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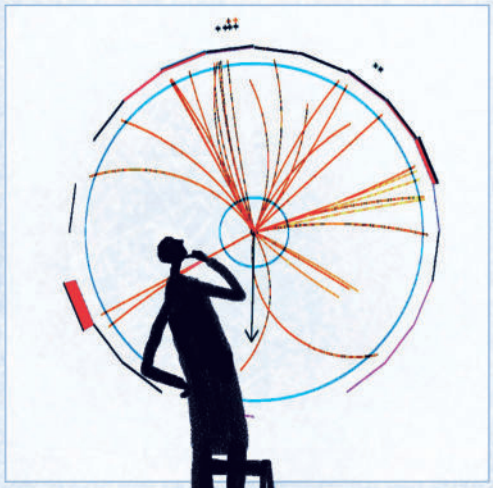

The power of silence

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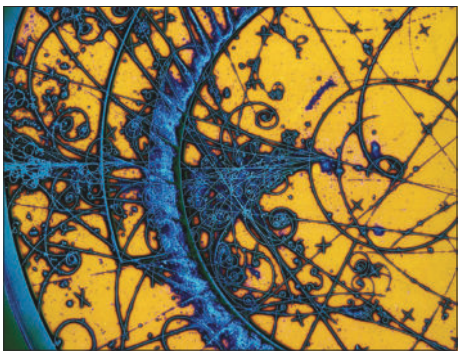

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Finding time to think in silence has proved vital throughout the history of physics. Yet with the pressure on today's scientists to collaborate, communicate and co-operate, *Felicity Mellor* wonders if a key precondition for creativity in physics is being lost

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In this fruitful age of exoplanet discoveries, *David Appell* reports on the work of scientists who are modelling the climates of such bodies to see if these alien worlds might be habitable

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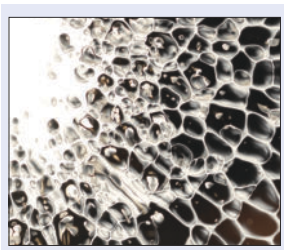

Roberto Zenit

Multimedia

Check out the digital version of *Physics World* for videos on:

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For the record

Our technician came in with a shotgun, and that was the end of the pigeons

Nobel laureate **Robert Wilson** *quoted in* New Scientist

Wilson, who together with Arno Penzias discovered the cosmic microwave background in 1964, was reminiscing about the time they thought that pigeon droppings on the telescope's antenna were interfering with the sensitive radio-wave measurements.

I was thought to be a bit eccentric and maybe cranky

Nobel laureate **Peter Higgs** *speaking on BBC Radio 4*

Higgs says that while nobody initially took his work on the Higgs boson seriously, it "kept him alive" during the breakdown of his marriage.

There is a fashionable trend of borrowing superficial features from overseas and not paying enough attention to substance

Physicist **Vladimir Fortov**, *head of the Russian Academy of Sciences, quoted in* Science

Reforms have hit the 290-year-old Russian Academy of Sciences that some say threaten independent research in the country.

A one-way journey poses a real risk to life, and that can never be justified in Islam

A fatwa issued by the General Authority of Islamic Affairs and Endowment in the United Arab Emirates

Clerics argue that an attempt to create a settlement on Mars would be so hazardous as to be suicidal, which is not permitted by Islam.

Science and art are two long-lost lovers, yearning to be reunited. And now I get to be a matchmaker

Writer and actor **Alan Alda** *quoted in the* New York Times

Alda has been using techniques from acting and directing to help scientists become better communicators.

It's like a cyclotron on bright people

London Mayor **Boris Johnson** *speaking to the BBC*

Mangling his physics definitions, Johnson says that London is rife with people sparking off one another, creating an "explosion of innovation".

