warns of "additional damage to the UK economy in terms of loss of scientific expertise both from experienced researchers leaving the UK due to a loss of scientific opportunity and from the reduced ability to train the next generation of scientists and engineers".

There was some better news for the UK after the government announced £222m in February for "capital spending" on science as well as some additional money for international subscriptions and for operating large facilities, which will see the STFC's budget increase slightly. In a statement, John Womersley, head of the STFC, says the council is now working to "translate the budget into a programme based on the review's recommendations", adding that the STFC will send its final programme to a council meeting this month for approval. Part of the £222m will go on a £42m "big data" institute to be named after the British computer scientist Alan Turing as well as £19m on a "catapult" centre to help commercialize graphene.

Michael Banks

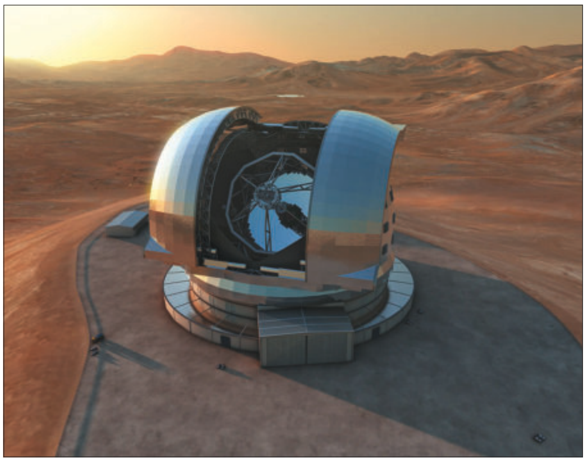
Astronomy

Russian space chief mulls huge 60 m telescope

The rector of Moscow State University has unveiled plans to build a massive 60 m optical telescope on the Canary Islands. Viktor Sadovnichy says that the telescope, if built, would be the world's largest, and would hunt for Earth-like planets around other stars. But the plans have divided researchers, with some Russian astronomers saying the country should not build its own facility but join the European Southern Observatory (ESO) instead.

According to Vladimir Lipunov, director of the Space Monitoring Laboratory at Moscow State University, the telescope would be built by Russia, Spain, and possibly Switzerland and Germany, with Russia getting a quarter of the observing time on the facility. The so-far unnamed telescope would dwarf all existing – and currently planned – facilities including the Chile-bound 39 m European Extremely Large Telescope (E-ELT) and the 25 m Giant Magellan Telescope as well as the Thirty Meter Telescope to be built in Mauna Kea on Hawaii.

"Astronomers are always happy to have a new instrument and will always find a use for it – as there are lots of objects out there to look at," says Sergei Popov of the Sternberg Astronomical Institute in Moscow. However, Popov questions whether it is the best option for Russian astronomy because since 2006 Russia has been debating whether to join the ESO. As a member state, its astronomers would gain access to the ESO's various telescopes, including the Very Large Telescope in Chile and the next-generation E-ELT.



ESO/L Calçada

Grand plans Russia's proposed 60 m telescope would dwarf even the planned 39 m European Extremely Large Telescope.

Membership, however, costs money – and Russia was told it would have to fork out €130m to join plus an annual subscription of some €13m. While the Russian government is deciding whether to allocate the necessary funds, some researchers argue that the money should instead be spent on a facility partly owned by Russia. "The idea is to leave the money at home and use it to build [the 60 m telescope] on the Canary Islands in one of Russia's factories," says Lipunov.

Yuri Balega, director of the Special Astrophysical Observatory of the Russian Academy of Sciences, questions the timing of the proposal to build a 60 m telescope. "Such an instrument will cost at least €2–3bn to build and today we do not have the necessary technologies, engineering power and money to start such a project," says Balega. "Even if we had all that in Russia, such a fantastic telescope would only be built 20–25 years from now." He feels that Russian astronomers, who lag behind the rest of the world, would do best getting access to the ESO's world-class instruments.

Katia Moskvitch

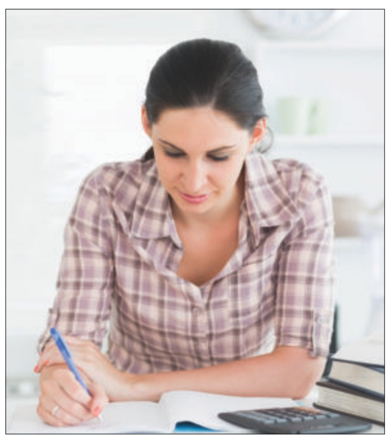
UK

Study shows women fail to land top grants

Women in the UK are less successful than men at securing research council funding at almost every stage of their careers, according to an analysis published by Research Councils UK (RCUK) – the umbrella organization for the country's seven research councils. Covering awards made between 2010 and 2013 in the UK, the analysis found that women do particularly poorly between the ages of 50 and 59 when they are about half as likely as men to secure "large" grants worth at least £1m and lasting more than four years. Above the age of 59 the number of women receiving such grants drops off almost entirely.

For "standard" grants worth less than £1m and lasting fewer than three years, women lag behind men only by a small amount – with an overall success rate of 25% compared to 29% for men. However, this gap widens with age such that success rates for male researchers aged between 40 and 49 rise to about 30% – a level that women do not reach for at least another 10 years. Overall, women make up just 24% of the total applicants for standard grants and 17% for large grants.

The study also shows that 31% of successful female principal investigators are under 40, compared with just 10% for men. "While it's encouraging that there are more younger women applying for awards, the data still indicate the 'leaking pipeline' of female academics in science," says Dorothy Griffiths, chair of Imperial College London's Academic Opportunities Committee. Griffiths adds that she is hopeful that parity will be reached with men soon in terms of success rates. "However, the actual number of [women] applicants is, sadly, still very different," she says.



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Losing out According to a UK study, about 31% of successful female principal investigators are under 40, but women do particularly poorly between the ages of 50 and 59 when applying for grants.

Although some reasons for why women fail to be awarded grants may include unintentional gender bias or lack of support in their early career, some say that the findings rather reflect the dominance of men in UK science, particularly in the physical sciences.

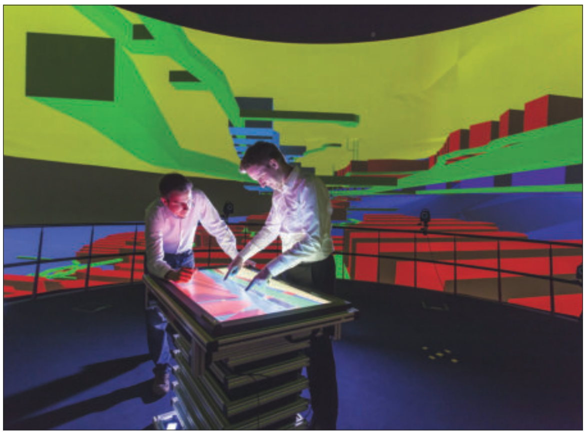
"The results aren't a great surprise," says Helen Wollaston, director of WISE – an organization that promotes women in science – adding that the discrepancy is unlikely to be due to ability. "Women do just as well if not better than men in terms of science exam results, so we would expect female researchers to be just as likely to receive funding as their male counterparts."

Nicola Jenner

Energy

Nuclear waste heads into the virtual

A new computer-based tool designed to help find the best sites for nuclear-waste repositories and to win public confidence in them has been developed by researchers in Germany. The €3m VIRTUS virtual underground laboratory will allow scientists to explore the behaviour of highly radioactive materials inside specific rock formations, with the aim of making it cheaper to develop and build repositories. Critics, however, argue that the new software will do little to improve safety and might disrupt real laboratory studies of nuclear waste.



Dirk Mahler

Testing ground The virtual underground laboratory will let scientists explore the behaviour of highly radioactive materials inside specific rock formations.

Many scientists believe that the best way to dispose of spent nuclear fuel and other long-lived radioactive materials is to bury them hundreds of metres underground, with Sweden and Finland having both selected sites for national waste repositories next to existing nuclear power stations. France plans to open its own facility in 2025, and, like Sweden, has built a major underground lab to test the geology and technologies to be used at the site.

However, the development of a national repository in Germany has been mired in controversy. A formal site-selection process has still to be set up, even though exploratory work at the Gorleben salt mine in the north of the country began as far back as the 1970s. The nearby Asse mine, meanwhile, was set up in the 1960s as a research facility but was decommissioned in 1997 after a brine leak threatened to flood the complex and cause it to collapse.

Developed by the Fraunhofer Institute for Factory Operation and Automation in Magdeburg, together with Germany's nuclear-safety organization (GRS), the Federal Institute for Geosciences and Natural Resources and the waste-repository company DBE Technology, VIRTUS will attempt to partially address this issue. The software enables detailed models of specific rock formations or mine structures to be created and then fed into a simulation to calculate how a repository would evolve physically and chemically over time. The results of these calculations can then be visualized graphically, and it is planned that members of the public will in future be able to see those graphics inside a 360° projection system.

Members of the public will in future be able to see simulations of rock formations evolving over time inside a 360° projection system

Klaus Wieczorek from the GRS, who is also head of VIRTUS, says that the software could, among other things, model the heat emitted by the radioactive decays taking place inside canisters, and the resulting temperature-induced stress that would build up in surrounding rocks. It could be used to improve the design of lab experiments, he explains, and to simulate the performance of potential repositories – ensuring that safety criteria, such as maximum-allowed temperatures, are met and that the position of tunnels can be optimized to minimize mining costs.

A prototype VIRTUS system was supposed to have been completed this spring, but unexpected difficulties associated with matching up the geological models with those simulating the behaviour of nuclear waste has now pushed that deadline back. "We are continually improving the prototype and we will present it to funding institutions in October this year," says Wieczorek. In fact, he admits that it might be "another two or three years" before it is ready for public use.

Johan Swahn of Swedish nuclear-repository watchdog MKG believes that the new software has little or nothing to contribute to research on radioactive-waste disposal. He says that experiments carried out in underground laboratories continue to provide "a lot of surprises". "Creating a generic safety case with a nice visualization will in my opinion only enhance a dangerous belief in modelling, creating a false impression that we have understood more than we actually have," he says.

Edwin Cartlidge

Sidebands

NSF picks first female boss

France Córdova has been sworn in as head of the National Science Foundation (NSF) after confirmation by the US Senate on 12 March. Córdova, who received a PhD in physics from the California Institute of Technology in 1979, spent 10 years at Los Alamos National Laboratory before heading to Pennsylvania State University until 1993. She went on to became the youngest person and the first woman to be NASA's chief scientist – a position she held until 1996. Córdova then was vice-chancellor for research at the University of California at Santa Barbara until 2002 before becoming chancellor of the University of California at Riverside and later, president of Purdue University. Córdova will serve as head of the NSF for six years and succeeds Subra Suresh, who stepped down in March.

Practicals axed from A-level grades

Ofqual – the independent body that monitors exam standards in England – is to reform science A-levels from 2015 so that final grades are based entirely on written tests, with practical exams no longer counting towards a student's final mark. Science practicals will still take place, but the scores will be recorded separately on exam certificates as either "pass" or "fail". Practical exams currently make up 20–30% of a student's final score. Ofqual has reformed the system in part because it is concerned that students use social media to discuss assignments set in practical exams, which students do not all perform at the same time, giving some an unfair advantage. Ofqual's decision has come in spite of a campaign by learned societies, including the Institute of Physics, which publishes *Physics World*, to keep practicals as part of the main A-level grade.

● See also "Test failure" on p15

First MeerKAT antenna installed

The first antenna for South Africa's new radio telescope – the MeerKAT array in the Karoo region – has been installed. When complete in 2017, MeerKAT will feature 64 identical antennas – each being 19.5 m tall and weighing 42 tonnes. MeerKAT will form around 25% of the much larger planned Square Kilometre Array (SKA) of radio telescopes that will be located in Southern Africa and Australia. The 64 antennas will be connected by 170 km of underground fibre-optic cable to allow them to act as a single, highly sensitive instrument, which will be controlled remotely from the MeerKAT control centre in Cape Town.

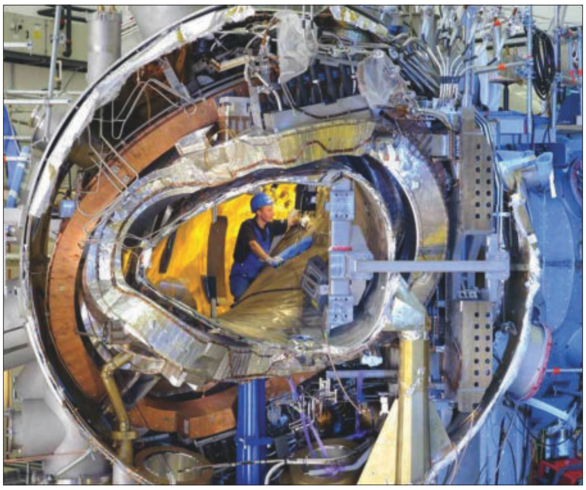
Rebirth of the stellarator

A technology largely abandoned by plasma physicists is making a comeback and might even be the one to give us commercial fusion energy, as **Edwin Cartlidge** reports

On a site near the city of Aix-en-Provence in the south of France the ITER fusion reactor is slowly nearing completion. Due to be finished by the early 2020s, the €15bn "tokamak" machine – the most powerful ever – will mark the culmination of a decades-long international research effort to try and reproduce the process that fuels stars by confining light nuclei at tens of millions of degrees using enormous magnets. While no tokamak to date has yielded a net power output, the 5000 tonne ITER should produce 10 times as much energy as it consumes, and so, say its supporters, finally demonstrate that fusion is indeed a viable source of energy here on Earth.

However, while scientists at ITER are still reeling from a report that criticized the experiment's management (see April pp6–7), other researchers in Germany are switching on a different kind of fusion device. Called Wendelstein 7-X, this machine has been built at the Max-Planck-Institut für Plasmaphysik in Greifswald, next to the Baltic Sea, and since last month has been undergoing commissioning.

The device is modest by the standards of ITER, weighing in at a little over 750 tonnes and costing €1bn. It is also not expected to produce significant quantities of fusion energy. It should, however, be able to do something that ITER cannot, or will struggle to do – operate in a steady state. This is essential if fusion is to become a commercial reality.


MPI-IPP

Hotter than the Sun The Wendelstein 7-X Stellarator, built at the Max-Planck-Institut für Plasmaphysik in Greifswald, Germany, will use 50 niobium–titanium coils to hold plasmas that have a temperature of around 100 million degrees.

An unusual beast

Wendelstein 7-X is a "stellarator" – a type of fusion reactor that predates the tokamak but which fell out of favour after physicists discovered it was not actually very good at containing the heat of an ultrahot plasma. The new German machine has been designed to overcome this problem by using an incredibly complex arrangement of magnets that makes its innards resemble a kind of alien centipede.

Glen Wurden of the Los Alamos National Laboratory in the US is convinced that Wendelstein 7-X will play a vital role in the pursuit of fusion energy. Part of a US team that joined the German project after the National Compact Stellarator Experiment at Princeton was axed in 2008, Wurden argues that tokamaks are "not likely to ever be economical for fusion electricity production". He adds that it is therefore "absolutely essential" that scientists continue to develop other fusion technologies. Large stellarators, he says, are "very difficult to build", but will be "simpler to operate" than tokamaks.

Wendelstein 7-X has been designed from the outset to produce very specific magnetic-field configurations, which means that its coils and the plasma vessel they surround do not have the nice, simple shapes found inside other fusion reactors (see box opposite). To a casual observer, the 50 main niobium–titanium coils might appear to have been randomly twisted and crumpled. In fact, those coils have been designed and manufactured to millimetre precision. They (and the 20 standard coils that add magnetic flexibility) are hidden from view by the 15 m diameter cryostat that keeps them at their superconducting temperatures, and which contains myriad ports of all shapes and sizes to monitor and control the temperature of the plasma.

To a casual observer, the coils might appear to have been randomly twisted and crumpled. In fact, they have been designed and manufactured to millimetre precision

This feat of design and engineering should, if all goes well, allow Wendelstein 7-X to hold plasmas at 100 million degrees for at least as long as, and at densities at least as great as, those achieved in equivalent-sized tokamaks. "To date, tokamaks have always outperformed stellarators. But computer simulations and results from the prototype Wendelstein 7-AS give us strong grounds for thinking that we can achieve tokamak-standard plasmas," says the project's scientific director Thomas Klinger. Wendelstein 7-AS operated from 1988 to 2002 and had a partially optimized magnetic field.

Reaching steady state

The plasma inside Wendelstein 7-X will not be the mixture of deuterium and tritium contained in any potential fusion power reactor, but will instead contain only hydrogen or deuterium. The plasma volume – 30 m^3 – will also be too small to achieve significant self-heating. According to Klinger, however, the facility will be large enough to produce results that can be extrapolated to predict the performance of a self-heated, power-producing stellarator.

Klinger says it should be able to confine the plasma for up to 30 minutes at a time – enough to be dubbed steady state – although he admits that removing the enormous amounts of heat generated will provide a stern test of the facility's cooling system, which relies on 4 km of piping that must be absolutely leak-resistant in order not to destroy the surrounding vacuum. "Supporting a heat flux of up to 10 MW per square metre is technically feasible," he says. "You saw fluxes like that when the Space Shuttle re-entered the atmosphere, and tokamaks do it for between 5 and 30 seconds as standard. But going to 1800 seconds is a big step."

Over the next year the cryostat and plasma vessel will be evacuated and the magnets switched on, with the hydrogen or deuterium gas then injected into the torus and progressively heated using microwaves. At some point in 2016 or 2017, the plasma should reach its design temperature, confinement time and density.

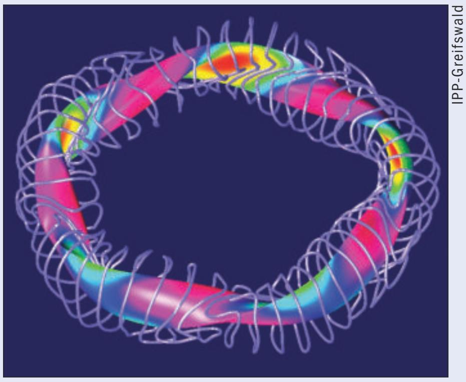
Although fairly small beer compared to the travails of ITER – the cost of which has tripled – Wendelstein 7-X has had its own price tag double from an initial estimate of €550m at the project's outset in 1997. The device has also taken nine

A brief history of the stellarator

Why is fusion so hard?
The basic challenge is trying to hold a plasma of suitable light nuclei at high enough temperatures and pressures for a long enough time that those nuclei fuse and produce heat to generate electricity, as well as stimulating further fusion reactions. As the temperatures involved are so high – far higher than that in the centre of the Sun – the hot plasma would ruin any physical container it is placed in. One way to try and get round this is to confine the plasma for extremely short periods of time using ultrahigh-power lasers, which is the approach being investigated at the National Ignition Facility based at the Lawrence Livermore National Laboratory in the US. The better-developed alternative, however, is to exploit the fact that the ions and electrons that make up the plasma are electrically charged and can therefore be made to follow magnetic field lines.

What does magnetic confinement involve?
It involves filling a hollow, ring-shaped vessel, or "toroid", with a hot plasma and keeping that plasma away from the walls of the vessel by setting up a magnetic field along the ring using a series of current-carrying coils positioned around it. Unfortunately, however, the fact that the coils are closer together on the inside of the toroid than they are on the outside causes the plasma particles to drift outwards and escape.

How do you ensure confinement?
Tokamaks, first demonstrated in the Soviet Union in the 1960s, address this problem by using a transformer to induce a current in the plasma itself, which in turn sets up a magnetic field across the ring that, combined with the original field lines, forces the particles to follow a closed, helical trajectory. However, this inductive process is inherently pulsed, resulting in bursts of fusion energy rather than a continuous output – something that would limit a plant's average power and make it potentially uneconomical. In addition, any sudden loss of the induced current can produce what is known as a "disruption" that releases heat and particles from their magnetic cage and damages the plasma vessel.



IPP-Greifswald

Grand designs Model of the plasma that will be held inside the Wendelstein 7-X stellarator.

Where do stellarators come into this?
During the 1980s physicists realized that these disruptions could be a major problem for tokamaks, which were getting bigger and relying on ever-larger induced currents, while increasingly powerful computers were allowing researchers to tackle the problems that had originally dogged stellarators – a concept put forward in 1950 by the Princeton University astrophysicist Lyman Spitzer. Spitzer proposed combating particle drift by twisting a plasma chamber into a figure of eight. Subsequent designs over the next two decades sought to achieve the same end by shaping the magnetic fields rather than the chamber itself, and introducing a pair of large helical coils in addition to the existing planar coils. However, these devices produced less stable and, crucially, less-well-confined plasmas than were possible using tokamaks, and many labs devoted their efforts exclusively to the latter.