Seen and heard

Mikael Vejdemo-Johansson

Tied in knots

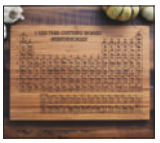
If you have ever pondered how many ways there are to tie a necktie then wonder no more. Mikael Vejdemo-Johansson, a mathematician at the KTH Royal Institute of Technology in Stockholm, and colleagues have come up with a mind boggling 177 147 variations (arXiv:1401:8242). The inspiration for the work apparently came from a *YouTube* tutorial that showed how to tie the fiendishly complex knot sported by the "Merovingian" villain from the *Matrix* films. The number Vejdemo-Johansson and co came up with is a vast increase on the 85 ways that the physicists Thomas Fink and Yong Mao from the Cavendish Laboratory in Cambridge found in 2000. According to Vejdemo-Johansson, their number is much larger because Fink and Mao made a number of assumptions about tie knots that drastically reduced the number available, including that tie-wearers would only make a "tuck" –pushing the tie into the knot to lock it in place – at the end of a given tying sequence. So what is his favourite from the 177 147 variations? "I waver back and forth between the Eldredge (see above image), the Trinity and the Allwin depending on my mood and the current tie," Vejdemo-Johansson revealed to *Physics World*.

Strangelets reborn

Here we go again. It's the return of the strangelets – postulated lumps of stable matter containing many strange quarks that can absorb normal matter. You may remember that in 1999, Hawaiian resident Walter Wagner tried to stop Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) from coming online after some had proposed that the machine could, in principle, create particles called strangelets that would either blow up the planet or suck it into oblivion. The lab then appointed a four-person committee to evaluate the possibility, concluding that the probability of strangelets being produced – if they exist at all – is almost infinitesimally small. Yet that hasn't stopped law experts Eric Johnson from the University of North Dakota and Michael Baram from Boston University who are calling for a "blue-ribbon commission" to look into the risks now that the RHIC has had some recent upgrades. "There is some reason to think this next run will present elevated risks," the authors write in the *International Business Times*. "Collisions will be run at a low-energy level, and physicists consider this to be more likely to produce strangelets." The RHIC is now 15 years old, but it seems that some things never die.

Star of the class

While some children get their parents to help them with homework, four-year-old Lucas Whiteley from West Yorkshire in the UK can boast to his friends of having had a NASA engineer help him. When faced with a couple of taxing questions such as "How many stars are there?" and "Did any animals go to the Moon?" he turned to NASA for help. With the aid of his father, the pupil from Silcoates Sunny Hill School in Wrenthorpe starred in a video asking the questions, which he posted on the NASA website. To his surprise he received a 10-minute video response from NASA engineer Ted Garbeff of the Ames Research Center in California who answered all his queries.



Elysium Woodworks

Periodically in use

Want to get your hands on a periodic-table-inspired chopping board? Then log on to the online shop Elysium Woodworks, based in Santa Rosa, California, which is selling these novel kitchen objects on Etsy. The boards – with the complete periodic table of the elements engraved into it – are made from "caramelized bamboo" and protected with a "blend of food grade mineral oil and beeswax". They come in two sizes – a 20 × 30 cm cheese board costing £21.50 and a 25 × 38 cm chopping board priced at £30.80. The boards are designed and made by "third generation craftsman" Gerald von Bargen III who has apparently had a passion for woodworking since he was a nipper. Indeed, one of the main features of the chopping board is that you can add your own custom-made element in place of the 118th element ununoctium, which apparently makes it an "incredible gift" for almost any wedding/birthday/retirement occasion.

Frontiers

In brief

'Dropleton' quasiparticle makes its debut
A new type of quasiparticle dubbed the quantum droplet, or "dropleton", which comprises a small number of electrons and holes that are bound together in a liquid-like drop, has been identified by researchers in the US and Germany. The drops were created by firing laser pulses at gallium-arsenide quantum wells. Each pulse "pumps" electrons into the conduction band and is followed by a "probe" laser pulse that is used to measure the absorption spectrum of the quantum wells. Initial measurements revealed that the pumping merely creates more excitons – another quasiparticle that is formed when a semiconductor absorbs a photon – just as expected. After a while, however, the team found that the electrons and holes formed unpaired configurations. The result is neutrally charged droplets typically composed of about five electrons and five holes (*Nature* 10.1038/nature12994).

Researchers spin a yarn into a muscle
An unusually simple approach to artificial muscles – based on high-strength polymer fibres – has been developed by an international team of researchers. Rather than needing sophisticated or expensive materials, the muscles can be produced from simple polymers, such as those used to make fishing line or sewing threads. Polymer fibres tend to shorten when heated – as the entropy of the system increases, individual polymer chains become more disordered, which also makes the fibre thicker. The researchers worked out a simple way to use this radial expansion to amplify or, alternatively, to reverse the thermal contraction. In fact, when heated, these fibres shorten or lengthen far more than biological muscle, suggesting applications as diverse as temperature-sensitive window shutters, "smart" clothing and robotics (*Science* 10.1126/science.1246906).