So who stuck with the stellarator concept?
A few continued to believe that the inherent advantages offered by a lack of induced current were worth pursuing. Building on key theoretical insights by US scientist Allen Boozer, who was then at the Princeton Plasma Physics Laboratory, the German plasma physicist Jürgen Nührenberg from the Max-Planck-Institut für Plasmaphysik in Garching sought to work out theoretically the magnetic-field geometry that would deliver the most fusion-friendly plasma. This was an extremely difficult task because it involved optimizing a number of variables – relating to plasma confinement, equilibrium and stability, among others – that had to be traded off against one another. But Nührenberg and his team persisted, and towards the end of the 1980s their efforts were rewarded. Using one of a new generation of powerful supercomputers, they finally found the optimum field geometry, and it is that geometry that forms the blueprint for Wendelstein 7-X.

years longer to build and assemble (funding being provided by the German federal government and the EU, as well as by the local state government). Klinger, who was appointed alongside engineer Remmelt Haange in 2005 to overhaul the ailing project, puts these problems down partly to an initial shortage of engineers and partly to problems of management. "The work culture of a purely research-based institute was wrong," he says. "We needed an industrial culture, with strict procedures and line responsibilities, and a capacity for resolving problems quickly."

Proof of the pudding
According to Klinger, the machine's budget and schedule have now been brought "under control". It remains to be seen, however, how well the machine performs in practice. Since 1998 Japan has been operating a similar-sized stellarator to Wendelstein 7-X called the Large Helical Device (LHD). Although this device relies on more traditional helical coils, Hiroshi Yamada, scientific director of the LHD, believes that the two machines will be "complementary" to one other. Yamada "readily" admits to the "sophisticated physics design" of Wendelstein 7-X, but warns that the European facility will require "very delicate control" of the spontaneous currents that can still appear in a stellarator's plasma. The Japanese device, he says, "is much more robust" in this respect.

Another tricky aspect of the machine's operation will be ensuring that magnetic "islands" produced at the edge of the plasma are able to extract power and particles from the plasma as required during experiments. Doing so will involve a careful fine-tuning of the device's magnetic fields, says David Campbell, head of ITER's plasma directorate, given the complicated field patterns that are inherent to stellarators. "To be really practical, this fine tuning will have to be valid over an acceptable range of plasma parameters," he adds, "or turn out to have a simple dependence on key parameters."

Campbell points out that Wendelstein 7-X is effectively a couple of generations behind ITER, which has an 800 m^3 plasma, and that the German device's plasma volume is smaller even than that of JET at Culham in the UK, which is still the only fusion device to date to have approached energy breakeven.

He estimates that Wendelstein 7-X will need to run for around 10 years in order to establish the physics case for a larger, power-producing device. Campbell adds it will then remain to be seen how competitive an industrial-scale stellarator could be, given the complexity of its components, although he notes that much of the necessary technology – such as suitably heat-resistant materials and tritium breeding – will be investigated at ITER.

"There is still some way to go to establish that stellarators can be fully competitive with tokamaks," says Campbell. "But it is valuable to maintain at least one alternative to the tokamak, and the stellarator looks to be it."

Comment

physicsworld

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The listening game

Opening up science is the best way for scientists to earn the trust of politicians

Why don't politicians listen to scientists? It's a question I've asked myself many times over the years and one that *Physics World* columnist Robert Crease tackles in this month's issue (p19). The matter is also addressed by Philip Webber – chair of Scientists for Global Responsibility – in a review of a new book *Arguments That Count* (pp44–45), which examines why the US government for so long ignored concerns raised in the 1980s about problems with its planned missile system to defend the US from a nuclear attack from the Soviet Union.

From my observations, politicians do listen to scientists, but they don't necessarily act on what scientists say. As Crease points out, politicians tend to think that science has a special power or magic, which means that science thrives when it can offer things politicians feel will be worthwhile, such as building a nuclear-missile shield. When science doesn't appear to offer solutions, sends mixed messages or is sabotaged by opponents, it goes out of fashion. As a result, science's authority in political circles tends to rise and fall over time.

iStock/bertos

But science doesn't really have any special authority – in fact, as Crease argues, that lack of authority is its very strength. Scientists are – or ought to be – disinterested in the outcome of their experiments, which means their results are more than mere opinions or beliefs. Having authority by virtue of having no authority is, though, a subtle story to tell. The only solution is to open up the workings of science as much as possible so that the rest of the world can learn to fully trust science and scientists.

Experimental mistake

Removing practical exams from science A-levels is a bad idea

My hackles were raised last month when news broke that Ofqual – the body that monitors school science exams in England – is to reform A-levels so that final grades are based entirely on written tests, with practical skills no longer counting towards a student's final mark. Practical skills will be still be assessed, but scores will be recorded separately to the main grade as either "pass" or "fail".

Some teachers welcomed the reforms because rigorously monitored, one-off practical exams have largely been replaced by continuous assessments for which, they say, pupils can all too easily be "coached". My concern, though, is that a separately recorded practical mark sends out the message that experiments are not integral to science, but an adjunct to it. I fear that universities will simply ignore the practical grade when deciding which students to accept, to the detriment of those who are experimentally gifted.

Matin Durrani
Editor, *Physics World*

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Turning a double-blind eye

Penny Gowland calls for publishers to implement "double-blind" peer review – where not only are the reviewers anonymous, but the authors too

Shutterstock/HieroGraphic

Bias cut If the reviewers of a paper don't know who the authors are, will they judge it more fairly?

If the reviewers know who has written a paper they may prejudge the work

Few researchers would deny that peer review forms the bedrock of all science. It is the crux of how almost all journals operate. People reading media reports in magazines or newspapers about the latest research finding are often told that the work has been published in a peer-reviewed journal with the implication being that such peer review is an objective measure of "correctness". Yet in reality the process of peer review is inevitably based on human judgement, with current practices explicitly encouraging subjectivity.

When a scientist submits a paper to a journal, the journal editors then send it to one or more scientists not directly involved in the work. These scientists review the paper and judge whether or not the work is scientifically credible and appropriate for that journal. This is standard peer review. Most journals operate a form of peer review known as "single-blind", in which the reviewers' identities are hidden from the authors, but the reviewers know the identity of the authors. This, in my view, throws up some obvious issues.

One is that reviewers inevitably bring their personal prejudices to bear on the review process. Clearly if the reviewers know who has written a paper they may prejudge the work based on the authors' lab, the nationality of the authors or their views on the authors' prior work. You might expect that scientists would deny behaving in this way, but many senior scientists I have spoken to happily state that they do this deliberately. They claim it speeds up the review process. However, this prejudice is blatantly – and explicitly – unfair on some groups, for instance people from less well known labs whose work is prejudged to be substandard. In other words, there is a bias.

This problem isn't just an issue for scientists, but science too. It may lead to excellent ideas from smaller labs being overlooked or it may result in "the benefit of the doubt" being given to bad work from top-ranking researchers. It will also limit what is published: Nobel prizes may come from paradigm-shifting work, but the jobbing scientist, trying to get through the next promotion round, may prefer to follow accepted wisdom rather than risk making a fool of him or herself. Single-blind review encourages scientists to play safe, embedding current scientific paradigms.

We need to ask ourselves: what would the general public's view be of single-blind review? What would be the effect on climate-change discussions if the public understood that scientists had the power to block their opponents' publications without even reading them? I believe single-blind review risks undermining the public's faith in all scientific evidence. It's now time to try "double-blind" peer review – where both the reviewers and the authors are anonymous – if only to avoid any perception of bias in science.

Bad for science

One thing that is clear is that the majority of scientists prefer double- to single-blind peer review. In a 2007 survey by the Publishing Research Consortium – a group of UK publishers that support research into issues that impact scholarly communication – it was found that around 56% of researchers preferred double-blind peer review. Around 25% of participants opted for single-blind peer review, while 13% favoured open review – where a paper is opened up for review to the whole community. Just 5% chose post-publication review, where a paper is reviewed after it has been published. Preference for the status quo was strongest among older researchers and English-speaking scientists.

Of course there are problems with double-blind peer review. One is of reviewers just guessing who the authors are – in fact, opponents of double-blind peer review claim that identifying authors is easy. In one study in 1991 reviewers believed they could definitely guess the authors in around 25% of cases and maybe guess them for 21% of papers – although they wrongly guessed in 16% of those cases (*Am. J. Public Health* **81** 843). This means, however, that for more than half of the papers the reviewer did not correctly guess the author and for 100% of papers the reviewer did not *know* the author for sure. Guessing is not the same as knowing, and I believe that people will be less quick to stereotype if they are not certain whom they are dealing with.

It is often argued that double-blind peer review will create more work for the publishers, who will have to ensure the papers are completely blinded. But this hardly seems a good justification for not doing the right thing, and these problems have had to be overcome by many medical and humanities journals that already operate in this way. I believe that most of the perceived disadvantages of double-blind peer review are procedural or practical, while several studies have found that compared with single-blind peer review, double-blind subtly benefits groups such as female scientists or those from the developing world (*Science Communication* **35** 603), although some other studies have failed to replicate these results.

The practical issues should not and do not carry much weight against the scientific and ethical advantages of double-blind peer review. I hope that publishers can come together to implement double-blind peer review to help advance science and stop the perception of bias in science.

Penny Gowland is a physicist from the University of Nottingham, UK, e-mail penny.gowland@nottingham.ac.uk

Critical Point Why don't they listen?

Robert P Crease thinks he might know why science has lost its authority when it comes to political decisions

In mid-September 2001 letters containing deadly anthrax spores were mailed to several news agencies and two US senators in a terrorist attack that killed five people and injured more than a dozen others. A top-level adviser to president George Bush asked his then science adviser John H Marburger III how to neutralize the spores on existing anthrax-ridden mail. Marburger convened a team of scientists, who came up with a carefully researched recommendation based on irradiating the mail with electron beams. It seemed to be a triumph of science's application to the American national interest.

But when US Postal Service officials implemented the method – to kill anthrax but preserve the mail – the electron beam burnt some batches to a crisp. Surprised, Marburger investigated. He found that government officials had second-guessed the scientists. The officials had reasoned: if scientists said the right radiation dose to blitz the death spores was x, then $2x$ was surely safer! When Marburger ordered the dose scaled back, the method worked fine.

Marburger, who died in 2011, liked to cite this episode as a "relatively benign example of a potentially disastrous behaviour", namely, the tendency of government officials to alter or ignore scientific advice. His store of more damaging examples included the Bush administration's claim, in 2002, that aluminium tubes sought by Iraq were for a nuclear-weapons programme, contrary to the conclusion of scientists. In these and other cases, it is simply a fact that, as Marburger put it, "the methods of science [are] weaker than other forces in determining the course of action".

Marburger – the longest-serving US presidential science adviser and an experienced scientist – grew curious about why science has such weak authority among political leaders. After he stepped down in 2009, he began to investigate.

Three grounds for authority

Marburger turned to the works of German historian and sociologist Max Weber, who in his influential book *Economy and Society* (1922) examined different types of authority, or the grounds on which people voluntarily comply with commands issued by others. There are three, Weber said: traditional, rational-legal and charismatic.

Martin H Simon/Corbis

Caution The US Postal Service initially second-guessed scientific advice regarding anthrax.

Traditional authority, Weber wrote, is rooted in a "belief in the sanctity of age-old rules and powers". This is the authority possessed by village elders. Legal authority – the authority of a bureaucracy – is grounded in a "belief in the legality of enacted rules and the right of those elevated to authority under such rules to issue commands". Charismatic authority is possessed by those who are "considered extraordinary and treated as endowed with supernatural, superhuman or at least specifically exceptional powers or qualities".

Difficult to sustain over time, charismatic authority requires periodic reinvention and occasional proofs of exceptional powers such as an ability to perform miracles or to disclose secrets of nature. Weber called charismatic authority "irrational", but noted it is one of the few means leaders have to take people on new, progressive paths; think of the authority of Martin Luther King, Mahatma Gandhi or Winston Churchill.

But which type applies to science? Clearly not the first two: no country is traditionally scientific or requires that its laws be grounded in sound science or scientific methods. Marburger concluded that the authority of science in governmental circles is, in Weber's terms, charismatic. Science's authority among politicians, that is, depends on them regarding it as possessing a special power or magic.

Scientists, Marburger continued, find this absurd. For them, science is not an "authority" but the only means at our disposal to understand nature. Because scientists have first-hand experience of how science works – of its roots in empirical testing and open discussion – they see acting against science as "a mild form of insanity", as Marburger put it. "It is precisely because the power of science *does not* [my italics] require charismatic authorities that we should trust it to guide our actions," Marburger wrote (*Issues in Science and Technology*, Summer 2010).

Yet from the standpoint of politicians lacking such first-hand experience, the voice of a scientist is but one among many voices clamouring to be heard. For them, "science is a social phenomenon with no intrinsic authoritative force", which is why "the authority of science is inferior to statutory authority in a society that operates under the rule of law".

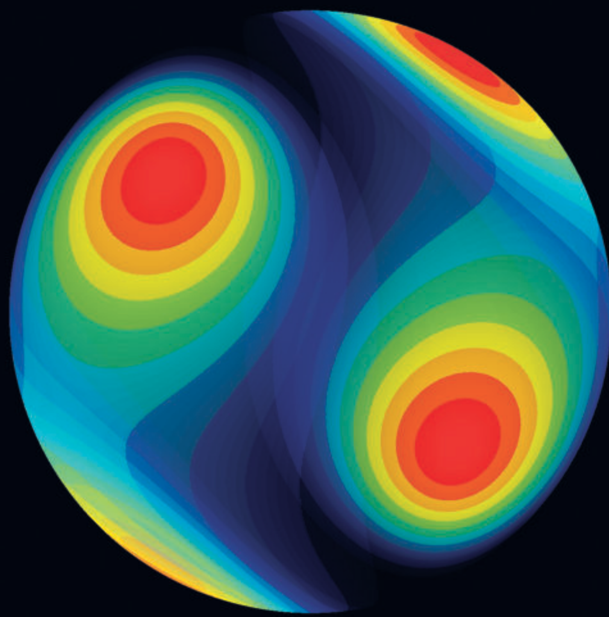
This observation explains the waxing and waning of science's authority in politics. When scientists make dramatic, socially communicated breakthroughs, their authority shoots up; in fallow years when they don't, it tends to decline. That is why, for instance, physicists had such political power after the Second World War. Characterizing science's political authority as charismatic also suggests that the only way to garner more authority for scientists in government is to improve the charisma of their calling. For this reason, Marburger concluded, "science must continually justify itself, explain itself, and proselytize through its charismatic practitioners to gain influence on social events". For starters, we need more people like Brian Cox and Neil deGrasse Tyson.

The critical point

But I think there's a fourth possible source of authority that I'll call trust, which overlaps with Weber's third type without involving irrationalism. We trust someone – that is, defer to them about something beyond our knowledge or power – when we "know their story"; when we've seen them operate in different contexts, and know their customs, long enough to acquire a sense of how they behave. (Think of the trust we place in postal workers, for example.)

If we can somehow give the apparatus of science – the empirical tests, the supervised institutions, the open discussions – more public visibility, it would be clearer to non-scientists that scientific results are more than opinions or beliefs. Science then might acquire more authority, with the public and with politicians, without having to rely on miracles or staging magic shows.

Robert P Crease is a professor in the Department of Philosophy, Stony Brook University, US, and co-editor-in-chief of *Physics in Perspective*, e-mail robert.crease@stonybrook.edu



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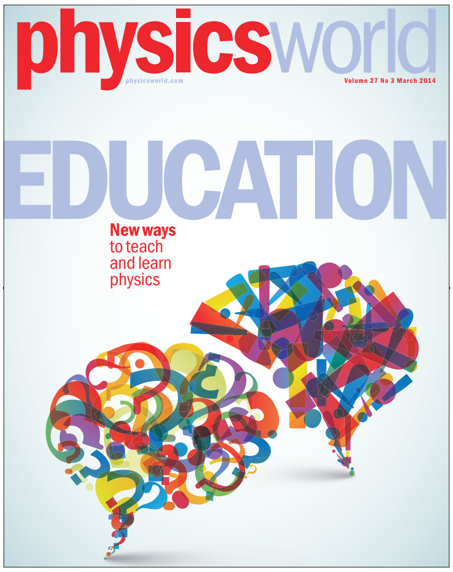
Beyond MOOCs and videos

In reply to Philip Moriarty's article "The power of *YouTube*" (March p31–34, http://ow.ly/vAL2T) in the *Physics World* special issue on education.

Having spent last year working with the Edinburgh Physics Education Research Group, I was thrilled to see the topic of education featured in *Physics World*. I was, however, surprised by Moriarty's comments in which he implied that online education consisted solely of *YouTube* videos and MOOCs (massive open online courses), and questioned whether it can ever result in learning. Online education can in fact be much more varied, and often offers features that are not available in face-to-face learning.

For example, the use of asynchronous discussion boards encourages students to spend more time thinking about the posts and considering their answers than would typically take place in a classroom setting. This is beneficial for developing deep conceptual understanding. Having recently graduated with an MSc in e-learning/digital education (taught solely online) from the University of Edinburgh, I can say from personal experience that online learning can be just as interactive, effective, challenging and rewarding as face-to-face learning – if not more so.

Of course, as with any technology, the use of online learning in physics education should be guided primarily by pedagogy, not technology. For example, the use of electronic voting systems in undergraduate lectures is unlikely to lead to deeper student learning unless it is used with an effective pedagogy such as peer instruction. Many research groups around the world are evaluating, developing and understanding student learning and pedagogies, making education more a science than an art. This means that the use of new technology and novel learning techniques, such as those discussed in the March issue of *Physics World*, can be introduced in a research-informed way,



thereby increasing their chances of success. Continued discussion of, and investment in, physics education research is vital.

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MOOC pros and cons

In reply to James Dacey's article "The MOOC point" (Features, March pp43-46, http://ow.ly/uqH4W) about the rise of MOOCs in science education.

As an educator as well as a researcher, I have participated in quite a few MOOCs, from Peter Norvig and Sebastian Thrun's original "Artificial intelligence" course to courses such as "Probabilistic graphic modelling and computational molecular evolution". I was (and continue to be) interested in what innovative applications of technology and talent can bring to ordinary "talking head" distance learning. Some of these courses have been pretty far away from my area of experience, but I have found them all to be extremely interesting.

Whether MOOCs can match the "social and educational experiences" to be found in a class on campus is an interesting question. In my view, discussion forums are among the most beneficial parts of the MOOC courses. They create real and timely discussion among students from all over the world, with totally different backgrounds, on current quiz problems and assignments of the day in a "help each other understand" environment. I guess I am becoming a fan!

There are some downsides, though. One is that it seems like almost every community college believes it needs its own MOOCs on algebra or physics or whatever to be taught online by its own faculty. The problem is not that the faculty couldn't do it well (though that is sometimes a possibility), but that requiring students to come to campus in order to access and participate in "online courses" seems like an effort to increase enrolment and decrease the number of faculty, with little apparent benefit for students. Schools doing this often seek grants for the substantial IT investment required, and are often also in "revenue-critical" situations, worsened by poor student retention rates.

ASIWEL
via *physicsworld.com*

Teaching by doodling

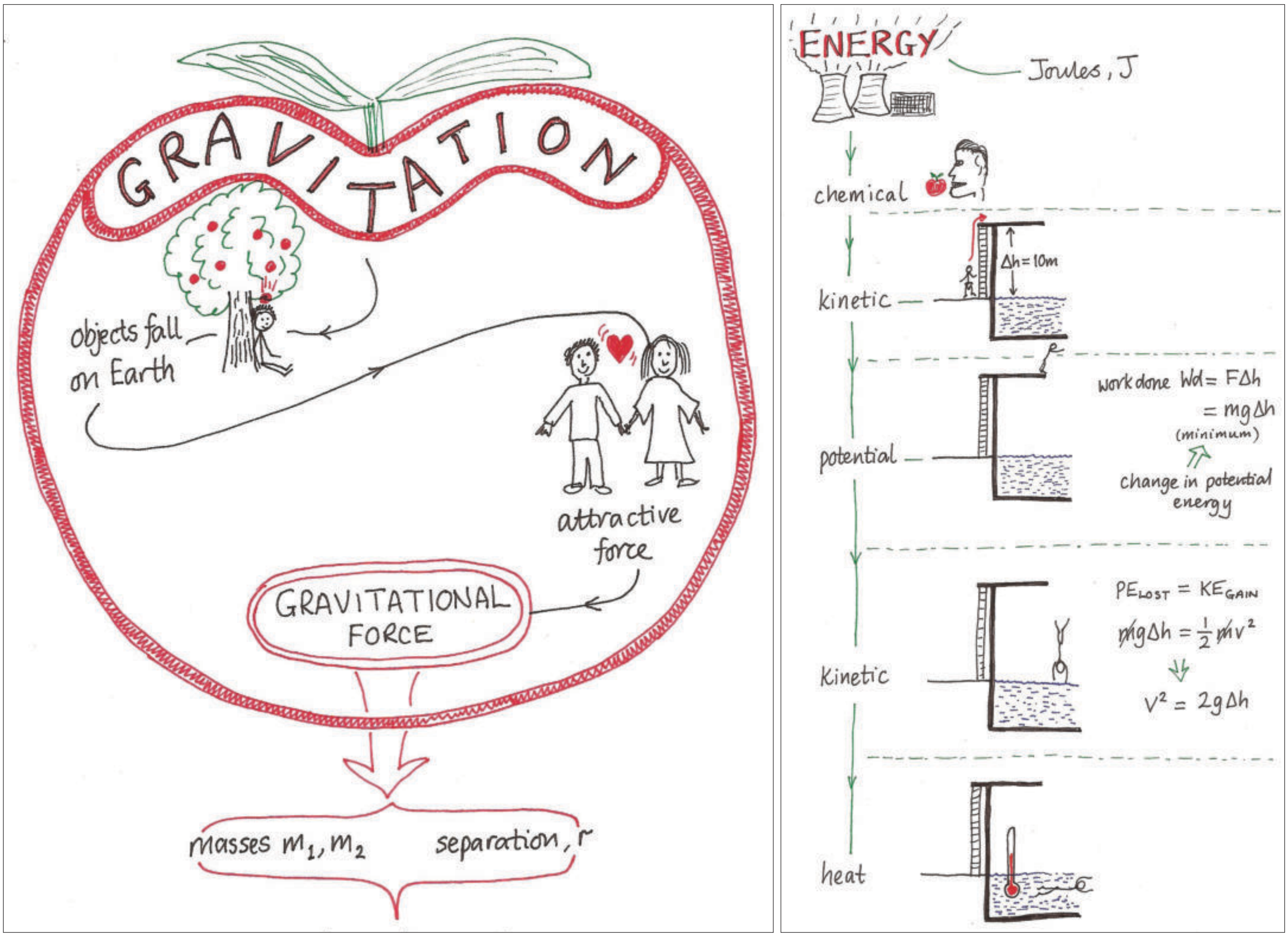
In reply to the article "Learning by doodling" (March pp40–41) in the *Physics World* special issue on education.

I teach basic physics within a first-year undergraduate module called "Physical oceanography and meteorology foundation", which is taken by students on a range of marine science degrees here at Plymouth University. Most of these students have no background in physics beyond GCSE science and tend to find the physics concepts they encounter difficult. A few years ago, I therefore started drawing out the content I wanted to cover in my lectures, using a mix of linked text and quirky pictures (such as the one overleaf) to add fun/interest. I write/draw out the content "live" during the lecture so the students get to see things unfold in front of them.

This approach to teaching basic physics within my module has proved popular with students and routinely receives very positive feedback; in fact, I received the university's Student and Staff Teaching and Representation Award for "Most Innovative Use of Teaching Methods" for this work in 2011. Alongside my visual aids, I also include a few other quirky "gimmicks" such as using a *Star Wars*-style "lightsaber" as a pointer when I cover forces, trying to play a fanfare on a bugle to emphasize a key result or equation, using a line of students to demonstrate longitudinal and transverse "Mexican waves" and throwing a foam ball around. All of this works to maintain positive engagement from students towards topics that many have previously struggled to enjoy – although I realize that my efforts are more "teaching by doodling" rather than "learning by doodling".

On a separate note, I also enjoyed your video interview with the Massachusetts Institute of Technology's Walter Lewin ("Walter Lewin – a truly inspirational teacher", http://ow.ly/vAMzc). I think he is an extreme version of how I aspire to be with these first-year lectures at times. It was interesting to hear his comments

Tim O'Hare



Visual aids Tim O'Hare "teaches by doodling" – he draws pictures like these during his lectures to help his students learn physics concepts.

about lectures being a "performance". That is exactly how I see my large first-year classes, although I refer to them with my tongue somewhat in cheek as an "entertainment experience". The key thing is not that we should all be like Lewin – to reach that level would take an inordinate amount of time and effort – but rather that we should all aspire to be a little like him in our approach when we can, and we should not lose sight of the value of that kind of approach even when we can't.

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Objecting to 'glamour physics'

In reply to Martin Hendry's article "Taking modern physics into schools" (Forum, March pp21–22).

I have never taught physics in schools, and so I hesitated before writing this comment on Hendry's interesting article. He is, of course, correct in saying that exciting things are happening in fields such as cosmology and particle physics. These are examples of what I call "glamour physics", in contrast to older areas such as Newtonian mechanics and classical optics. But whether glamour physics has a legitimate place in schools (as distinct from universities) is, I think, debatable.

Alarm bells rang in my mind when I read that the schools referred to in Hendry's article study a unit called "Our dynamic universe", which incorporates evidence for the Big Bang, dark matter and dark energy and also looks at aspects of the Standard Model of particle physics. Alarm bells rang still louder when, later in the article, I read that the focus in the schools has shifted from "specific pieces of factual knowledge to more emphasis on method and the scientific process".

It seems to me that well-meaning efforts to make physics entertaining – coupled with a slight but detectable distaste for mathematics in favour of essay-type verbal exposition – have trumped a more traditional focus on acquiring the skills that make a person employable in physics. Such skills must be developed in areas of classical physics such as Newtonian mechanics, electromagnetism, thermodynamics, the conservation laws and optics. It would be fair to categorize these topics as coming from the physics of the 19th century or earlier. They are not glamorous, but they are essential background for later studies in quantum mechanics and relativity, and then, of course, the glamour physics of black holes, the Big Bang and other newsworthy topics. How can the rise of quantum mechanics be explained without a quantitative understanding of the experimentally observed distribution of radiation from a black body and its inconsistency with the theoretical distribution? How can the rise of relativity be explained without a quantitative understanding of the Michelson–Morley experiment?

If the schools referred to by Hendry have indeed taken up glamour physics to the extent that he describes, I can imagine universities in the near future spending precious time and resources in remedial catch-up.

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Learning from Feynman

In reply to Robert P Crease's article "Feynman's failings" (March p25, http://ow.ly/uKDFS), which asked why Richard Feynman's *Lectures on Physics* are still popular 50 years after they were published.

[Feynman was] humorous, honest, open and in command of the material (and audience). He said "we think we know", "we believe"; he didn't dodge mystery.
@Eris379
via *Twitter*

Crease's article claims that people always fail when they try to use Feynman's *Lectures* as a textbook. Here I will claim an exception. In the summer of 2008 we built a three-semester course for the three volumes of Feynman's book, and used it as a substitute for the traditional general physics course in our department of physics at Tsinghua University in Beijing, China. Six professors were assigned to the course, with each pair forming a group in charge of one volume and one semester. A colleague and I arranged to teach the second volume of the book.

This semester I am teaching the same course for the third time, and my colleague has also taught it three times before. So over the past six years, we have taught it a total of six times. It's been successful, not a failure. The key here is that the students who choose this course are those who have very strong basic physics knowledge before they enter our university – most of them have taken part in a national or international Physics Olympiad competition. They thought a traditional general physics course would be too simple and boring, and want to challenge themselves in our course.
Wangquing00
via *physicsworld.com*

I am a physicist who did an undergraduate degree in electrical engineering. I taught myself physics during my undergraduate days from these books. They worked for me and I enjoyed them thoroughly. So I wouldn't call these books a failure at all.
Balasath
via *physicsworld.com*

We used the Halliday and Resnick textbooks at California State University, Los Angeles. Their approach favoured intense "problem solving". I was encouraged to do all the problems in the books, which I did. At the time, students at the nearby California Institute of Technology (Caltech) were using Feynman's *Lectures* and relying on supplemental materials for problem solving. I took my graduate school entrance exam in physics with a room full of mostly Caltech students. I was able to complete the entire exam and review it thoroughly twice before I left. I was the first one out of the room and scored in the 98th percentile. I am no genius or super physicist. Clearly, the problem-solving approach works very well. Feynman was a brilliant lecturer, but textbooks were not his thing.
cmfluteguy
via *physicsworld.com*

I once hosted a British playwright who had enjoyed success with his play at the National Theatre, London, and I asked him how these plays unfold. He replied, "You start with basic ingredients and the story sort of unfolds naturally from this starting point, tempered by my own understanding of things." This is precisely what one experiences when listening to leading physicists. You are led along very gracefully from a starting point and everything makes perfect sense, often in a deep way. But note what happens when you're asked about the lecture a few days or weeks later. You have to work hard to set the context accurately and even harder to recall just what it was about the logical sequence that engaged you at the time. I find my scribbled notes can help, but not always.

In the end, as a lecturer, in order to tell a good story of your own, you're often better off hitting the key facts, tempered by your own understanding. It's pointless to attempt to recreate the Feynman aura. But students do respond superbly to good storytelling.
Josshawthorn
via *physicsworld.com*

I am a physician and pathologist with an abiding interest in physics. Having spent an entire lifetime in basic research on leprosy and tuberculosis (TB), I felt long ago that there must be something in quantum mechanics that could help us understand TB better. Having retired from active research in a lab, I am now happily reading Feynman's three volumes and find them very enjoyable. Maybe this is because I do not have to prove myself to anyone, so I take it at my own pace. I would certainly recommend his books to people like me who are reading physics for enjoyment and not for employment.
Vdrnathan
via *physicsworld.com*

It's pointless to attempt to recreate the Feynman aura but students do respond superbly to good storytelling

Patenting perils

In reply to Robert P Crease's article "Patenting science" (April p16, http://vQkje), which asked for readers' examples of cases where patents have hindered or prevented fundamental research.

I personally am not aware of any cases where patents have hindered or prevented fundamental research. In my experience the converse is usually true: fundamental research hinders or prevents patenting.

A typical situation is when a researcher – let's say an academic – publishes a paper or gives a lecture or demonstration on their research, and subsequently applies for a patent. In general, the patent application will be refused on novelty grounds because the academic has disclosed their invention by publishing, lecturing or demonstrating before the application was filed. It happens all the time.

It's always better to patent and then publish, but academics who do things in this order should beware of what they write in publications following the filing of a patent application. Academics are not known for expressing themselves in a retiring manner, and they will proudly write (or say) things like "The results of our previous experiments enabled us to predict the behaviour of this novel material" or "Based on the results of Doohickey and Whatnot, it seemed logical to use their design to construct the present detector" and even "Enhanced sensitivity was readily obtained as our earlier calculations suggested".

Comments like these all send the message that "it was obvious to try and it was obvious that we would succeed". In this way, authors of such statements (who are also the inventors as far as the patent applications are concerned) may shoot themselves in the foot by saying that their inventions are non-inventive, or that their invention was obvious. That is good enough reason for a patent office to decide to revoke the patent.

On the other hand, provisions known as "research exemptions" prevent patents from hindering fundamental research. These exemptions, which vary in scope and specificity from jurisdiction to jurisdiction, essentially allow patented inventions to be used for pure research, without risk of litigation for the researcher. Crease mentions the case of Nicholas Christofilos, who apparently succeeded in getting what is now the Lawrence Berkeley National Laboratory to pay for the right to use his invention. This case might have turned out differently if Berkeley had invoked the research exemption, or indeed used Christofilos' first manuscript of 1940 to revoke his later filed patents.

Finally, I note that Crease's article refers mainly to US patents and US case law. The patent world extends beyond the US, however, and is alive and kicking throughout the rest of the planet. Christofilos, for example, was a prolific inventor who also filed patents in his native Greece, the UK, Germany and Canada. It is easy to find these patents, and those of other notable inventors (including Leó Szilárd, Enrico Fermi and Albert Einstein) from the early 19th century to the present day, in the European Patent Organisation's free patent database, http://worldwide.espacenet.com.

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Debating the BICEP2 results

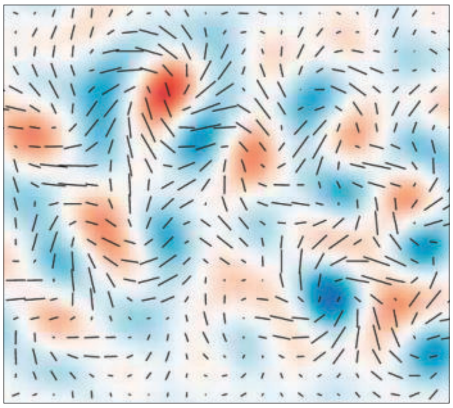
In reply to the *physicsworld.com* news story "BICEP2 finds first direct evidence of cosmic inflation" (17 March, http://ow.ly/vyMOO, see also pp6–7).

The BICEP results provide the first detection of primordial gravitational waves, but this is in no way direct evidence for inflation. There are other sources of primordial gravitational waves, such as decaying cosmic string loops. In addition, some alternatives to cosmic inflation as a theory of the very early universe also produce primordial gravitational waves. In fact, the spectrum of the detected waves gives a mild preference for a "blue tilt" of the spectrum (larger amplitude on smaller wavelengths), which in fact would rule out inflationary cosmology, and would agree with the predictions of "string gas cosmology", an alternative to inflation that is based directly on superstring theory.

rhbmcgill
via *physicsworld.com*

In reply to the follow-up article "Neil Turok urges caution on BICEP2 results" (18 March, http://ow.ly/vyNen).

Among the seven billion people who currently live on this planet, Turok is clearly the number one or number two



BICEP2

Polarized The BICEP2 evidence for cosmic inflation, announced in March, has prompted much debate.

loser after the publication of the BICEP2 data. He has turned the struggle against inflation into his life mission. It's painful that this article failed to articulate this point clearly. His "caution" – which he will clearly promote as long as possible – is unquestionably self-serving.

lumidek1
via *physicsworld.com*

Lumidek1, if you'd been around in 1905, you would have hanged Einstein. It is most urgent for scientific progress that we have a critical look at every new claimed result or piece of data. Moreover, every person can have their own views – who are you to decide the final outcome of a theory? Sometimes it takes hundreds of years to discover the correct natural law. Before that, every view is allowed.

ranjeetdalal
via *physicsworld.com*

Physics and philanthropy

In reply to the news story "Cambridge physicists divided over Hawking chair" (April p12, http://ow.ly/vyLil) about the university's new Stephen W Hawking Professorship, which must, according to its philanthropic funders, have an associated salary "equal to or greater than the average" for other professorships of similar rank in the department.

The high salary of Cambridge's Hawking chair is a typical example of the difficulties with philanthropic donations.

Leila Whitworth (@LeilaWhitworth)
via *Twitter*

Personally I wouldn't consider a donation under such conditions as a donation, but rather as a quite open attempt to interfere with the internal rules of university in a most unfortunate way.

Ragtime
via *physicsworld.com*

As a maths-grounded physicist who made the mistake of working in financial services for a while, I have a different perspective. Commercial reality is what it is. If I have a rich friend who wants to help me, then that's lucky for me. If other folks are jealous of this, then that's up to them. Any extra money coming into maths/physics is good in my view. It may not help me but it may still help other areas – or at least enlighten some theorists as to why they could be wrong.

Nolowerboundonsize
via *physicsworld.com*

It would appear that the requirements and constraints of the gift had been agreed to upon acceptance – there was no negotiation available, except to turn it down (not likely).

Quandry12
via *physicsworld.com*

Wearable electronics

In reply to the *physicsworld.com* news story "Graphene oxide could make textiles smarter" (10 March, http://ow.ly/uqScv), which described a new type of fibre with an electrochemical capacitance of up to 410 F/g.

What happens if a fully charged piece of this fabric gets snagged on something and the capacitor is shorted out? Suppose, for example, that a 1 g cloth panel with all fibres connected in parallel is charged to 1.5 V. The stored energy is ½ CV^2, or about 460 J. Given the high electron mobility in graphene oxide, and the likely low electrostatic resistance of the capacitor, the discharge power could be in excess of 100 kW. I wouldn't want to be wearing it when it happens!

MNice
via *physicsworld.com*

I'm hoping the graphene oxide will only be included in small amounts in a textile blend, and distributed so the charge density is lower and shorts can only affect small areas. Otherwise, arc protection and grounding will become a new selling point in consumer clothing: "Are you tired of getting an electric shock every time you hug your loved ones? Adidas performance apparel has the solution!"

em gee bee two
via *physicsworld.com*

"Fully functioning smart textiles" indeed! What is this mania for wearable electronics? I've never wanted to wear any electronics, in spite of the idea having been promoted for at least the past 45 years. What's the point?

GrahamRounce
via *physicsworld.com*

Examples for mass consumers include increased ergonomics and style. No more carrying around electronics in your pockets. Clothes that change their colours, weave density or absorbance and insulation properties. Possibly self-cleaning fabrics, too. With all of this manipulation, you might need fewer clothes, which would reduce the power consumed by washers and dryers. There are also applications in medical diagnostics for garments that can record heart rates and other data (possibly with much better granularity), which would be much easier than having an expensive technician apply probes or operate a machine. Electronic clothing creates a new platform for creative solutions to many problems.

em gee bee two
via *physicsworld.com*

Gravitational tests of antimatter

In reply to the *physicsworld.com* news story "Interferometry tips the scales on antimatter"(7 April, http://ow.ly/vvQVF), which described an experiment designed to test whether antimatter "falls up" under gravity.

I recall a similar experiment way back in the 1960s involving a piece of apparatus called a FLEA (Fantastically Low Energy Accelerator), which compared the acceleration of electrons and positrons falling under gravity in high vacuum in a metal tube. The results were initially (to me) counterintuitive, but the explanation inspirational: electrons showed zero acceleration, whereas the antiparticles (positrons) fell with an acceleration of 2*g*. The explanation becomes obvious when one considers the electric field set up at equilibrium by the conduction electrons in the metal tube, which also redistribute under gravity. A delightfully simple experiment that has always inspired me.

AlanCooper
via *physicsworld.com*

The electron drift-tube experiment you refer to was conducted in 1967 by Bill Fairbank and Fred Witteborn. Their original goal was to measure the gravitational acceleration of positrons. Initially, to test the apparatus they used electrons. Much to their surprise they found that the electrons experienced an acceleration of less than .09*g*. This was conveniently explained by assuming that gravity acting on the tube generates an electric field within the tube that exactly cancels the effect of gravity acting on the electrons. If that were true, and positrons experienced normal gravity, they were expected to accelerate at 2*g*. If the positrons experienced antigravity, they were expected, like the electrons, not to accelerate at all.

So what happened? We don't know, because the experiment with positrons was never done. Fairbank never received the funding for the required slow positron source, and he died in 1989. So here we are in 2014, nearly a half century after the Fairbank/Witteborn experiment, and we still don't know how positrons fall. We know the mating habits of shrimp in low Earth orbit, but we don't know if bulk antimatter (such as antihydrogen) falls up.

There are cases throughout the history of science where theorists were sure of a certain result only to find, through experiment, that nature had different ideas. For example, back in 1880 everyone "knew" there was aether to conduct light waves – "had to be" – until the Michelson–Morley experiment showed otherwise. In 1990 everyone "knew" the universe's expansion was slowing under gravity – "had to be" – until observations of supernovae showed otherwise. So you will forgive me if I don't take any theoretical arguments to heart until an actual experiment is performed.

S Dino
via *physicsworld.com*

Better approximations

In reply to Richard Gill's letter "Approximately correct" (March p16), which stated that the trajectory of an object thrown in the air is an ellipse rather than an upside-down parabola.

The trajectory of something thrown in the air is not a parabola and not an ellipse. It is perhaps best described as a "tiring parabola", and depends on the mass, size and shape of the object.

John Wesson
Abingdon, UK
jo@wessonj.plus.com

Now you know

In reply to "Penalizing Iranian research" (Forum, April p17) and "Tied in knots" (Quanta, April p3).

I never realized that Iranian scientists couldn't publish their work due to trade sanctions. The things you learn in *Physics World*!

@hapsci
via *Twitter*

So, there are 177 147 ways to tie your necktie? *Physics World* is truly an entertaining start to a cloudy Sunday!

Stella Chan (@StellaWYChan)
via *Twitter*

The drop heard round the world

When physicists at Trinity College Dublin began looking after an antique funnel full of pitch, they had no idea their humble experiment would spawn one of 2013's most "viral" news stories. **Shane D Bergin**, **Stefan Hutzler** and **Denis Weaire** reflect on the value of "slow science" to a hyper-connected, social-media world

Shane D Bergin and **Stefan Hutzler** are in the School of Physics, Trinity College Dublin, Ireland, where **Denis Weaire** is professor emeritus, e-mail berginsd@tcd.ie

The authors wish to acknowledge Alan O'Meara and David Whyte for their role in recording and analysing the video of the falling pitch drop.

It has been described as an experiment, but it lacks most of the essentials needed to qualify as such. The material is not well characterized, its environment is poorly controlled and, until recently, it was not even regularly monitored. Nevertheless, in 2013 our observation of a falling drop of pitch attracted more than two million hits on *YouTube*, was listed in *Discover* magazine as one of the year's top 100 science stories and even formed part of an Australian cricket commentator's Test Match report for *The Times*.