Metal nanotubes make for better batteries
Researchers in the US have taken an important step towards understanding exactly how the performance of lithium-ion batteries is boosted by single-walled carbon nanotubes (SWCNTs), which are often used as additives to improve their charge and discharge rate. The team found that metallic SWCNTs are able to accommodate more lithium atoms than semiconducting SWCNTs, which could lead to better performance. The researchers also found that the spacing between nanotubes in a battery appears to influence the uptake of lithium (*ACS Nano* 10.1021/nn405921t).

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Disorder sharpens images

Salman Karbasi

Localization in action Simulation of image carried by the new fibre (top) and a conventional fibre.

Researchers in the US have created an optical fibre that is very good at transmitting images even though it is highly disordered. The fibre, which could be used for endoscopy, was developed by Arash Mafi and colleagues at the University of Wisconsin-Milwaukee, Corning Incorporated and Clemson University, who say it is the first ever, practical application of an effect from condensed-matter physics called "Anderson localization". First identified by the US physicist Philip Anderson in 1958, Anderson localization refers to the fact that the interference of waves scattering from random impurities in a crystal can abruptly halt the waves' propagation.

Mafi and colleagues' fibres consist of 40 000 strands of poly(methyl methacrylate) (PMMA) mixed randomly with 40 000 strands of polystyrene and then drawn into a fibre with a square cross-section that is 250 μm wide. As light passes down the fibre, it cannot scatter into the plane normal (or "transverse") to the direction of travel because of the random distribution of PMMA and polystyrene. But as the disorder does not extend along the length of the fibre, the light is free to propagate in that direction.

The team showed that its technique works by sending tiny images – some just 30 μm across – along a 5 cm section of fibre. The images were created by placing a small stencil of various digits and letters across the face of the fibre and illuminating it with a blue laser. After emerging from the opposite end of the fibre, the image was magnified by a lens and then captured with a CCD detector. By measuring the blurriness of the image, the team says that light entering the fibre deviates by barely 10 μm from its initial trajectory as it passes along the fibre – a distance called the "localization length".

The team then repeated the experiment using commercial fibres that are designed to carry images. The performance of all the fibres was calculated using the mean structural similarity index – a measure of how true the resulting image is to the original object – and the researchers found that their fibre was slightly better than the commercial products as it scored 0.5877 while the best commercial index was 0.5591 (*Nature Comms.* **5** 3362).

Graphene-oxide sieve

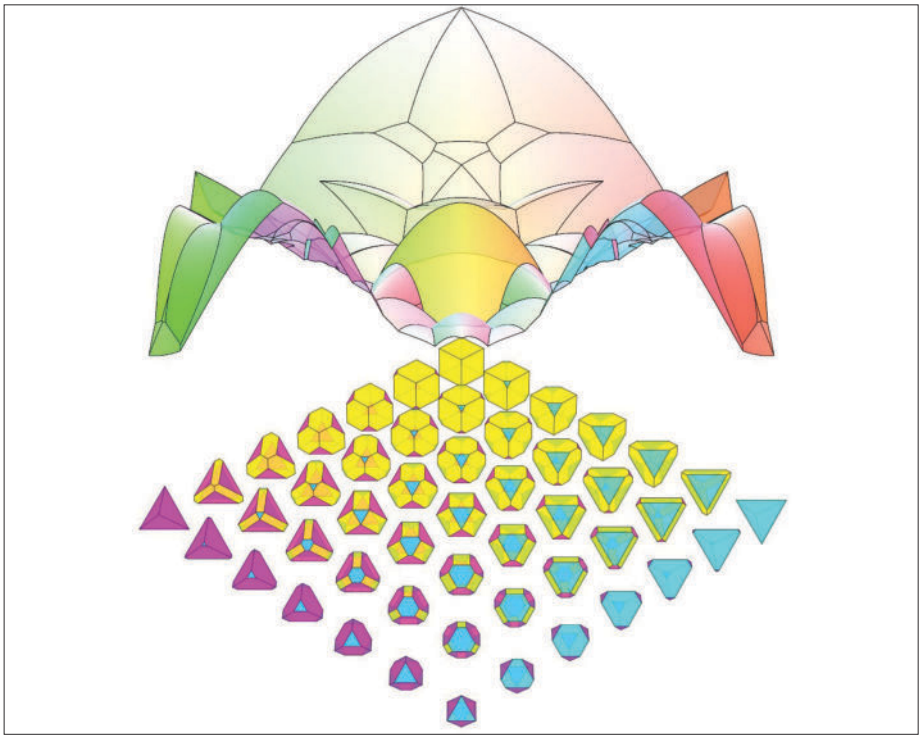
Membranes made from graphene oxide could act as perfect molecular sieves when immersed in water, blocking all molecules or ions with a hydrated size larger than 9 Å. This finding, made by Andre Geim and colleagues at the University of Manchester in the UK, means that these laminated nanostructures could be used to filter and desalinate water.