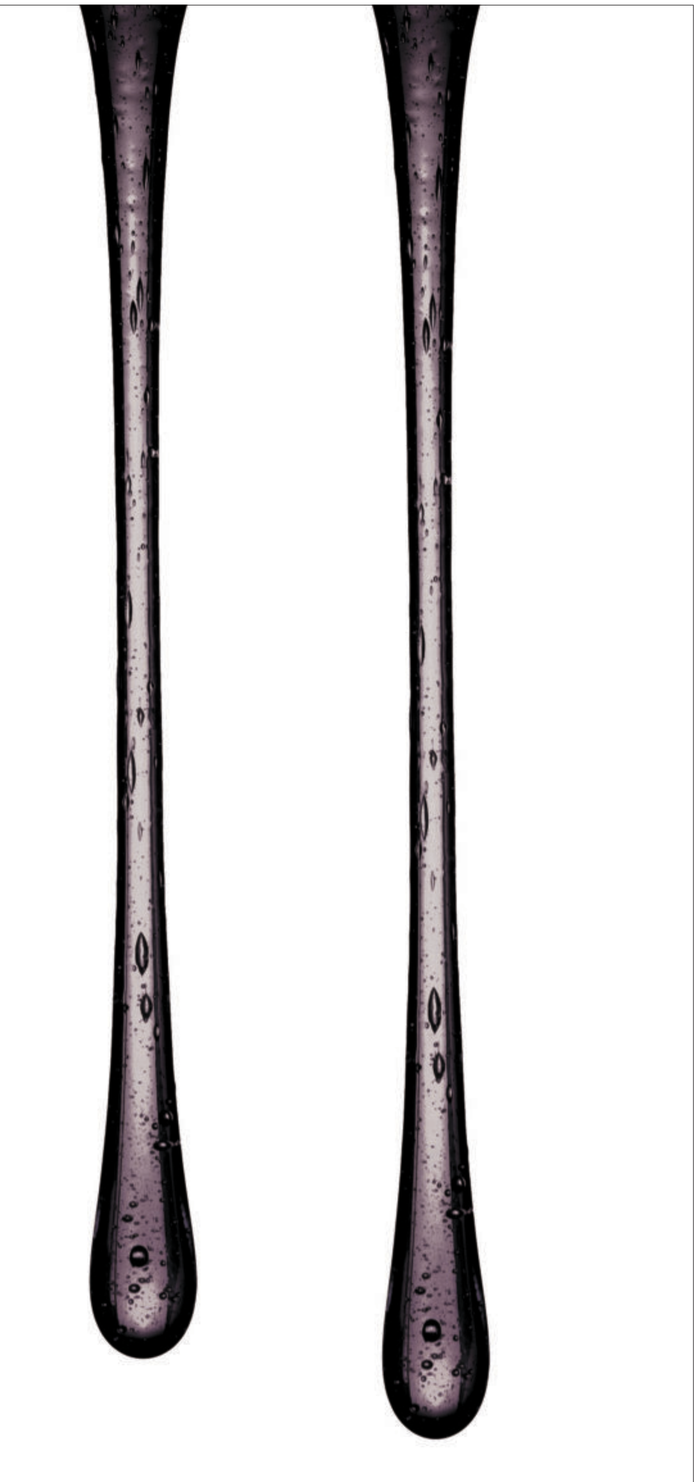
This apparently mundane event captured the public imagination to an extent that none of us anticipated. It seems that even in the modern world of research, the meek shall sometimes inherit the Earth. But how, exactly, did a funnel full of pitch at Trinity College Dublin become "the drop heard round the world"?

The modern chapter of this story began in the 1980s, when dusty cupboards were emptied of their antique contents in the School of Physics at Trinity. During this clear-out, many strange objects came to light, including a funnel filled with pitch and dated October 1944. Pitch is a black polymeric material. If you hold it in your hand, it feels solid. If you were to hit it with a hammer, it would shatter. However, if left for long (really long) periods of time under the pull of gravity, pitch will flow, like a liquid. And since October 1944 that's what our experiment had been doing. Indeed, we could see a drop slowly forming at the bottom of the funnel, preparing to join older ones that had evidently detached in earlier times, at a rate of about once per decade (see photo on p29).

Unfortunately, there was no clue to the identity of the experiment's creator. In October 1944 Trinity was home to the future physics Nobel laureate Ernest Walton, who loved simple demonstrations, but nobody could remember him talking about this one. But even without a confirmed distinguished progenitor, the funnel still seemed worthy of display, so it survived the cull and was returned to a shelf where it could be observed. Year after year, undergraduate students idled past it, paying no heed to the "slow science" of the pitch drop.

Watching pitch flow

After decades of this benign neglect, our attention was once more drawn to the pitch experiment in November 2000, when news stories emerged that a similar funnel at the University of Queensland, Australia, had just produced a drop (details of the Australian set-up can be found in R Edgeworth *et al.* 1984 *Eur. J. Phys.* **5** 198). When you consider the time it takes for a drop of pitch to form, the chances of being there to see the drop drip are exceed-



ingly small; despite the age of these experiments, it seemed that nobody had ever witnessed or recorded this momentous event. The Australian drop's curator, John Mainstone, had intended to remedy this by videoing the drop. Sadly, the camera was not switched on at the crucial moment. Sadder still, Mainstone died in 2013 before he could record the sequel – which, with incredible timing, finally fell as this article was going to press.

Noting the attention that the Australian drop had attracted (which included an Ig Nobel Prize in 2005 "for patiently conducting an experiment that began in the year 1927"), we resolved to set up a camera to monitor the one at Trinity. By the time we did so, our funnel appeared heavily pregnant. Then, in the early hours of 11 July 2013 – perhaps assisted by some exceptionally warm weather – a heavy tear-drop blob of pitch fell to the base of the beaker below, with a thin thread connecting it to the stem of the funnel. The drop had dripped.

A complex drop

Before we discuss the media storm that followed our drop's fall, let us concentrate for a moment on the physics. In the years before the Second World War, the "pendant drop" was a set-piece of the elementary physics curriculum. Through it, students learned about surface tension, which they measured by finding the critical mass of a drop of water, at which gravity wins out and causes it to fall from a nozzle. The Plateau–Rayleigh instability of a thin column of fluid is implicated in the final breakaway; hence, only in the drop's ultimate demise does viscosity play much of a role.

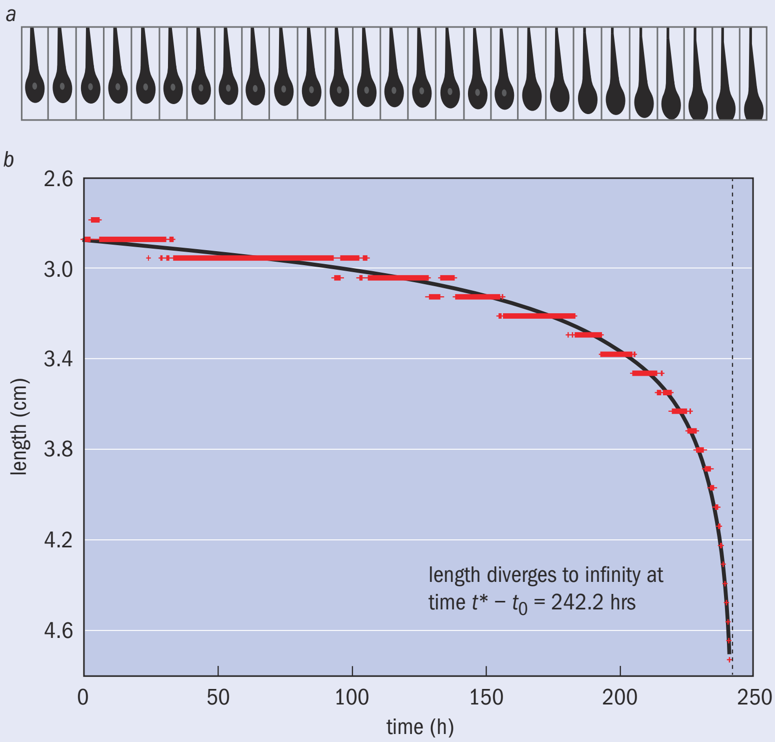
When, instead of water, one considers a liquid that is highly viscous (and perhaps viscoelastic), the situation changes. Three forces are now involved at every stage, including viscosity. Compare a dripping tap with honey pouring from a spoon. Not only is the stream of dripping honey much slower to develop, but it eventually forms a long, thin filament, or neck, with the drop acting as a fixed weight, stretching it out. At this stage inertia begins to play a role, with the drop entering a regime of nearly free-fall while still remaining attached to an ever-longer and thinner thread.

However, the ultimate process of detachment for such a drop remains mysterious. It may feature the generation of a cascade of a series of necks of ever-decreasing diameters, with surface tension again playing an important role (as suggested by X D Shi *et al.* 1994 *Science* **265** 219). As is so often the case in physics, an apparently simple and mundane problem becomes more complex and intriguing the closer you look.

In our pitch drop, the endgame was not visible, as the drop did not entirely detach, being still linked to the stem of the funnel by a thin thread. Given the small size of the apparatus, this was not surprising. Even before the drop dripped, we could see that it was going to touch the pool of pitch below before detaching, and while we had managed to raise the funnel somewhat by carefully loosening rusty screws that were last tightened in October 1944, we were only able to put 5 cm of clearance between the drop

Year after year, undergraduate students idled past the funnel, paying no heed to the "slow science" of the pitch drop

1 Going, going, gone!



(*a*) Sequence of the pitch's final drop (taken from the pitch-drop video). (*b*) Measured variation of drop length with time.

and the pool. This proved insufficient. Indeed, in a series of complementary experiments using honey, we found thread-lengths of up to about 12 cm before break-off, and the break-off length is known to increase with viscosity (A Rothert *et al.* 2005 *New J. Phys.* **5** 59.1).

Nevertheless, we were able to extract useful information by analysing video footage of the final 250 hours of the pendant drop (figure 1*a*). Data taken from the video images show that the drop's fall accelerated towards the end, in accord with a formula from Y M Stokes *et al.* (*Quarterly Journal of Mechanics and Applied Mechanics* **53** 565) that was derived for flow opposed only by viscosity.

Under these circumstances, the length of the drop, L, diverges to infinity at a finite time, $t^* - t_0$, according to

$$L = L_1 - L_0 \frac{t^*}{(t+t_0)} \ln\left[1 - \frac{(t+t_0)}{t^*}\right],$$

where L_0 is some effective initial length of the drop at $t = -t_0$, and L_1 is an off-set fitting parameter. The crisis time t^* (244.5 hours for our pitch drop) is related to the viscosity, μ, density, ρ, and the gravitational constant, g, by $t^* = 3\mu/(\rho g L_0)$. The fit shown in figure 1*b* is consistent with a viscosity of $\sim 2 \times 10^7$ Pa·s – not far from that found for our drop's Australian cousin.

A drop of media gold

Unlike previous Australian drops, the final moments of ours had been caught on camera (http://ow.ly/vqbRA). Once made available on the World Wide Web, a time-lapse video of the drop's final days induced the kind of viral explosion of interest that characterizes our age. Perhaps primed by the coverage given to the rival Australian drop in 2000, the world's media were energized by the uniqueness of this event and keen to report on a short, quirky world-first that resonated with the social-media generation.

Remarkably, within two weeks our video had been viewed more than two million times by people in almost every country in the world. Calls were coming in thick and fast to Trinity from various media giants, including the German publications *Die Zeit* and *Der Spiegel*, the *Huffington Post*, *National Geographic* and even the *Wall Street Journal*. Being asked hard questions by the world's press compelled us to take the thing a little more seriously. So why the worldwide interest?

In January the *New Yorker* published an article asking why certain online content "goes viral". What pushes someone to not only read a story but to pass it on? According to the article, a positive outcome, strong narrative and bizarreness are all key ingredients, as is a story's ability to arouse curiosity. Furthermore, the article argued that readers are drawn to material that creates "social currency" – information that, when we pass it on, allows us to feel smart and be perceived as smart by others. This is a phenomenon that physicists would enjoy analysing (and they probably do), since it is akin to the cascade of photons in lasers or the chain reaction in a nuclear pile.

The Trinity pitch drop seems to tick all of these boxes. It was not a Eureka! moment. We learned nothing we did not know before. However, our Australian colleagues had built up a remarkable tension when extraordinary bad luck saw them miss previous drops falling. (The 2014 Australian drop *was* caught on camera and a video is available at http://ow.ly/w1k1M.) The human aspect of the story resonated with the public, as evidenced by the extensive media coverage given to Mainstone's death. It seems that our video brought finality to this scientific saga.

What more can we say of the global interest in our drip? Are there lessons to be learned for science outreach? Perhaps. With astute insight, the *New Yorker* article warns that the more we mine data on viral content in order to define a "precise calculus" of why people share some things and not others, "the less likely it will be for what we know [about why things 'go viral'] to remain true. If emotion and arousal are key, then, in a social application of the observer effect, we may be changing what will become popular even as we're studying it." It's almost quantum mechanical!

A legacy of slow science

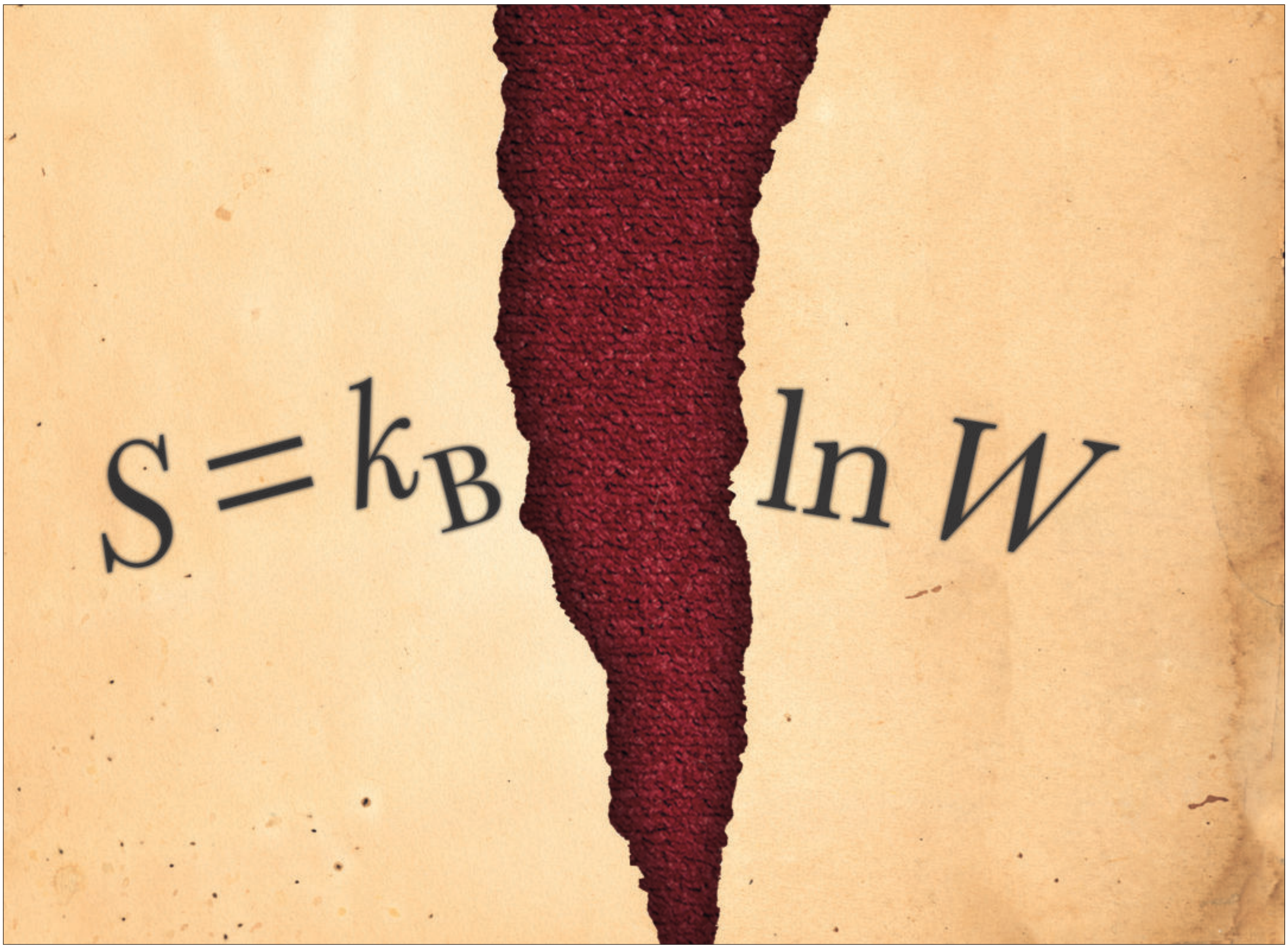
Our burst of fame was bright, but short-lived: the initial $\sim 10^5$ daily views of the pitch-drop video fell exponentially, with a half-life of 2.5 days. *Sic transit gloria mundi*. However, our own interest continues. Not long after the flurry of activity generated by the momentous drop, one of us happened to be inspecting old instruments at Aberystwyth University. Hidden among them was yet another pitch-drop

Slow science (left) The Trinity College Dublin pitch-drop experiment as it appeared in May 2013, two months before the most recent drop finally dripped. The glass funnel is marked 1944 – the year the demonstration was begun – and the bottom of the cylinder contains an accumulation of pitch from previous drops. (Right) A recent photograph of the Aberystwyth University pitch-drop demonstration, begun in 1914. Despite its age, the pitch has barely entered the stem of the funnel, let alone formed a drop.

experiment, this one begun in 1914 by G T R "Taffy" Evans, who subsequently emigrated to South Africa. But even if he had stayed he would not have seen much happen: current estimates suggest that it will take at least 1000 years for the pitch to emerge from the funnel, let alone form a drop. This confirms that pitch is a poorly defined substance, of variable properties (see photograph above).

Back in Dublin, we now intend to set up a larger version of the funnel apparatus, one that may enable us to see the stretching of a viscous filament to a much greater length, and perhaps its eventual *dénouement*. If pitch is used, the experiment will require great patience, but perhaps, as Milton put it, "they also serve who only stand and wait". Indeed, we have an excellent example of this in Lord Kelvin, whose experiments in "slow science" are still cherished today, a century after his death. Among them was a ramp down which pitch flowed, rather in the manner of a glacier. His interest in pitch was part of a wider search for a substance that might mimic the properties of the aether of space, which he considered (at various times) to be analogous to a jelly, a foam or a network of fluid vortices. During Kelvin's fruitless search for a better aether model, he placed some of the first footprints in modern materials science.

The pace of data-gathering and publication is not hectic, but slow science provides good food for thought in tranquilitude. ■



Roll over, Boltzmann

To many physicists, "Tsallis entropy" has been a revolution in statistical mechanics. To others, it is merely a useful fitting technique. **Jon Cartwright** tries to make sense of this world of disorder

Physics may aim for simplicity, yet the world it describes is a mess. There is disorder wherever we look, from an ice cube melting to the eventual fate of the cosmos. Of course, physicists are well aware of that untidiness and have long used the concept of "entropy" as a measure of disorder. One of the pillars of physical science, entropy can be used to calculate the efficiency of heat engines, the direction of chemical reactions and how information is generated. It even offers an explanation for why time flows forwards, not backwards.

Our definition of entropy is expressed by one of the most famous formulae in physics, and dates back over a century to the work of the Austrian physicist Ludwig Boltzmann and the American chemist J Willard Gibbs. For more than 20 years, however, the Greek-born physicist Constantino Tsallis, who is based at the Brazilian Centre for Physics Research (CBPF) in Rio de Janeiro, has been arguing that entropy is in need of some refinement. The situation, according to Tsallis, is rather like Newtonian mechanics – a theory that works perfectly until speeds approach that of light, at which point Einstein's special theory of relativity must take over.

Likewise, says Tsallis, entropy – as defined by Boltzmann and Gibbs – works perfectly, but only within certain limits. If a system is out of equilibrium or its component states depend strongly on one another, he believes an alternative definition should take over. Known as "Tsallis entropy" or "non-additive entropy", it was first proposed by Tsallis himself in a 1988 paper (*J. Stat. Phys.* **52** 479) that has gone on to become the most cited article written by a scientist (or group of scientists) based in Brazil. So far it has

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Tsallis entropy defined

Standard Boltzmann entropy, where the probabilities of all microstates are equal, is given by the classic equation $S = k_B \ln W$, where S is entropy, k_B is the Boltzmann constant and W is the total number of microstates in the system.

If the system has lots of different microstates, i, each with its own probability p_i of occurring, this equation can be written as the Boltzmann–Gibbs entropy $S = -k_B \Sigma p_i \ln p_i$.

Tsallis entropy, S_q, is claimed to be useful in cases where there are strong correlations between the different microstates in a system. It is defined as

$$S_q = \frac{1}{q-1}\left(1 - \sum p_i^q\right),$$

where q is a measure of how strong the correlations are. The value of q is either more or less than one in such systems – effectively to bias the probabilities of certain microstates occurring – but in the limit where q approaches 1, Tsallis entropy reduces to the usual Boltzmann–Gibbs entropy. The parameter q is called the Tsallis index by proponents of the theory.

clocked more than 3200 citations, according to the Thomson Reuters Web of Science.

To many who study statistical mechanics, Tsallis entropy makes for a much broader view of how disorder arises in macroscopic systems. "Tsallis entropy provides a remarkable breakthrough in statistical mechanics, thermodynamics and related areas," says applied mathematician Thanasis Fokas at the University of Cambridge in the UK. In fact, Fokas goes as far as saying that subsequent work motivated by Tsallis's discovery has been "a new paradigm in theoretical physics".

Tsallis entropy has, though, been divisive, with a significant number of physicists believing he has not uncovered anything more general at all. But the voices of these detractors are fast being lost in the crowd of support, with Tsallis's original paper being applied to everything from magnetic resonance imaging to particle physics. So are these applications exploiting a truly revolutionary theory? Or to put it another way: is Tsallis to Boltzmann and Gibbs what Einstein was to Newton?

Old concept

Entropy as a physical property was introduced by the German physicist Rudolf Clausius in the mid-1860s to explain the maximum energy available for useful work in heat engines. Clausius was also the first to restate the second law of thermodynamics in terms of entropy, by saying that the entropy, or disorder, of an isolated system will always increase, and that the entropy of the universe will tend to a maximum. It was not until the work of Boltzmann in the late 1870s, however, that entropy became clearly defined according to the famous formula $S = k_B \ln W$. Here S is entropy, k_B is the Boltzmann constant and W is the number of microstates available to a system – in other words, the number of ways in which a system can be arranged on a microscopic level.

Boltzmann's formula – so famous that it is carved on his gravestone in Vienna (as $S = k \log W$) – shows that entropy increases logarithmically with the number of microstates. It also tends to class entropy as an "extensive" property – that is, a property, like volume or mass, whose value is proportional to the amount of matter in a system. Double the size of a system, for instance, and the entropy ought to double too – unlike an "intensive" property such as temperature, which remains the same no matter how large or small the system.

One example of entropy being extensive is a spread of N coins. Each coin has two states that can occur with equal probability – heads or tails – meaning that the total number of states for the coins, W, is 2^N. That number can be entered into Boltzmann's formula, but, given that an exponent inside a logarithm can be moved to the front of the same logarithm as a multiplier, the expression simplifies to $S = Nk_B \ln 2$. In other words, the entropy is proportional to N, the number of coins, or matter, in the system; by Boltzmann's definition, it is extensive.

Boltzmann's formula is not, though, the final word on entropy. A more general Boltzmann–Gibbs formula is used to describe systems containing microstates that have different probabilities of occurring. In a piece of metal placed in a magnetic field, for example, the spins of the electrons inside are more likely to align parallel than antiparallel to the field lines. In this scenario, where one state (parallel alignment) has a much higher probability of occurring than the other (anti-parallel alignment), the entropy is lower than in a system of equally likely states; in other words, the alignment imposed by the magnetic field has made the system more ordered. Nonetheless, the entropy here is still extensive: double the electrons, double the entropy.

Unfortunately, it is not always possible to keep entropy extensive when calculating it with the Boltzmann–Gibbs formula, says Tsallis, and this, in his view, is the crucial point. He believes that entropy is extensive not just some of the time, but all of the time; indeed, he believes that entropy's extensivity is mandated by the laws of thermodynamics. Calculations must always keep entropy extensive, he says – and if they ever suggest otherwise, those calculations must change. "Thermodynamics, in the opinion of nearly every physicist, is the only theory that will never be withdrawn," Tsallis insists. "The demands of thermodynamics must be taken very seriously. So if Boltzmann–Gibbs entropy does not do the job,

So are the applications of Tsallis entropy exploiting a truly revolutionary theory? Or to put it another way: is Tsallis to Boltzmann what Einstein was to Newton?

you must change it so it does do the job." For Tsallis, thermodynamics is a pillar of physics and must not be tampered with at any cost.

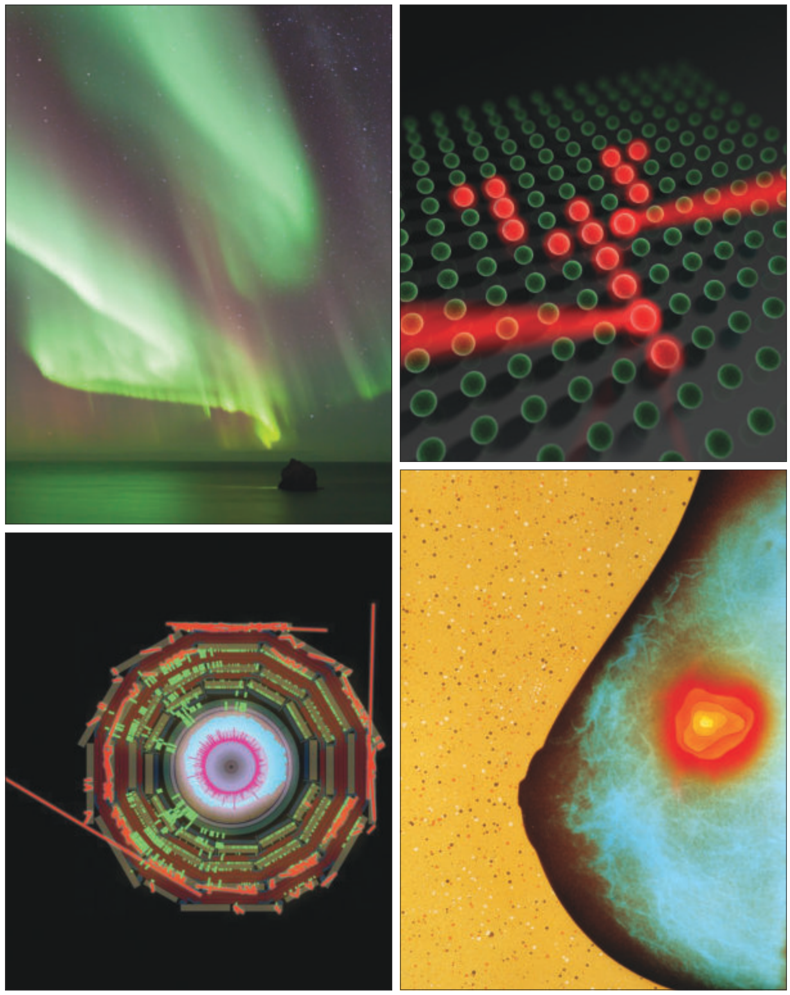
As to why thermodynamics restricts entropy to being extensive, he says, there are two main arguments. One is a complex technical argument from large deviations theory, a subset of probability theory. But another, simpler, argument is based on intuition. Thermodynamic functions depend on one or more variables, which for most systems can be either intensive or extensive. However, it is possible to switch a function that depends on an intensive variable to a version that depends on a corresponding extensive variable, and also vice versa, by using a mathematical "Legendre transformation". For instance, a Legendre transformation can switch a function for energy that depends on temperature to one that depends on entropy – and since temperature is an intensive variable, this implies that entropy must be correspondingly extensive. "The Legendre transformation is the basic mathematical ingredient that makes thermodynamics work," says Tsallis. "And you quickly see that entropy must be in the extensive class."

Systems in which the Boltzmann–Gibbs formula does not keep entropy extensive include those that are out of equilibrium, or where the probability of a certain microstate occurring depends strongly on the occurrence of another microstate – in other words, when the elements of a system are "strongly correlated".

As an example of such correlation in statistics, Tsallis gives linguistics. Take four words almost at random, for example "one", "many", "child" and "children", and you might expect to find, via probability theory, $4 \times 4 = 16$ possibilities for two-word phrases. As it happens, many of these possibilities are not permitted – you cannot say "one children" or "child many". There are, in fact, only two syntactically correct possibilities: "one child" and "many children". Grammar produces strong correlations between certain words, and so greatly reduces the number of allowed possibilities, or entropy.

There are other obvious examples in the physical world of strong correlations affecting entropy. In the presence of a whirlpool, for instance, water molecules do not take any path, but only those that give the overall resemblance of a vortex, because the molecules' motions are correlated. And it turns out that in any system with strong correlations, the number of possible microstates, W, no longer increases exponentially with the number of elements, N, as it does in the coin example where $W = 2^N$; instead, it might, say, follow a power of N such as $W = N^2$.

This is a problem for the Boltzmann–Gibbs expression of entropy, says Tsallis, because mathematically N can no longer be taken outside the logarithm as a multiplier. The formula is now written as $S = k_B \ln N^2$, which simplifies to $S = 2k_B \ln N$. In other words, entropy is no longer proportional to N; it is forced to be non-extensive. "If you keep using Boltzmann–Gibbs entropy, you are going to violate extensivity," says Tsallis. "And I don't want that."



Wide benefits Tsallis entropy has been used to describe (clockwise from top left): fluctuations of the magnetic field in the solar wind; cold atoms in optical lattices; signs of breast cancer in mammograms; and particle debris generated at the Large Hadron Collider.

From top left: iStock/SERG_AURORA; I Bloch, MPQ; Chris Bjornberg/Science Photo Library; CERN/CMS Collaboration

A cloudy idea

None of this was clear to Tsallis back in 1985. At that time he was at a meeting in Mexico City about statistical mechanics, when the study of fractals was becoming fashionable. Fractals are shapes that can be broken down into parts, each of which retains the statistical character of the whole, and are found throughout nature in, for example, lightning bolts, clouds, coastlines and snowflakes. Look closely at one of the arms of a snowflake, for instance, and it is possible to discern features that resemble the snowflake's overall shape.

A mathematical generalization of a fractal is a "multifractal", which describes such hierarchical structures using probabilities raised to a power, q (that is, p^q). Tsallis describes how, during a coffee break at the meeting in Mexico City, he stayed behind in a room where another professor was explaining this concept to a student. "I couldn't hear them," he recalls, "but I knew they were talking about multifractals because of their writing on the blackboard – probability to the power q. And suddenly it came to my mind that that could be used to generalize Boltzmann–Gibbs entropy."

Tsallis believes he instantly thought of entropy because the famous Boltzmann–Gibbs formula was

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Making sense of disorder Constantino Tsallis feels that our conventional understanding of entropy, as developed by Ludwig Boltzmann and J Willard Gibbs, works only within certain limits and that for systems that are out of equilibrium or host to strong correlations his alternative definition should take over.

always somewhere in his mind, "as it is for every statistical mechanist in the world". But having written down a new formula, he did not know what, if anything, he had discovered. For two years he mulled over its implications, until a workshop in Maceió, Brazil, where he discussed it with two physicist colleagues, Evaldo Curado of CBPF and Hans Herrmann, who is now at ETH Zurich in Switzerland. "They were very stimulating, both of them," Tsallis says.

From the discussion with Curado and Herrmann as well as with others around that time, Tsallis realized that his expression for entropy could be used to preserve the property's extensive nature in cases when the Boltzmann–Gibbs formula makes it non-extensive – that is, in systems with strong correlations. Leaving Maceió, on a plane back to Rio, he performed calculations to convince himself that his formula worked, and then looked upon it with admiration. "I found it very cute, very pretty," he recalls.

The new expression, called by him non-additive entropy and by others Tsallis entropy, derives its merit from the exponent, q, of the probability (see box on p32). When the correlations in a system are weak or non-existent, q tends to one and the expression reduces to the standard Boltzmann–Gibbs formula. However, when the correlations in a system are strong, q becomes more or less than one to "bias" the probabilities of certain microstates occurring. The parameter q, which is now called the Tsallis index by proponents of the theory, is therefore a way of characterizing a system's correlations – particularly how strong they are.

Three years after his formulation of non-additive entropy, in 1988, Tsallis published his *Journal of Statistical Physics* paper on the topic. For five years, few scientists outside Brazil were aware of it, but then its popularity skyrocketed – possibly due to research showing how non-additive entropy could be used in astrophysics to describe the distribution functions of self-gravitating gaseous-sphere models, known as stellar polytropes. Since then it has been used to describe, for example, fluctuations of the magnetic field in the solar wind, cold atoms in optical lattices, and particle debris generated at both the Large Hadron Collider at CERN in Switzerland and at the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory in the US. In these cases, unlike Boltzmann–Gibbs entropy, Tsallis entropy is claimed to describe much more accurately the distribution of elements in the microstates; in the case of the LHC, these elements are the momenta of hadrons. More recently, Tsallis entropy has been the basis for a swathe of medical physics applications (see box opposite).

Defenders and detractors

Many people – notably the US physicist Murray Gell-Mann, who won the 1969 Nobel Prize for Physics for his theoretical work on elementary particles – agree that Tsallis entropy is a true generalization of Boltzmann–Gibbs entropy. But there are many detractors too, among whom the principal charge is that the Tsallis index q is a mere "fitting parameter" for systems that are not well enough understood.

Naturally, Tsallis disagrees. If the fitting-parameter accusation were true, he says, it would not be possible to obtain q from first principles – as he did in 2008, together with quantum physicist Filippo Caruso, who was then at the Scuola Normale Superiore di Pisa in Italy. Tsallis and Caruso showed that q could be calculated from first principles for part of a long, 1D chain of particle spins in a transverse magnetic field at absolute zero. The value of q, which was not equal to one, reflected the fact that quantum effects forced some of the spins to form strong correlations (*Phys. Rev. E* **78** 021102).

This calculation required a knowledge of the exact microscopic dynamics, which is not, however, always possible. In situations where the dynamics are not known, says Tsallis, then q indeed has to be obtained from fitting experimental data, but he claims that doing so is no different to how other accepted theories are employed in practice.

As an example, Tsallis cites the orbit of Mars, which could be calculated from first principles – but only if both the distribution of all the other planets at a given moment, and the initial conditions of masses

Many people agree that Tsallis entropy is a true generalization of Boltzmann–Gibbs entropy, but there are many detractors too

and velocities, were all known. Clearly, he says, that is impossible. “For the specific orbit, astronomers collect a lot of data with their telescopes, and then fit that data with the elliptic form that comes out of Newton’s law [of gravitation], and then you have the specific orbit of Mars,” he adds. “Well, here, it’s totally analogous. In principle, we would always like to be able to calculate q purely from mechanics, but it’s very hard, so q often has to be obtained from fitting.”

Mathematical physicist Henrik Jensen at Imperial College London takes a more nuanced view. He says that, for many years, proponents of Tsallis statistics did in fact make their case by calling attention to its greater ability to fit to data. But this, he says, is no longer true. “In the last couple of years work…has demonstrated that one might arrive at Tsallis statistics from very general assumptions about how complex correlated systems behave,” he adds.

That the Tsallis index is merely a fitting parameter is not the only criticism, however. In 2003 physicist Michael Nauenberg at the University of California, Santa Cruz claimed that Tsallis statistics is, for various technical reasons, incompatible with the zeroth law of thermodynamics, which states that two systems at different temperatures placed in thermal contact will reach thermal equilibrium at some intermediary temperature (*Phys. Rev. E* **67** 036114). “Boltzmann–Gibbs statistics leads to this law, but Tsallis statistics violates it,” says Nauenberg. Why that should be the case is a rather technical argument, but he claims that if a thermometer were made from a substance whose entropy could only be described with Tsallis statistics, it would not be able to measure the temperature of ordinary matter.

“Tsallis statistics is a purely ad hoc generalization of Boltzmann–Gibbs statistics,” Nauenberg continues. “But since the appearance of Tsallis’s paper, applications of the new statistics have been made, without any justification whatsoever, to virtually every system under the Sun. As a fitting technique it may have some merits, but it is not a valid generalization of Boltzmann–Gibbs statistics.”

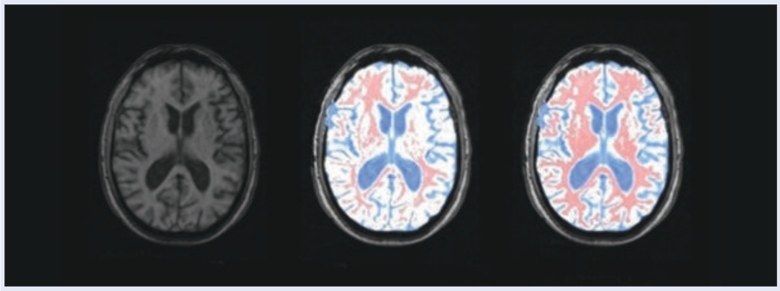
Eugene Stanley, a statistical and econophysicist at Boston University in the US, believes Nauenberg’s criticism is misplaced. He says that the zeroth law of thermodynamics is an “important and quite subtle” point that is still being explored for systems with strong correlations. “I suspect that many people don’t have a clear idea about a very deep question such as the extended validity of the zeroth principle of thermodynamics. Up to now, everything seems consistent with the possibility that the zeroth principle also holds for [Tsallis] systems, which violate Boltzmann–Gibbs statistical mechanics.”

Certainly, not everyone is convinced by the new theory of entropy, and the debates look set to continue. But on the wall of his office, Tsallis has posters of both Einstein and Boltzmann – perhaps in the subconscious hope that he will one day be known for overturning conventional statistical mechanics, as Einstein’s special theory of relativity overturned classical mechanics.

“Any physicist is supposed to know that classical mechanics works only when the masses are not too small and not too fast,” says Tsallis. “If they’re very small, you have to use quantum mechanics, and if they’re very fast, you have to use relativity.” But with statistical physics being one of the pillars of contemporary physics – and an obligatory subject in physics degree courses all over the world – he feels that students should be taught its limitations. “They should learn where Boltzmann–Gibbs statistics works, and where it doesn’t.”

If Tsallis’s ideas hold sway, that equation on Boltzmann’s gravestone may soon need updating. ■

Medical applications of Tsallis entropy



Obvious benefits A functional magnetic resonance imaging scan of a brain (left) that has been analysed first with conventional statistics (middle) and then with Tsallis entropy (right), which more clearly reveals different kinds of brain tissue.

In recent years, one of the most active fields in which Tsallis statistics has been applied is medical physics. In 2010, for instance, medical physicist Luiz Murta-Junior and colleagues at the University of São Paulo in Brazil applied Tsallis statistics to magnetic resonance imaging (MRI), to help them to delineate different types of tissue in the brain. A loss in the brain’s grey matter, for example, can be the cause of neurodegenerative diseases such as multiple sclerosis, which is why doctors turn to MRI to see how much grey matter there is relative to other tissues.

In any MRI scan, different tissues appear as different shades of grey, but each of these shades is actually made up from pixels with a range of different luminosities. The trick therefore is to work out the top and bottom thresholds in luminosity for each tissue – for instance, grey matter may contain pixels with luminosities between 20 and 90 on an eight-bit scale. This range corresponds to a certain value of entropy, since the greater the spread of luminosity values the greater the “disorder”. If there are just two different tissues in an MRI scan – grey matter and white matter – a scientist can analyse the image to determine the distribution of each tissue using an algorithm that adjusts two entropy variables until their total is a maximum.

An algorithm based on Boltzmann–Gibbs entropy, and typical extensions of it, can do this. But according to Murta-Junior and colleagues, Boltzmann–Gibbs entropy does not allow for long-range correlations between pixels, which can arise in regions with complex, fractal-like shapes. The São Paulo researchers therefore turned to Tsallis entropy, and found that it could delineate grey matter from white matter and cerebrospinal fluid much more precisely (*Braz. J. Med. Biol. Res.* **43** 77). “By accurately segmenting tissues in the brain, neurologists can diagnose the loss of grey matter earlier, and patients can be treated sooner with much better results,” says Murta-Junior.

In the same year as the São Paulo group’s research, electrical engineers at the Indian Institute of Technology Kanpur used Tsallis statistics to improve the detection in mammograms of mineral deposits known as microcalcifications, which are sometimes a sign of breast cancer. And in 2012 computer scientists at the Changchun University of Science and Technology in China again used Tsallis entropy with MRI, this time as an aid for image-guided surgery. This suggests that the debates about the fundamental validity of Tsallis statistics are scarcely deterring those wishing to make use of it.

Unravelling our atmosphere

A main limiting factor in climate predictions is that we do not understand atmospheric processes as a function of height. An upcoming European and Japanese space mission called EarthCARE seeks to remedy this, as **Martin Caldwell** explains

Martin Caldwell is an instrument development scientist at RAL Space, part of the Rutherford Appleton Laboratory in Oxfordshire, UK, operated by the Science and Technology Facilities Council, and is currently working on the Broad-Band Radiometer instrument for the upcoming EarthCARE mission, e-mail martin.caldwell@stfc.ac.uk

The gases held in place by the Earth's gravity – our atmosphere – are the scene of some of the most dramatic processes on our planet. Great masses of air heat and rise upwards, powered by energy arriving at the Earth as sunlight, which is absorbed particularly at the Earth's surface and in the tropics. This warm air picks up moisture from the oceans, while global wind patterns are set up as the energy transfers to colder latitudes, polar regions and the upper atmosphere. Energy originating from sunlight is thereby converted into thermal energy (air temperature), kinetic energy in the wind and latent heat in the air (the stored energy it took to turn the liquid water into water vapour).

Despite the Earth's atmosphere being a complex and chaotic system, predictions can be made about its behaviour. Long-term modelling of the Earth's atmosphere as a whole indicates its climate decades ahead, while models of the atmosphere locally on short timescales give us weather forecasts. The better we can understand the atmosphere, and the more accurately we can measure its parameters, the better these forecasts will be.