Graphene oxide is like ordinary graphene, but covered with atoms such as hydroxyl (OH) groups. Sheets of this material can easily be stacked on top of each other to form extremely thin but mechanically strong membranes, consisting of millions of small flakes of graphene oxide with nanosized empty channels (or capillaries) between them.

Two years ago, a team led by Geim found that such membranes are impermeable to all gases and vapours except for water, which passes through a film of graphene oxide as if the membrane is not there. Water can travel through a membrane so fast because the graphene-oxide sheets are arranged in such a way that there is room for only one layer of water molecules. In the absence of water, however, the capillaries shrink and do not let anything through this way, making the material impermeable to everything but water.

Now, Geim's team has found that when the membranes are immersed in water, as opposed to just being exposed to water vapour or ambient humidity, they appear to swell slightly and are able to block all molecules or ions with a hydrated size larger than 9 Å. (A hydrated sugar molecule, for example, has a diameter of 10 Å.) What is more, the membranes are able to distinguish between atomic species that differ in size by only a few per cent. In addition, ions that are smaller than 9 Å across can pass through the membranes 1000 times faster than is expected by simple diffusion processes alone (*Science* 10.1126/science.1245711).

Elizabeth Chen



Finding better ways to pack polyhedrons

Determining the most efficient way to pack simple objects such as spheres has entertained and infuriated mathematicians from Aristotle to the present. Now, Sharon Glotzer and colleagues at the University of Michigan in the US have taken a new computational approach to the problem, by studying how packing efficiency varies as the shape of an object is modified. The researchers looked at how the maximum packing efficiency of tetrahedrons and several other simple polyhedrons varies according to two parameters. So the alien spider that seems to be guarding its colourful bounty of eggs in the image above is nothing to worry about. In fact, it illustrates a plot of maximum packing efficiency as a function of the two parameters for one selected family of polyhedrons with tetrahedral symmetry. The polyhedrons are shown below, while the corresponding maximum packing density surface is shown in a 3D plot (*Phys. Rev. X* **4** 011024).

Electronic whiskers

Inspired by the whiskers that many different animals use to gauge the wind and to navigate around obstacles, researchers at the University of California, Berkeley have made highly sensitive, lightweight electronic versions that can detect the lightest of touches or a gentle breeze. The new electronic or e-whiskers made by Ali Javey's team consist of a mixture of carbon nanotubes and silver nanoparticles, and could be used to create "skin" for robots and in interfaces between humans and machines.

The researchers made their whiskers by painting composite films of the nanotubes and nanoparticles onto thin elastic fibres made of the polymer PDMA. The resulting carbon-nanotube "paste" forms a conductive matrix that can be bent and unbent at will without suffering any damage. The silver nanoparticles further increase the conductivity of the composite and also make it highly sensitive to strain.

According to Javey, the strain sensitivity and electrical resistivity of our composite film is readily tuned by changing the composition ratio of the carbon nanotubes and the silver nanoparticles. When the e-whiskers experience a light touch or a gentle breeze, they bend and their resistance changes dramatically. The structures are sensitive to changes in pressure of just 8% and are 10 times more sensitive to pressure than all previously reported capacitive or resistive pressure sensors.

The Berkeley team is now looking to make the devices using different printing processes and to produce them on a larger scale. Structures such as these whiskers that mimic biological systems could help in the development of so-called smart and user-interactive electronics, explains team member Zhibin Yu. Researchers have already made rudimentary e-skin and electronic eyes on thin, flexible substrates. Such devices are capable of "feeling" and "seeing" their local environment (*PNAS* 10.1073/pnas.1317920111).

Innovation

Storing data in magnetic holograms

A new type of memory device based on the interference of spin waves has been unveiled by scientists in the US and Russia. Data are stored in the form of magnetic bits and are read out simultaneously as holographic images. Because the wavelengths of the spin waves are much shorter than those of visible light, the storage density of the memory has the potential to be much greater than systems based on optical holograms, and could someday be used to store very large amounts of information.

The new type of holographic memory has been created by Alexander Khitun and colleagues at the University of California, Riverside and the Kotel'nikov Institute of Radioengineering and Electronics in Saratov, Russia. The team's prototype device comprises two small magnets – each about 360 μm wide – that are connected by a magnetic wire. Data are stored in the device in terms of the orientations of magnetic moments of the magnets. As well as being connected to each other, each magnet also has three other magnetic wires connected to it for inputting and outputting spin waves. The waves are created by applying an electrical signal to tiny antennas connected to the wires, with the antennas also acting as spin-wave detectors.

Data are written to the device using spin waves with relatively large amplitudes that can change the orientation of the magnetic bits. The read process involves sending spin waves with smaller amplitudes through the device – the waves' phases are affected by the orientations of the two bits and the antennas are then used to measure the interference between them. By varying the relative phases of the input spin waves, the team can build up a holographic image of the orientation of the two magnets. This is analogous to how an optical holographic image is built up by varying the angle between the object and the illumination beam.

Unlike hard-disk drives, which read and write data sequentially from magnetic bits, the new method could be used to read and write huge amounts of data simultaneously, to and from large arrays of magnetic bits. The team's first prototype uses relatively large wires and magnets, but Khitun says his team has already built a working prototype where the magnets have been shrunk to 12 μm (arXiv:1401.5133). Furthermore, he says that numerical simulations suggest that reliable devices could be made with feature sizes as small as 10 nm. Khitun and colleagues are also working on a memory device based on a 4 × 4 matrix of 16 magnetic bits.

News & Analysis

ITER faces management turmoil

A scathing report into the management of the ITER fusion experiment has thrown the whole project in the spotlight and even calls for the director-general to go, as **Daniel Clery** reports

The biggest challenge facing the ITER fusion project may not be piecing together the one million components that make up the 23 000 tonne superconducting tokamak, or even controlling the 150 million degree plasma that will burn inside it, but rather simply managing the unwieldy and politically riven organization in charge of the effort. A biennial management assessment, which was accepted by the ITER council in February, is scathing about how badly the project is being run, identifying numerous problems with its leadership, general management and governance.

The management assessment was carried out last year by Bill Madia, former director of the Pacific Northwest and Oak Ridge national laboratories, together with two colleagues Charles Shank, emeritus professor at the University of California, Berkeley, and Theodore Glauthier, who runs the energy consultancy TJG Energy Associates. Such was the seriousness of its conclusions that the ITER council held an extraordinary meeting on 13 February to discuss it. A terse four-sentence statement after the meeting stated that: "The council will ensure that all the reforms are properly carried out in the near- and intermediate-term."

But the council also decided to keep the contents of the report confidential. "Certain things can be misinterpreted," says nuclear engineer Bob Iotti who chairs the ITER council. "Each of the [member delegations] needs time to inform their funders."

Following some details being revealed, the *New Yorker* magazine published the assessment's 13-page executive summary online. Iotti acknowledges that the report is "blunt", adding that it "didn't mince words – it is not a very favourable report". One ITER insider, who prefers to remain anonymous, says that while the technical parts of the project are largely solved, "the management is a disaster".

ITER Organization

Clouds on the horizon
A biennial management assessment of the ITER experimental fusion reactor currently being built in Cadarache, France, warns that the project is in "a malaise".

Taming the hydra

First proposed nearly three decades ago, ITER is a collaboration between China, the EU, India, Japan, Russia, South Korea and the US that aims to demonstrate that nuclear fusion can generate useful energy. It is scheduled to be completed by 2020, at which point a giant doughnut-shaped chamber, known as a tokamak, will use strong magnetic fields to contain a heated plasma of deuterium and tritium at a temperature of tens of millions of degrees so that atomic nuclei collide and fuse. In theory, the reactor will produce 10 times the power it takes to heat it. Construction of buildings is now under way at its site at Cadarache in southern France and manufactured components will begin arriving this summer.