A current limitation in forecasting – and climate modelling in particular – is that we do not fully understand the significant interactions in the atmosphere between radiant energy (from sunlight and thermal emission) and the air type, which varies depending on the amount of moisture, clouds and aerosols. For example, when air molecules and particles absorb, scatter or emit radiation, the air temperature varies, and changes in temperature can cause sudden phase transitions, such as clouds or fog forming when water condenses, or water freezing to form ice in clouds. These phase changes in turn alter the local absorption, scattering and emission properties, so there can be strong feedback in the interactions between radiant energy and the air type.

One phenomenon we are still unclear about is the so-called forcing effect of clouds on climate – whether different types of cloud lead to a positive or negative net energy effect. We know that low, thick cloud gives net cooling because it scatters sunlight very well, so a lot of it is reflected back out into space. But thin, high cloud can give net heating because it lets visible light through but blocks thermal light from escaping. We are also not sure about the role of aerosols, such as smoke pollution. Does increased smoke pollution lead to net heating of the atmosphere because it contains black soot particles that absorb lots of sunlight? Or does it cause net cooling because the soot particles act as nuclei that promote cloud droplet formation, triggering more clouds?

Our lack of understanding is not for want of trying. The Earth's atmosphere has been examined using many space satellites and in particular those with optical, infrared and millimetre-wave cameras used for weather forecasting. Unfortunately, the views of these weather satellites are often veiled by clouds. And even if there are no clouds, these cameras can measure only the net properties of the vertical column below. As for measuring the aerosols in the atmosphere, these appear very faint in satellite images, and so are difficult to detect against the bright background of clouds or the Earth's surface.

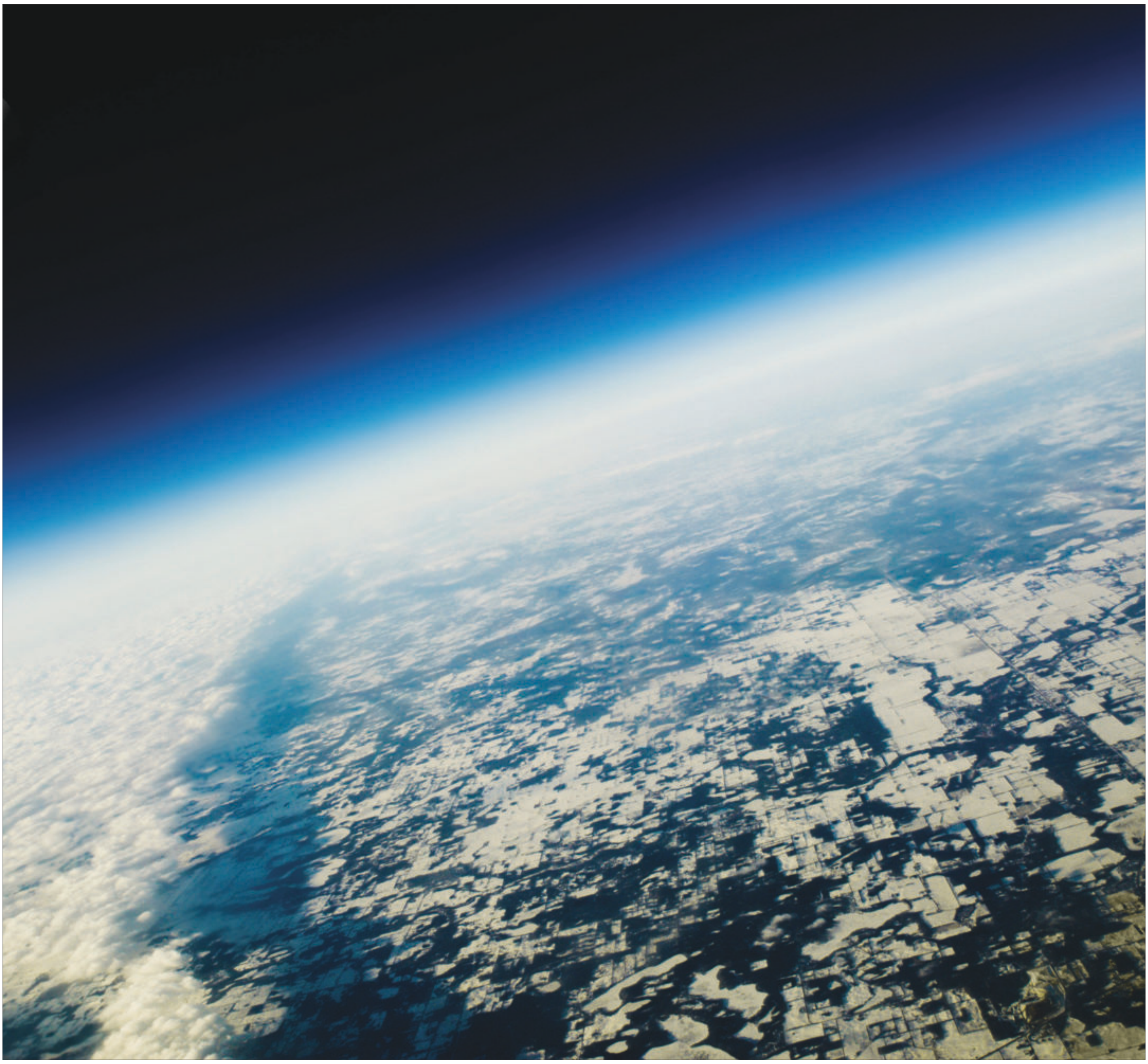
These limitations mean we have so far not been able to unpack the vertical structures of clouds, precipitation and aerosols in the atmosphere. The processes involved are complex, occurring on the scale of a kilometre or more, which is why measuring these properties in profile – and simultaneously measuring the associated sunlight and radiant heat energy flow – is so important. Our inability to differentiate what is happening as a function of height hinders our understanding of these atmospheric processes, and their energy-transfer effects, so that in current global climate models one of the main uncertainties is the net effect of energy flow per vertical column of atmosphere.

We do not fully understand the interactions in the atmosphere between radiant energy and air type

Instrumental importance

Seeking to fill the gaps in our knowledge is a new mission from the European Space Agency (ESA), being implemented in collaboration with the Japan Aerospace Exploration Agency (JAXA). Known as the Cloud, Aerosol and Radiation Explorer (EarthCARE), it is one of six current and planned missions in ESA's Earth Explorer series. Scheduled to launch in 2016, EarthCARE is currently being developed by teams in Europe and Japan, which are creating a suite of four instruments that will simultaneously measure the cloud, aerosol and radiant-energy properties as a function of height through vertical sections of the atmosphere.

To do this, the EarthCARE craft will benefit from



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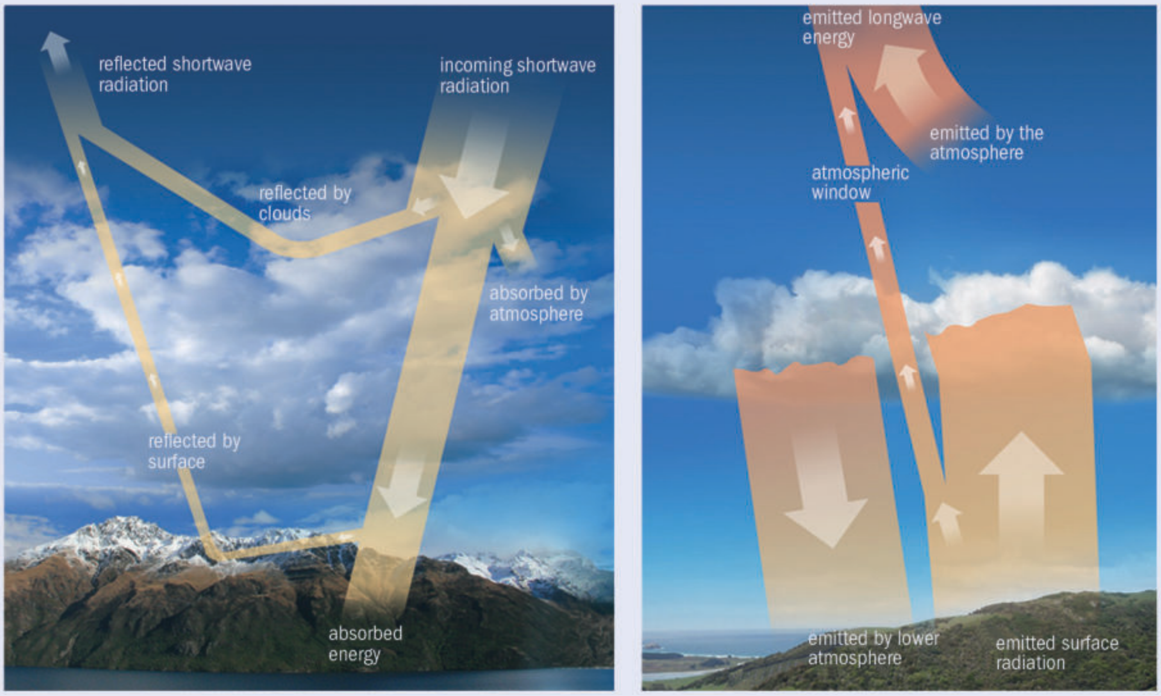
recent advances in "active" sensors that do not just passively receive a signal, but send out a pulse of radiation and detect the radiation scattered or reflected back from the atmosphere. In fact, there are now cloud-penetrating radar systems that operate using high-frequency radio waves (94 GHz) and can detect cloud and precipitation properties throughout the full vertical column of the atmosphere. Likewise, the vertical profiles of microscopic aerosol particles such as those in smoke pollution can now be obtained with laser radar systems, which operate in the ultraviolet spectrum.

A first step towards this type of observation has been undertaken by NASA with the A-Train constellation of Earth-observation satellites, which has instruments observing the same geographical location within a few minutes of each other. EarthCARE is unique in that it will, for the first time, combine these types of instruments on a single satellite, to record these important properties simultaneously and with improved geographical co-registration. It is also designed to operate at a lower orbit than A-train (400 km rather than 700 km), significantly improving the sensitivity of the instruments. These features will give better observations of atmospheric phenomena and their interactions, thereby unravelling these previously hidden processes.

The emergence of these technologies means we can now in principle measure the vertical profiles of clouds, precipitation and aerosols from space. We can also measure the total sunlight and emitted heat associated with each vertical column. This measurement of the Earth's total outgoing radiation involves looking at the overall energy flows in and out of the atmosphere to determine net warming or cooling effects, in the so-called Earth radiation budget (ERB) (see box on p38).

The beauty of the planned EarthCARE mission is that it will combine these new technologies onto a single spacecraft. Its four main instruments will

Earth radiation budget



Incoming sunlight is absorbed or reflected in the atmosphere and at the Earth's surface (left), while thermal radiation is emitted from the Earth's surface and the atmosphere (right). The calculation of whether the energy entering and leaving Earth cancel out is called the Earth radiation budget (ERB) and is an important factor in climate predictions. Overall, there is a net energy gain at lower latitudes and on the day-time side of the Earth, and a net energy loss back into space at the colder latitudes and on the night-time side of the Earth. A positive or negative overall ERB would mean the Earth as a whole is heating or cooling, respectively, and our climate would eventually change.

work together and, by combining all of these data in a single model of the atmosphere, scientists will be able to test and improve their theories on the cloud–aerosol–radiance processes that drive atmosphere dynamics, and hence improve their climate forecasts.

Two of the instruments – the cloud-penetrating radar dish and laser-radar telescope, as described above – will let us characterize the cloud and aerosol properties to a vertical resolution of a few hundred metres. The third instrument is an optical and infrared spectral imager, which will give scene identification for each measured column of the atmosphere – another important input to atmosphere models. The imager will determine if the scene is uniform – for example, all cloud, ice, ocean, desert or vegetation – or a mixture of types.

Finally, the Broad-Band Radiometer (BBR) will detect the reflected sunlight and emitted heat coming from the Earth (figure 1). This instrument is being developed in the UK by Systems Engineering and Assessment and its subcontractors, under contract to the EarthCARE mission prime contractor Airbus Defence and Space. The radiometer unit is currently being built and tested at Rutherford Appleton Laboratory in the UK.

The EarthCARE radiometer instrument faces the challenge of measuring all wavelengths of radiation leaving the Earth, spanning more than two orders of magnitude

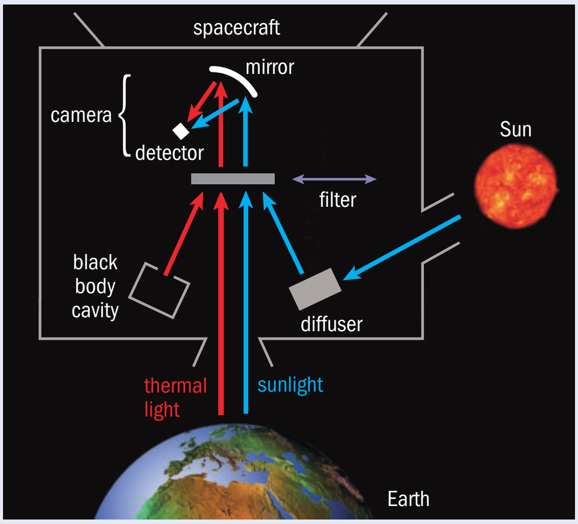
The broad-band challenge

The BBR will measure all the radiation leaving the Earth – both reflected sunlight and emitted thermal radiation. The spectral shape for each type lies within the envelope given by the black-body spectrum for the temperature of its source (figure 2). These sources are thus the Sun's surface, with an effective temperature of about 5800 °C, and the Earth itself, with a temperature that can range from about –65 °C for cold, high-altitude clouds, up to more than 70 °C for hot desert under clear-sky conditions.

Conventional radiometers measure just one part of the electromagnetic spectrum to high precision. Instruments such as the BBR, however, face the challenge of measuring all wavelengths of radiation leaving the Earth, spanning more than two orders of magnitude. The instrument measures the entire solar part, from ultraviolet at 0.3 μm to mid-infrared at 4 μm, and the total heat emission, from 4 μm to far infrared at more than 50 μm. This measurement of the total radiated energy creates datasets that can be used to characterize the ERB.

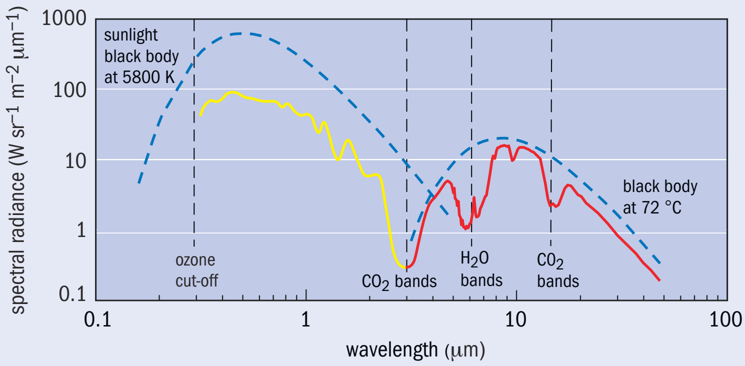
Measuring the total sunlight and heat leaving the Earth is one thing – it is also important to record their angular distributions so that you can measure the total energy flux in watts (i.e. the sum over the column area and over all angles), which is needed in energy-budget models. For this reason the instrument includes oblique views fore and aft along the satellite track as well as the conventional downward view, so that for any point on the Earth the measurement is made at three angles. (These are taken several minutes apart, as the spacecraft flies at about 7 km/s and at a height of about 400 km.) Fur-

1 Broad-Band Radiometer



The Broad-Band Radiometer (BBR) instrument that is being built to go on the EarthCARE spacecraft will consist of three cameras pointing fore, downwards and aft. Each camera will feature mirror optics to focus light onto a sensor called a bolometer, which converts temperature increases caused by incident radiation into wavelength measurements. The filter is used to look at just sunlight, or sunlight and thermal radiation together, while the diffuser and black body cavity are used as calibration sources for sunlight and thermal radiation, respectively.

2 The heat is on



This example spectrum shows the measured radiation leaving a hot desert scene. The left-hand portion (yellow) shows sunlight reflected from the Earth while the right-hand portion (red) shows the heat emitted from the Earth. The spectrum for each type of radiation lies within the envelope given by the black-body spectrum for the temperature of its source (blue). For the solar part, this is the Sun's effective surface temperature of about 5800 °C, with the Earth's albedo assumed to be 1, and for the thermal part it is the desert's surface temperature of 72 °C.

thermore, to make this scheme work it is important to co-register the three views so you know how high up in the atmosphere for each column the measured radiance is coming from. So, for example, if EarthCARE is viewing an overcast cloudy scene, the BBR sunlight views that need to be combined are those at the effective height of the cloud-tops because that is where the signal is coming from. Or if a clear-sky cloud-free scene is being viewed, the BBR measurement of the emitted heat signal may be that coming directly from the Earth's surface or from gases higher in the atmosphere. This co-registration of the measurements to the correct height for each atmosphere column is made by triangulation calculations in the data processing.

Capturing Earth's light

The BBR's measurements will have to be accurate to approximately 1% to ensure that we can monitor the Earth well enough to detect signs of climate change. Achieving this level of accuracy for the very wide wavelength range, and for the great variability in scene types and brightness, is not easy. Brightness can vary from near-zero at night and in dark-ocean scenes, to maximum in snow or cloud viewed with the Sun overhead, while scene colour can run from deep blue (ocean) through green (vegetation) to red (desert). And in thermal light the brightness varies from very cold scenes (high cloud) to very hot (desert). The instrument must also be able to calibrate itself in flight so that it can maintain this accuracy over the three years of the mission, even as its response worsens due to the effects of space radiation and it simply ageing.

The only optics capable of achieving the required detection range and sensitivity are mirrors, and the only type of detector capable of sensing through the wide wavelength range is a bolometer, which absorbs light, converts it into heat, and then converts this heat into an electrical signal. The bolometer detector on EarthCARE consists of an array of thermally isolated pixels, each about 0.1 mm wide. These have a black coating to maximize the amount of light absorbed at all wavelengths, with a porous structure to help trap longer-wavelength light. While some bolometers need to be cooled to cryogenic temperatures to reduce noise – the thermal background in the readings – the BBR receives such a wide range of wavelengths that the devices need only moderate cooling, to –10 °C. In space this is achieved by transferring heat away using a radiator panel on the instrument, which is much simpler than on the Earth where cryogenic cooling would be required.

But even with the instrument operating at –10 °C, it still picks up some of its own internal thermal radiation. This background changes with the precise temperature of the instrument, which varies depending on how much it is heated by the Earth as it orbits over the poles and tropics. This effect can be accounted for by interrupting the measurement of the Earth at regular intervals and moving a calibration light source in front of each camera, such that they then measure the source instead of the Earth. For the thermal signal, this light source is a black-coloured cavity, heated to a known temperature, which acts as an ideal thermal emitter – i.e. a black body. Its light level is therefore accurately known by measuring its temperature and using the Planck function relation between radiance and temperature.

Another effect that must be accounted for is the decline in accuracy of the camera's response to solar radiation. Just as materials on the ground fade if left in the Sun for too long, so the optical response of the mirrors and detectors is prone to degradation

ESA/P Carrill

Awesome foursome Artist's illustration of the EarthCARE satellite, which will host four instruments that will simultaneously measure atmospheric properties.

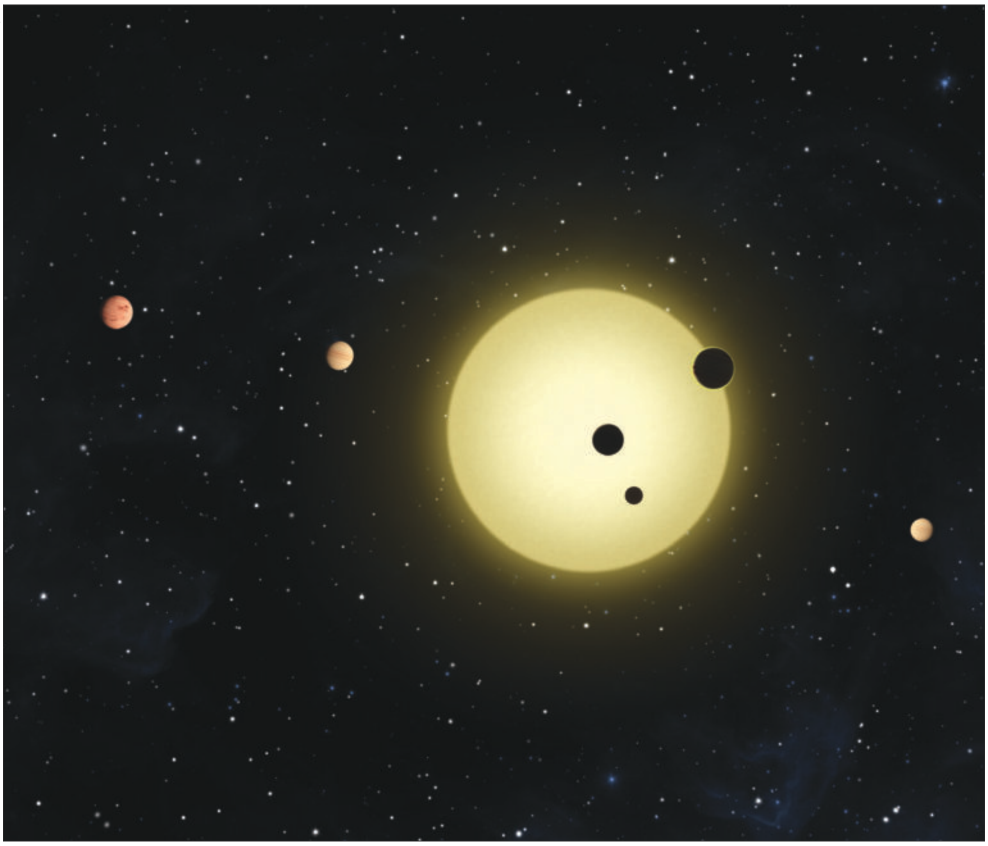
towards the UV end of the spectrum, under the photochemical action of sunlight and other space radiation. This effect also occurs if the surfaces of the optical components are contaminated by molecules such as hydrocarbons, which is one reason why optical space instruments have to be kept very clean. The recalibration of sensitivity to remove these effects requires a known light level in the UV-visible range, and for this the Sun itself is an ideal source. Direct sunlight would be too bright, but a Sun-illuminated white diffuser gives just the right light level, being similar to that from Sun-illuminated clouds. Therefore a Sun-lit diffuser is periodically moved in front of the camera. This can be done conveniently once per orbit, at a point when the same Sun–satellite angular position occurs.