Much of ITER's management problems, according to the report, stem from the way in which the whole collaboration was set up. The project's seven partners wanted their own industries to be involved in the project so they would learn skills that could be vital in a future fusion power industry. This meant that the manufacturing of components was carved up between all the partners – 45% to the EU, as host, and 9% to each of the six others. All countries would then simply make the equipment and deliver it to Cadarache with no money changing hands. This, however, has created huge complexity and inefficiencies. The superconducting cable for the magnets, for example, is not all being made in one plant but in six different plants around the world. Any changes in the ITER design lead to lengthy international negotiations.

To manage this many-headed hydra, the 500-strong ITER Organization in Cadarache must work with seven "domestic agencies" – organizations set up by each partner to place contracts, liaise with industry, and ensure timely delivery. The staffing of the ITER Organization itself also has constraints enshrined in the ITER agreement, with staff nationalities reflecting the division of support from partners. This also requires seven deputy director-generals, one appointed by each partner. As a result, the management structure is top-heavy and highly qualified people often end up in jobs they might not be best suited for. "Inefficiencies, which are inherent in the international nature of the project, were built in with the full knowledge of the parties," adds Iotti.

The tyranny of consensus

Many of the 11 recommendations in the assessment deal with the spirit of the ITER Organization. "There has been a lack of strong project management culture inside [the organization]," the report states, and "[it] has not operated as an efficient or effective management organization". The report also warns that the project "is in a malaise and could drift out of

control…Time is of the essence to get this project back on track". Iotti acknowledges these problems. "It is not easy to change management culture," he says. "What you want are people at all levels personally owning their part of the project, developing a can-do attitude. That culture is lacking in some people and even a few can undo the good of the many."

The assessment proposes specific actions to create a project culture within the ITER Organization, to hold the director-general accountable for resolving conflicts, to reduce the number of senior managers in the organization, to strengthen systems engineering and to instil a nuclear safety culture, among other things. Perhaps most controversially, the assessment recommends accelerating the transition to a new director-general. The current director-general, Japanese physicist Osamu Motojima, ends his five-year term in June 2015. "The [ITER council] should immediately conduct an appropriate search for a new director-general with the requisite skills and appoint this new leader as soon as practical," the report says. Iotti adds that the council has formed a working group on succession planning.

The assessment also looked in detail at the relationship between the ITER Organization and the domestic agencies. "The ITER Organization and the seven domestic agencies should work as a single project team. That's not really the case. Communication is not ideal," says Jean Jacquinot, a former director of the JET fusion reactor and now scientific adviser to the head of France's Atomic Energy Commission. Insiders say that relations between the ITER Organization and domestic agencies is often acrimonious and sometimes if an agency does not like what the organization is asking it to do, it will go to its national delegate on the ITER council and get them to put pressure on the organization to back off. The report says that "Agreements are often hindered by perceptions that each side is favouring its own interests in negotiations rather than focusing on the best interests of the ITER program overall." Iotti acknowledges that the central body and the domestic agencies have "a divergence of incentives" and says that the council has set up a study group to find ways to improve their working together.

Madia and his assessment team also turned attention towards the ITER council itself, the body that commissioned the report. The council, they say, avoids or takes too long making difficult decisions and will only act when the partners are unanimous. "If the [council] continues to operate in this manner, the ITER project will undoubtedly continue to experience long delays and cost increases," the report warns, adding that the council should behave more like a board of directors and act even when there is no consensus.

Slipping timescales

At the extraordinary council meeting in February, the ITER Organization outlined proposals for carrying out the report's recommendations. Iotti says the council temporarily endorsed some of these proposals because it was "not convinced that this was the ultimate answer" and asked the organization for more information and justification. The partner governments will now be watching the organization closely to see if it makes the necessary changes in its management, although as construction of ITER approaches its peak in activity during 2015 and 2016, some partner governments are straining to keep up with their contributions. The US Congress has even gone as far as capping its cash contribution to the ITER Organization until it demonstrates that it has adopted the recommendations of the management review.