Preparing for launch

Modern space-science missions involve many teams of people, spread over a wide range of disciplines and countries, working over many years. EarthCARE, for example, was originally conceived and proposed by atmospheric scientists, now forming the EarthCARE Joint Mission Advisory Group. These scientists are now developing the relevant atmospheric computer models, in order to have these ready in time for launch when the measured data start to arrive. The mission also involves instrument specialists to develop and build the new detectors, optics, materials and engineering design, so that they are space-worthy in time for the mission. We also need experts to design and build the spacecraft, to launch and operate it, to build the communications systems for collecting the data, and to process this once it arrives. EarthCARE will finally come to fruition when the data get sent to atmosphere scientists, who will start combining the measured atmospheric structures with theoretical models. The result will be a better understanding of the complex relationships between clouds, aerosol pollution and energy dynamics in the atmosphere, thereby promising the improved weather and climate models that are needed over the coming decades. ■

Jack J Lissauer

All alone in the universe?



NASA/Tim Pyle

Is anyone out there? Artist's impression of Kepler 11 – a small, cool star around which six extrasolar planets orbit.

Five Billion Years of Solitude: the Search for Life Among the Stars
Lee Billings
2013 Current Books
£16.88/$27.95hb
294pp

One of the most basic questions, and one that natural philosophers have pondered for many millennia, concerns humanity's place in the universe: Are we alone? Although the history of this question dates back to the ancient Greeks, and it was surely asked for many years before that, the first inklings of an answer did not come until a few centuries ago, when Copernicus, Kepler, Galileo and Newton demonstrated that other worlds qualitatively similar to our Earth orbit around the Sun. The intellectual revolution they helped bring about transformed the question of life beyond Earth, moving it beyond philosophical and theological musings and making it a subject of scientific investigation. Within the past century, further technological advances have made it possible to investigate the likelihood of extraterrestrial life afresh, using experimental, observational and quantitative theoretical studies that draw on expertise in both the physical and life sciences.

In his book *Five Billion Years of Solitude: the Search for Life Among the Stars*, Lee Billings describes the quest for answers to this profound question. The book is, first and foremost, a collection of stories, and one that is at least as much about the journey as it is about the destination. The topics covered are extraordinarily diverse, including both modern events and those that occurred long before humans walked the face of Earth, while the protagonists range from modern-day scientists to great minds of centuries and millennia past.

In researching these topics, Billings spent a lot of time with many active scientists – interviewing them, going to meetings and on research trips with them and getting to know them personally. From the spirit of his writings, he clearly enjoyed these experiences, and he has a very engaging style, one that smoothly transitions between the personal stories of active researchers, ancient Greek philosophers and scientists of the Enlightenment.

The search for life beyond our planet is part of a major new interdisciplinary scientific endeavour known as astrobiology. This field encompasses several forms of direct searches for life elsewhere, including those that look for chemical signposts of life (most likely in the form of distinctive gases that simple microbes would produce in the atmosphere of a planet on which they reside) and those that monitor radio frequencies for transmissions that may be emanating from technologically-advanced civilizations. However, many astrobiologists are also interested in researching such topics as the origin and history of life on Earth; the fundamental requirements of life; the environmental extremes that life can tolerate; the interactions of a biosphere with the planet on which it resides; and the traces, or biosignatures, that life produces.

Billings' stories include elements of many of these astrobiological topics, but the primary focus of his book is the study of extrasolar planets (exoplanets) and what the deep history of our Earth implies for the potential habitability of such worlds. Over the past quarter century, exoplanetology has been transformed from a fraught and less-than-fully-respectable endeavour into one of the most vibrant and visible branches of astronomy. Yet we still cannot answer many basic questions about whether even the most apparently Earth-like of the planets we have found could be suitable for life. For example, we do not know whether terrestrial planets on which liquid water flows are rare, whether they are the norm for solar-type stars or whether they are intermediate in abundance.

The book also includes stories that stem from other areas of scien-

Exoplanetology has been transformed to one of the most vibrant and visible branches of astronomy

tific inquiry, including a history of the Earth that begins with the seeds of its formation; various topics in astronomy and sedimentary geology; models of planetary atmospheres around stars of different sizes; the conditions needed for a planet to be a habitable abode; and the Search for Extraterrestrial Intelligence (SETI). Billings takes some interesting side trips, including one that shows how the search for extraterrestrial life is entwined with the geological histories of California and Pennsylvania, the gold rush and the oil/gas booms of the late 19th and early 21st centuries. The gold rush, it seems, played a role in the construction of Lick Observatory, where much of the pioneering work searching for exoplanets was done: its patron, James Lick, was a California pioneer who struck it rich in the real estate boom that followed the discovery of gold. And the oil and gas boom is, of course, one of the contributors to climate change, which is threatening our civilization.

Billings has written neither a textbook nor even a science book for a lay audience. There are more direct ways to learn about exoplanets, the history of our planet or astrobiology. Rather, *Five Billion Years of Solitude* is an engaging story, filled with anecdotes and (often quite colourful) characters from the past as well as the present. It describes scientists, their motivations and how science interacts with the human world. From the story of Lick Observatory to accounts of the great potential (and great cost) of grand government-financed space-based observatories, Billings takes detours that are entertaining and informative. This is a very pleasurable read, and along the way, you'll learn some science, too.

Jack J Lissauer is a planetary scientist at NASA's Ames Research Center, US, e-mail jack.lissauer@nasa.gov

Web life: *Mahalo.ne.Trash*

URL: http://mahalonottrash.blogspot.co.uk

What does 'Mahalo.ne.Trash' mean?

Mahalo.ne.Trash is the personal blog of John Asher Johnson, an astronomer at Harvard University in the US who began blogging in 2007, when he was about to begin a postdoctoral fellowship at the University of Hawaii. The site's name was inspired by Johnson's realization that the Hawaiian word "mahalo" – which appears on rubbish bins (or "trash cans" in US English) all over the islands – means "thank you", rather than "trash". (The ".ne." part, Johnson adds, is "a form of nerd-speak for 'not equal to'".) Despite being initially dubious about writing a blog – in his first post, he claimed to have a "fear of digital commitment" – Johnson took to the medium like a natural, writing more than 100 posts in his first year. And unlike many bloggers, he's kept up the pace as his career has progressed, taking him first to the California Institute of Technology and then to Harvard, where he has been a professor since 2009.

What are some sample topics?

Johnson is, in his own words, "the first Black professor to attain tenure at Harvard in the physical sciences [sic]" and in recent months, he has often blogged about what it's like to be an "uber-minority" in astronomy. For example, in one post he recalls being uncomfortable with affirmative action programmes as an undergraduate because "I chafed at the idea that people thought I needed help just because I was Black, and being part of the physics-boy culture, I didn't want people to see me as weak." Since then, however, he has become a supporter of affirmative action because he's seen that "science suffers when only a fraction of the talent pool is in play". In lighter moments, Johnson also blogs about his family, his research on exoplanets and (during his Hawaiian days) his encounters with giant flying cockroaches, which are apparently one of the few downsides of doing astronomy on a tropical island.

Why should I visit?

In the wake of claims (made by a major UK newspaper) that two British physicists, Maggie Aderin-Pocock and Hiranya Peiris, were only invited to talk about the recent BICEP2 discovery on national television because they are female and not white, Johnson's candid and robust defences of diversity seem especially pertinent. Like this one from a post on 4 March: "Yes, I was hired in part because I'm Black, and Harvard needs what my unique racial make-up brings with it: namely, excellence. I bring viewpoints that are out of the norm, yet well aligned with the educational needs of an ever more diverse student body. I bring a formidable publication record, unique teaching methods and innovative approaches to all that I do. And I'm determined to see diversification accelerated here. Soon."

Can you give me a sample quote?

Johnson has a lot of interesting things to say, which makes it difficult to pick out a single quote. But this one from a March post on "The art of argumentation" seems fairly representative: "The over-reliance on politeness is one of the defining characteristics of discourse in astronomy. Wait, let me clarify that. The over-reliance on *apparent* politeness is one of the defining characteristics of discourse in astronomy. I suspect this dates back to the era when astronomy was run by British gentlemen, and the tendency of the older generation of astronomers to romanticize that period of time. But as an uber-minority in a monochromatic field of science living in a race-obsessed country, I have no inclination to romanticize the past. I can admire the specific accomplishments of past astronomers. But I refuse to deify them, given that they conducted science as part of such an exclusive club...
This is probably a major reason why I appear so confrontational to my peers in astronomy. The fact that I don't respect all points of view is seen as intolerance. But I see it as the result of a critical selection process. If an idea has merit, I'll respect it. If it lacks merit, then the idea deserves to be dragged out into the light and squished. If that makes the person with the idea feel bad, then go back to the drawing board and try again. It's the idea that was bad, not necessarily the person who made it."

Philip Webber

The problem of missile defence

Too many parameters Russell White of RAND – the R&D think tank that was created to advise the US armed forces – analysing the results of a computer program in the 1950s.

Arguments That Count: Physics, Computing and Missile Defense, 1949–2012
Rebecca Slayton
2013 MIT Press
£24.95/$35.00hb
272pp

The idea of building a missile system to defend a nation from the horrors of nuclear attack first entered the public consciousness in the 1980s, when US president Ronald Reagan – backed by prominent (and controversial) scientific advisers such as the physicist Edward Teller – promoted the Strategic Defense Initiative as a supposedly impenetrable shield against the Soviet Union's nuclear arsenal. At the time, debate about the technical feasibility of this so-called "Star Wars" system centred on questions about whether it was possible to detect a fast incoming missile, distinguish it from decoys or hit it with another missile or laser.

But while the physics problems associated with hitting incoming missiles are probably soluble (given sufficient resources), the computing problems are rather more challenging. Both types of problem had been hotly debated in the 1950s and 1960s as missile technology, software and computers evolved, and in 1963 the physicist Herbert York gave evidence to Congress that offensive missiles would always have the advantage over defensive ones. For a "missile shield" to be effective, it had to work quickly and precisely. It needed to work correctly the first time even though it would be impossible to test it in a realistic way. It needed to cope instantly with a whole range of (possibly unknown) countermeasures. And crucially, all of its multiple technologies and layers had to fit together seamlessly in order to pass flight data between them within minutes and without errors. Creating such a system would be like designing a computer that could beat Garry Kasparov at chess, first time and every time, in matches where the pieces and board were constantly changing.

These and similar arguments prevailed for many years, but when missile defence re-emerged as a hot topic in the 1980s, they were initially disregarded. Only in 1985, when a very senior software engineer resigned from the US programme, citing the risk of catastrophic failure, did these arguments begin to register with the Reagan administration.

The question of why it took so long for certain key issues, such as computing problems, to attract attention is explored in Rebecca Slayton's book *Arguments That Count: Physics, Computing and Missile Defence, 1949–2012*. Slayton, an expert in technology policy, is interested in why some scientific arguments "stick" and others do not, and her book offers some fascinating insights into how people from various disciplines involved in missile defence presented their arguments and counter-arguments. However, Slayton's book is far more than just a historical account of various missile-defence programmes. It also includes a whole series of thoughts and conclusions about the nature of scientific advice and decision-making in our highly technological world.

One of Slayton's conclusions is that scientific advice cannot be separated from politics. Missile-defence systems are a good example. Because their primary goal is to reduce the effectiveness of attacking missiles, one of the cheapest responses for an adversary is simply to deploy more missiles. The better a shield becomes, the more missiles the adversary must deploy to counter it. A complex system such as "Star Wars" could also be used to destroy space-based sensors, thus rendering an opponent electronically blind and facilitating a possible surprise attack. Both are prime examples of how scientific improvements can have politically destabilizing consequences – and indeed, they contributed to a breakdown in US–Soviet negotiations related to the START anti-missile treaty in 1986.

Slayton also argues that "experts" are never just technical experts; rather, they are also experts in persuading and presenting. In that sense she regards scientific advice as being staged and dramatized to gain maximum impact. Again, the history of missile defence offers supporting examples. Slayton points out that many supposedly objective field tests of anti-missile systems have, in fact, been heavily biased in ways that make it easier for systems to find and hit incoming "warheads" and distinguish them from decoys (some of which have helpfully been made much larger). During the Gulf War, the US Patriot missile system tragically led to the shooting down of an Allied Tornado jet, while failing numerous times to shoot down incoming Iraqi Scud missiles (despite initial claims to the contrary).

Slayton uses the term "disciplinary repertoire" to describe how experts use a set of rules, knowledge and habits to rhetorically distinguish the subjective (and politically controversial) aspects of a problem from its (putatively objective) technical parts. This definition may seem controversial to some, but in my view it is a useful way of stripping away the pretence that science can operate in an objective way when it is dealing with highly political, human-related issues.

From my UK perspective, it seems a pity that Slayton's analysis is solely based on US sources. During the 1980s a whole series of British-based analysts wrote books and articles opposing the Strategic Defense Initiative on political, strategic and technical grounds, and Slayton's software-related arguments were also made in the UK by groups of computer professionals such as Electronics and Computing for Peace. These groups later merged into organizations such as Scientists for Global Responsibility, which I now chair, that continue to make similar points today. Another factor that Slayton does not address is the role of funding, lobbying and finance in decision-making, which in my view is also a key issue.

Despite these limitations, however, her conclusions certainly have implications far beyond missile defence. For example, we rely upon "expert" opinion as to how far we should adopt genetic-modification technologies in our food products. But is it really possible to extricate such evidence from the fact that a handful of large corporations control the world's food supply? On the other hand, we have an unprecedented consensus among experts regarding climate change, but they still struggle to get governments to take sufficient action. I would argue that the problem lies partly with these experts' "disciplinary repertoire", but also with the existence of a strong, politically and financially motivated opposing lobby.

In her subtle and understated style, Slayton concludes that we must "recognize that the risks we face can only partly be addressed by the physical ingenuity of America's top scientists and engineers". She adds that all "complex technological systems…can never be *only* physical, but…are simultaneously social and political to the core". I agree with her, while adding that I wish scientists and engineers of *all* nations could be more usefully engaged in *less* complex technological solutions to problems such as climate change, rather than dedicating their skills to conflict and destruction.

Philip Webber is the chair of Scientists for Global Responsibility and a visiting professor at the University of Leeds, UK, e-mail pwebber@gn.apc.org

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Tiny pretty things

Nanoscience: Giants of the Infinitesimal
Peter Forbes and Tom Grimsey
2014 Papadakis £24.99 192pp, www.papadakis.net

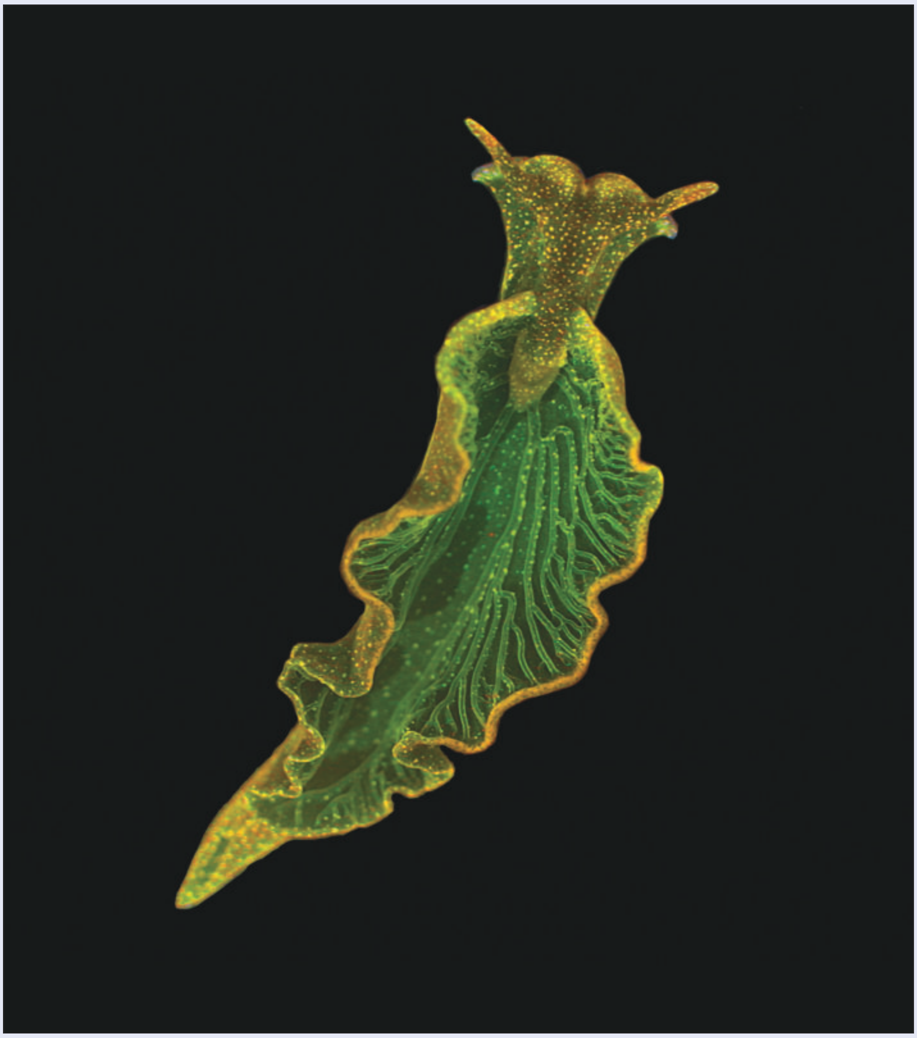
Nanoscience is a fascinating and diverse field, one that uses tools from chemistry, biology and physics to investigate objects that are bigger than atoms, but smaller than most living organisms. This nanoworld can be stunningly beautiful, and the book *Nanoscience: Giants of the Infinitesimal* demonstrates this with more than 100 gorgeous images drawn from research across the discipline.

These images illustrate how nanoscience has evolved since 1959, when Richard Feynman proposed that devices such as circuits and motors could be made smaller, citing the nano-machinery of living cells as an example. Feynman's ideas about miniaturization were soon adopted by the computer industry, with impressive results. However, the authors of *Nanoscience*, Peter Forbes and Tom Grimsey, suggest that nanoscale biomimicry could have even more far-reaching consequences. The large photo at right shows a type of sea slug, *Elysia chlorotica*, that adopts the photosynthetic apparatus of the algae it eats. Once it has done this, the slug can generate energy from sunlight directly, like a plant does. Might such a process form the basis of a new (literally) "green" energy source?

Forbes (a science writer) and Grimsey (a scientifically minded artist) are similarly keen on the potential of existing nano-inventions. Consider aerogels, which they define as "foams from which water has been withdrawn, leaving the structure intact and replacing the water with air". These materials are the world's most efficient insulators, as the photo at bottom right illustrates. If aerogels could be made more cheaply, Forbes and Grimsey write, "they would revolutionize insulation technology".

But nanoscience is about more than just new technologies and materials. According to Forbes and Grimsey, research in the field is also "bringing us to the point where life starts: the point where precisely nanostructured chemicals take on the properties of life". Consider the circuit shown at bottom left, which "assembled itself" via a series of random collisions as individual blocks dotted with solder were jumbled in warm water. Although this is not a nanoscale device (the circuit is several millimetres across), nature employs similar self-assembly processes on much smaller scales. For example, a virus known as a T4 phage can reconstitute itself by physio-chemical means after being smashed to pieces in a blender – a feat the authors compare to "assembling a 747 in a gale". Many scientists suspect that the earliest forms of life may have self-assembled in this way.

Despite all the pretty pictures, this is not a book for beginners. Readers will need a good scientific vocabulary to understand the text, and the authors are not as helpful as one might wish. For example, after a passing reference to "femtosecond pump-probe spectroscopy", they obligingly explain what a femtosecond is, but leave the far more complicated meaning of "pump-probe spectroscopy" unexplored. However, the book could be helpful for undergraduates considering their next career move, as it provides a good overview of the work that individual nanoscientists are doing to explore this tiny, mesmerizingly beautiful world.

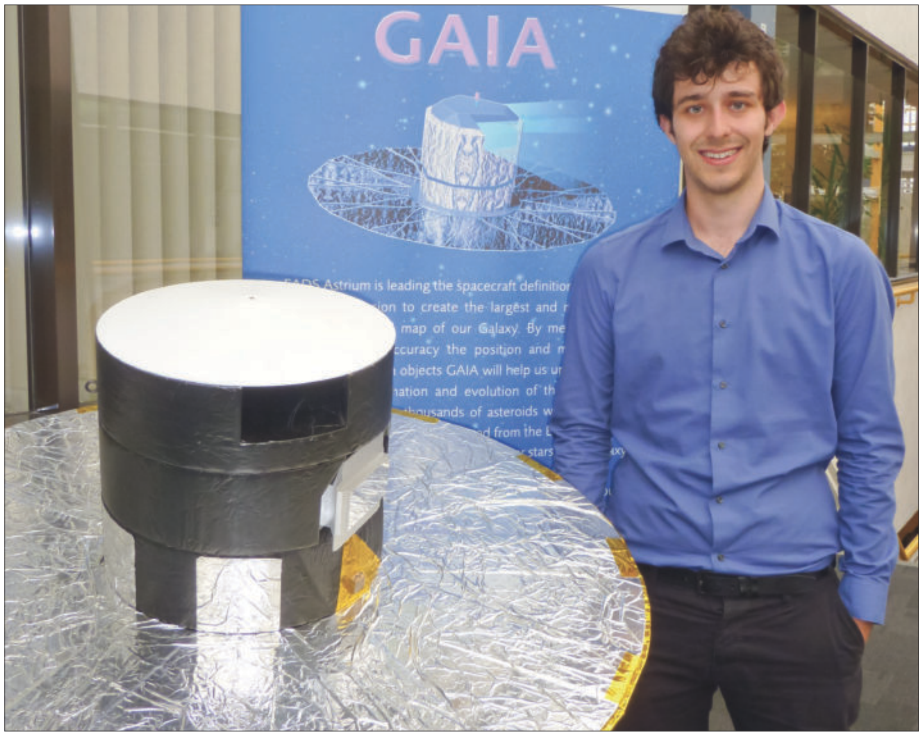


Margaret Harris is reviews and careers editor of *Physics World*

Careers

Looking for space

Kyle Palmer describes how his childhood dream of space travel led to a career at Europe's largest satellite firm



Airbus

Dream come true Kyle Palmer makes use of his mathematical physics background in spacecraft engineering.

When I was 14 years old, I knew exactly what I wanted to do: I wanted to go into space. The problem was that I didn't have a clue how do it, and when I was picking which subjects to study for my Standard Grades (the Scottish equivalent of GCSEs), I remember having the horrible feeling that I was already limiting my career options. Fortunately, I chose to continue with mathematics and physics, and nine years later, I've landed in my dream job, designing satellites for a living.

I joined Airbus Defence and Space (formerly Astrium Satellites) as a graduate mission systems engineer in the space systems division, which means I am part of a company that has been involved in nearly all of the Earth Observation and Science missions of the European Space Agency (ESA) to date. At my site in Stevenage, UK, I only have to take a short stroll around the factory to see missions such as LISA Pathfinder (which will test the techniques for a future mission to look for gravitational waves), Aeolus (which uses an innovative LIDAR system to measure global wind profiles for climate and weather predictions) and the test-bed rovers Bridget and Bruno, which are part of ESA's ExoMars project.

As a mission systems engineer, I am involved with the design of satellite missions from the very beginning, when we work with staff from ESA and academics at universities across Europe to understand their scientific needs and then design satellites to meet them. The "mission studies" that emerge from this process provide a top-level description of how a satellite could be put together to produce the required scientific output. These studies then get repeated in much more detail and along the way the teams working on them grow. After a few iterations, the projects leave my department and are given to a dedicated team made up of specialists from around the company. This new team then turns our preliminary studies into actual satellites in the company's clean rooms.

Many skills, many roles

The first big step in my transformation from space dreamer to space scientist came when, having completed a BSc in mathematics and physics at the University of Glasgow, I moved south to do an MSc in astronautics and space engineering at Cranfield University in England. I would be lying if I said I was completely confident about the move, as I was unsure how well I would cope with the switch to an engineering degree. But as it turned out, my fears were ungrounded. The course was full of mathematicians and physicists as well as engineers from all disciplines, all striving to learn everything they could about space and the satellites and rovers used to explore it. During the course's group project, about a dozen of us collaborated on the design of a spacecraft, and it soon became clear that everyone slotted into roles that suited their background.

Since then, I have come to realize that this process also reflects how things work in the real space industry. For example, the missions systems department at Airbus Defence and Space employs people from many specialisms, with distinct roles for physicists and astrophysicists as well as engineers. There are also numerous physicists in other areas of the business. Basically, as long as you have a scientific background, you can start almost any career regardless of whether your degree (or degrees) are in physics, mathematics and/or engineering.

In the seven months since I began working in mission systems, I have already been involved in several projects. My first task was to use MATLAB to create a simulator for a satellite mission, with the aim of modelling the performance of the payload. Later, I adapted this program to model the calibration technique that the satellite will employ. From this, it was possible to work out how well errors in the system can be estimated using the model, which in turn indicate the possible errors in the final scientific project. This project drew on the coding skills I learned in my physics degree and also the research skills I picked up along the way, since I had to sift through and understand academic papers on imaging techniques, mathematical methods of solving complex equations and orbital geometry.

> I was unsure how I would cope with the switch to engineering but my fears were unfounded

Another project I've worked on was related to a study on how to de-orbit defunct satellites. During this study I tested a harpoon designed to latch onto old satellites and make it possible to drag them to orbits where they will eventually burn up in the Earth's atmosphere. I also had a small role in a study called BIOMASS B1, working out disturbance forces and torques on a spacecraft for ESA's Earth Explorer 7 mission. (Previous Earth Explorer missions include the GOCE satellite, which recently gave us the best-ever measurements of Earth's gravity field.) Finally, I have worked on the concept for a sample-return mission to Phobos, one of Mars's moons.

Advanced opportunities

During the two-year graduate programme, I have to undertake at least one placement in another part of the business and I can do up to three six-month placements. These placements can include a stint in another division of Airbus Defence and Space, at one of the company's many international sites or even in a subsidiary such as Surrey Satellite Technology Limited. This gives all graduates the chance to explore the business and gain or improve technical skills as well as nurturing "soft skills". A placement abroad can also help graduates to appreciate the company's multicultural nature – although I don't even have to leave my department to take a trip around the world, as I work alongside people from Australia, Belgium, France, Germany, Italy and many other countries.

Airbus Defence and Space reinvests a large portion of its revenue into its own research and development. As part of this programme, there is a company-wide call for ideas each year, and any employee can submit ideas for projects that they believe will have a positive impact on our business. Last year, I submitted and received funding for an idea that involves examining innovative orbit designs to make our spacecraft more effective. This gives me a pre-determined budget to study my idea, and I will run this mini-project on my own, with the aim of providing an end-of-year report on my progress. This is great, because it means that Airbus has already given me the opportunity and responsibility of a project manager – even if I am only managing myself.

While I haven't gone to space in person, I have nevertheless landed somewhere that the 14-year-old me probably never imagined would be possible. Working in the space industry has been an incredible experience so far, and I can't wait to see where it leads.

Kyle Palmer is a mission systems engineer at Airbus Defence and Space in Stevenage, UK, e-mail kyle.palmer@astrium.eads.net

Once a physicist: A few we missed

Since 2004 *Physics World* has interviewed more than 100 people who studied physics at university and then went on to do amazing things in other fields. But sometimes we learn about the exploits of extraordinary "once a physicists" only after their deaths. This column is dedicated to a few of the people we missed, and is drawn from information in published obituaries, tributes and the subjects' websites

Elena Akhmilovskaya Donaldson

Chess champion

11 March 1957 – 18 November 2012

Donaldson studied physics and law at what is now the Siberian Federal University before dropping out to focus on her promising chess career. Her breakthrough came in 1978, when she helped the Soviet Union triumph in the International Chess Olympiad. Her success earned her a place in the elite of Soviet society, but in 1988 she defected in dramatic style, eloping with the captain of the US men's team, John Donaldson, during a tournament held in Greece. Two years later, she won the US women's chess championship, a feat she repeated in 1993, when she tied with Irina Levitina, and in 1994, when she won the title outright. In her later years, Donaldson ran a chess academy in Seattle, US, where she specialized in mentoring young female chess players.

Madeline Arakawa Gins

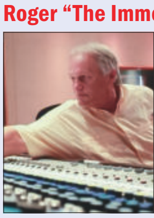
Artist and architect

7 November 1941 – 8 January 2014

Gins, a native of New York City, earned a bachelor's degree in physics and Eastern philosophy at Barnard College. An advocate of "procedural architecture" whose often whimsical designs were intended to "help the body organize its thoughts and actions to a greater degree than had previously been thought possible", Gins later co-founded an organization called the Reversible Destiny Foundation, which is dedicated to architecture that helps extend the human lifespan.

One of the foundation's best-known projects, which Gins designed with her husband and creative partner Shusaku Arakawa, is a group of riotously colourful lofts called "Reversible Destiny Lofts-Mitaka (In Memory of Helen Keller)". The lofts consist of several individual pods with undulating floors and corners with unusual geometries. The result is a disorientating fun-house atmosphere that, according to Gins, is intended to keep residents' minds active and questioning. Her still-active website, www.reversibledestiny.org, contains a rich trove of information about her work.

Roger "The Immortal" Nichols



Sound engineer

22 September 1944 – 9 April 2011

California-born Nichols was one of the music industry's most respected sound engineers, winning seven Grammy awards (plus a posthumous "special merit" award) over a career that spanned more than 40 years. But his first love was physics, a subject he studied at Oregon State University in the early 1960s. After graduation, Nichols landed a job as a nuclear operator at the now-defunct San Onofre Nuclear Generating Station. In his spare time, however, he and a few friends founded their own recording studio, Quantum Studios, and in 1968 he parlayed this experience into a new career at ABC/Dunhill Records in Los Angeles.

While at ABC, Nichols began working with the jazz-influenced rock band Steely Dan in a career-defining collaboration that lasted throughout the 1970s. But physics continued to be an important influence on Nichols' work, and his many inventions included an inexpensive rubidium-based atomic clock that he used to synchronize digital recording equipment. His nickname "The Immortal" allegedly stemmed from an incident in the 1970s when some of his recording equipment shorted out, melting part of a tape machine but leaving Nichols unharmed.

Stuart Schram

Political scientist

27 February 1924 – 8 July 2012

Schram, the author of an acclaimed early biography of the Chinese revolutionary leader Mao Zedong, began a degree in chemistry at the University of Minnesota in 1941, but switched to physics within a year. After graduating in less than three years, he was drafted into the US Army and assigned to the Chicago branch of the Manhattan Project, where he worked in the laboratory run by Enrico Fermi and Arthur Compton.

Schram became disillusioned with physics following the dropping of the atomic bomb, and he did his PhD in political science at Columbia University. A decade later, having already learned Russian and Japanese (and having briefly had his passport confiscated by the US State Department during the McCarthy-era "Red Scare"), he embarked on what would become his most important work: translating Mao's words into English and, in the process, helping to shed light on political developments in China, which was then largely "closed" to Westerners.

Careers and people

Spotlight on: Mildred Dresselhaus


MIT

This month's spotlight is on Mildred Dresselhaus, whose pioneering work in carbon nanoscience earned her the nickname "the queen of carbon". In recent years, Dresselhaus – now a professor emerita at the Massachusetts Institute of Technology (MIT) – has been showered in prizes for her academic research, including the $1m Kavli Prize in Nanoscience in 2012, and her work in education. But in a video interview Dresselhaus told *Physics World* that she has never been motivated by personal accolades. Rather, she has always been in it for the enjoyment she gets from doing fundamental physics.

"I work for love. Awards they come, but they are not that important. The doing of the work is what's important, not so much the recognition," Dresselhaus says. In the interview, she speaks frankly about her early life growing up in the Bronx area of New York City during the Great Depression. Initially, her interest in science developed largely from self-learning, but she got a big break when she was awarded a scholarship to attend Hunter College in Manhattan's Upper East Side, and she subsequently went on to earn a PhD at the University of Chicago in 1958.

After completing her doctorate, Dresselhaus moved to MIT, where she began researching graphite. In the 1960s carbon research was something of a backwater, which for her was part of the attraction: it meant there could be opportunities for breakthroughs. In the decades that followed, Dresselhaus has made many vital contributions to carbon research, which is now a flourishing field. She was a key figure in the discovery of fullerenes, including carbon "buckyballs", and also predicted the existence of carbon nanotubes.

As well as her materials research, Dresselhaus is revered for her reputation as a teacher. In 2012 she received the Enrico Fermi Award for her roles in science leadership and mentoring – an award she finds fitting because, she recalls, Fermi had a significant influence on her scientific development during her PhD, when he acted as her mentor for a while. In her *Physics World* interview, Dresselhaus also talks about her passion for education and how her students have been just as inspirational to her as she has been to them. "You're not teaching for yourself, you're teaching for them, conveying not only information but motivation," she explains.

● You can watch two exclusive video interviews with Mildred Dresselhaus in our digital edition

Movers and shakers

Jon Bagger, a particle theorist at Johns Hopkins University in the US, has been named as the new director of TRIUMF, Canada's flagship nuclear physics laboratory.

Two US physicists have been honoured for their contributions to science policy. **Lewis M Branscomb**, a former head of the US National Bureau of Standards, received the 2013 Philip Hauge Abelson Prize from the American Association for the Advancement of Science (AAAS), while **Siegfried Hecker**, director emeritus of the Los Alamos National Laboratory, received the 2013 AAAS Award for Science Diplomacy.

A trio of applied physicists in the US have won the 2014 Fritz London Memorial Prize for low-temperature physics. **Michel Devoret** and **Robert Schoelkopf** of Yale University and **John Martinis** of the University of California, Santa Barbara will share the award for their experimental work on quantum control, quantum information processing and quantum optics.

The mathematician **Yakov Sinai**, whose work on the connections between deterministic and probabilistic systems has influenced a generation of mathematical physicists, has won the 2014 Abel Prize, worth approximately £600 000.

Andrew Sessler, a former director of the Lawrence Berkeley National Laboratory, has been named as a co-recipient of the $50 000 Enrico Fermi Award.

A group of scientists led by **Hans Werner Schumacher** at Germany's national metrology institute, the PTB, have won the Helmholtz Prize for their work on redefining the SI unit of current, the ampere, in terms of the charge on a single electron.

Accelerator physicist **Tsumoru Shintake** of the Okinawa Institute of Science and Technology has won the European Physical Society's Gersh Budker Prize for leading the design and construction of the SACLA X-Ray Free Electron Laser facility at Japan's RIKEN Institute.

Astrophysicist **Belinda Wilkes** has been named as the new director of the Chandra X-ray Center.

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Closing date: 26 May 2014.

ONR Office for Nuclear Regulation

SPRACE

The São Paulo Research and Analysis Center
(SPRACE – http://www.sprace.org.br)

is a research group from São Paulo State University and ABC Federal University working on the Compact Muon Solenoid (CMS) experiment of the CERN Large Hadron Collider (LHC). The SPRACE project is mainly supported by funds provided by the São Paulo Research Foundation, (FAPESP) supplemented by Federal funds.

The SPRACE research team is engaged in two CMS physics analysis groups: Beyond the Standard Model and Heavy Ion physics. SPRACE also operates a Tier-2 facility of the Worldwide LHC Computing Grid (WLCG) and is responsible for the implementation of a statewide grid infrastructure – GridUNESP – that serves more than 50 research groups from different scientific communities. SPRACE participates in R&D activities on the conceptual design, simulation and proof-of-concept of a Level 1 trigger for the pixel tracking detector of the CMS experiment.

The SPRACE group has currently open positions for Ph.D. students, Postdoctoral Fellows and Electrical Engineers. In order to apply for those positions, candidates should send an application letter, résumé of work experience, and at least two letters of recommendation to
Sergio.Novaes@cern.ch.

SPRACE is committed to the principles of equal opportunity and affirmative action.
Applications from women and members of minority groups are encouraged.

‘Advance’ quantum mechanics

The question is whether the state of being the 20:08 is something that is intrinsic to the train or a property that is only meaningfully acquired by the train when it is observed in the act of departing

To the true physicist, there is surely no area of life that lies beyond the illumination of physical thinking. Consider, for example, the ticketing system on the UK railways. In its current form, this consists of “Advance” and “Anytime” tickets. Advance tickets are, as the name suggests, bought in advance of the journey and can be a lot cheaper than Anytime tickets, but they are specific to one particular pre-booked departure. Miss that specified train, for whatever reason, and you must pay the full fare afresh.

So suppose I turn up at the station with an Advance ticket – let’s say, hypothetically, for a certain 20:08 departure from Bristol Parkway to Swansea on a rather cold and wet evening. Unfortunately, the trains are all delayed, and the 20:08 will not depart for some indeterminate time, if at all. However, the previous train has also been delayed, and it will actually depart at...20:08.

But which of these trains is the actual 20:08, the one on which my ticket is valid? Is it the one departing at that time, or the one labelled thus? The question is, essentially, whether the state of being the 20:08 is something that is intrinsic to the train (and thus invariant under the transformation in time), or a property that is only meaningfully acquired by the train when it is observed in the act of departing.

Clearly, this is a matter for quantum mechanics. The true adherent of the Copenhagen interpretation would no doubt argue that what we have here is a new example of Schrödinger’s cat. The cat (sorry, I mean the train) is sitting there in a superposition of being the 20:08 and of being every other possible time of train, each with appropriate probabilities (and with the probability of me getting to Swansea that evening beginning to feel vanishingly small). It is only when a measurement is made of the train actually departing – when the box is opened – that the wavefunction collapses and the cat (sorry again, I mean train) is revealed to be either the dead 20:08 or the live 20:something else. Except, of course, I’m sure that in Copenhagen they make their trains run on time in the first place.

We can look at it from a different angle as well. Do trains follow Bose–Einstein statistics, where all trains collapse into the same ground state where they are indistinguishably equal, and the 20:08 only emerges when some random quantum fluctuation (and events on this railway are seeming increasingly random to me) causes it to start moving? Or do they follow Fermi–Dirac statistics, where the exclusion principle ensures that each train has a unique description, no two trains can occupy the identical slot on the timetable, and the description “20:08” can only ever apply to one train?

Or perhaps there is a characteristic distance scale (or in this case time scale) to this state of being the 20:08? As time from the notional state of 20:08 lengthens, there is a weakening of the identity of the physical train with the timetable slot it is nominally occupying, until when the characteristic time is exceeded, it jumps to the quantum state of the next timetable slot, and is replaced in the 20:08 slot by the previous train – the one that is at this very moment standing on the platform invitingly, if only I can persuade someone my ticket is valid on it.

In fact, I’m now wondering if I’m part of a conjugate pair subject to Heisenberg’s uncertainty principle. I know with great precision exactly where I am – I’m on the cold, wet, platform of a station in the middle of nowhere, getting colder by the minute. So, because I know my position so precisely, the uncertainty of all the other factors (such as whether I will ever leave this station, and why running a decent railway system is seemingly so difficult) is clearly increasing commensurately.

But of course, the Copenhagen interpretation is just one of many. The ensemble interpretation says, with almost Buddhist-like detachment, that we’re not supposed to think about these things at the level of the individual particle, train or traveller; rather, our equations are valid when applied to the ensemble of systems. So while we cannot say whether these warm and dry carriages in front of me, ready to depart, are indeed the 20:08 or not, we can be confident that when we look back at the whole evening’s trains, one of them will turn out to have been the 20:08. And I’m sure that’s true: of the ensemble of passengers sharing the platform with me, most will reach Swansea quite satisfactorily. They are, however, curse them, the ones who bought Anytime tickets that are not tied, like mine, to that wretched 20:08 departure, and thus this is of small comfort to me.

The instrumentalist interpretation, however, seems more hopeful. It argues that all these discussions are meaningless; what matters is producing a useful result. On the basis that what matters is indeed a useful result, and that the purpose of a train is to get me to my destination, I will follow the instrumentalists’ maxim of “shut up and calculate” – or in this case, “shut up and get on the first train that is leaving”.

Sadly, I fear I will find that the ticket inspector’s in-depth understanding of quantum mechanics has placed them firmly in the “many worlds” interpretation. “Maybe there is another universe where this train is the 20:08, but I’m in this universe, where it isn’t, and you owe me the full fare. Pay up.”

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