There is likely to be more bad news next year, as the ITER Organization seeks to firm up the project's schedule, with the date for first plasma having already put back from 2016 to 2019 to 2020. "ITER's schedule has slipped so consistently that almost no-one, including the [management assessment team], believes the announced dates for first plasma will be met," says the review. Insiders say that senior management has forbidden anyone to question the current schedule because it would be too politically embarrassing to let it slip again. "We don't have a realistic, believable, very high-quality schedule," says Iotti, adding that he hopes to announce a "high confidence" schedule in June 2015.

The way to ITER

1985
US president Ronald Reagan and Soviet Union leader Mikhail Gorbachev, at their first summit meeting in Geneva, resolve to develop fusion energy "for the benefit of all mankind".

1987
Work on the conceptual design begins, with the EU and Japan joining the US and Russia on the project. Conceptual design completed two years later.

1992
Work on the engineering design begins with teams at San Diego, Garching and Naka. Completed in 1997.

1998
US withdraws due to €10bn price tag.

2001
Revised design completed, resulting in the cost of the project being halved to €5bn.

2003
US rejoins ITER with China and South Korea also signing up. Partners meet but fail to agree on a site leading to an 18-month stalemate.

2005
The EU and Japan agree on ITER's home being Cadarache in southern France.

ENGAGE/ITER Organization

The vision Architect's drawing of the completed ITER.

2006
India joins ITER. The ITER Organization is formally established by treaty and civil engineering begins.

2010
Detailed design finalized. Cost estimate rises to around €15bn, with building construction starting.

2011
Construction delays push back the date of first plasma from 2016 to 2019, revised to 2020 a year later.

2014
An independent report warns that the project is in "a malaise" and recommends a management overhaul. Manufactured components of the reactor begin to arrive for assembly.

Japan

J-PARC facility reopens after radiation scare

A key facility at the $1.5bn Japan Proton Accelerator Research Complex (J-PARC) in Tsukuba has been reopened almost a year after a radiation leak at the facility put the whole complex out of action. The Materials and Life Science Experimental Facility (MLF) – a neutron centre at J-PARC – was made available again to users in February. However, J-PARC's other experiments are not expected to be fully operational until the end of the year. "Although we are still on the way to full recovery, this is a major milestone for the J-PARC centre," J-PARC director Yujiro Ikeda wrote in a note to users.

Lying on the north-east coast of Japan, 120 km from Tokyo, J-PARC is located in Tokai and is jointly operated by the Japan Atomic Energy Agency (JAEA) and the KEK High Energy Accelerator Research Organization. The facility boasts three massive machines – a 200 MeV linear accelerator, a 3 GeV proton synchrotron and a 50 GeV proton synchrotron – that accelerate and generate a smorgasbord of particles for the MLF, the Hadron Experimental Facility and the Tokai to Kamioka (T2K) neutrino experiment.

J-PARC

Back on track
A neutron facility at the $1.5bn Japan Proton Accelerator Research Complex is online again after being shut down due to a radiation leak at another experimental hall at the lab.

The radiation leak at J-PARC occurred on 23 May 2013 at the Hadron Experimental Facility, which produces kaons and antiprotons. Gamma-ray monitors located in the hall measured an increase in radiation levels of around 4 μSv/hr – some 10 times higher than normal. Although around 100 individuals were in the controlled area of the hall during this incident, only 34 were exposed to the higher radiation dose. Their total exposure was under 1.7 mSv – equivalent to a computerized tomography scan of the head but still not exceeding that maximum dose as stipulated by law for nuclear industry workers.

All experiments at J-PARC were immediately cancelled and numerous investigations have since been carried out to get to the bottom of the leak and to reassure residents nearby who remain on edge, especially after the nearby Fukushima nuclear accident in 2011. The conclusion of such reports and international review committees have resulted in the renovation of the Hadron Experimental Facility, which includes improving radiation protection for the target assembly, installing a double-layer shield for the primary beamline area and incorporating a filtered exhaust system for the entire hall.

Naohito Saito, deputy director of J-PARC, told *Physics World* that the hall is expected to be back in use by the end of the year. He adds that the leak has not put scientists off from doing experiments at the MLF and that J-PARC has received the usual number of proposals for beam time at the centre.

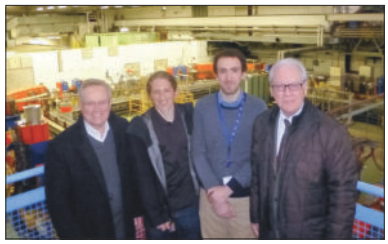
Michael Banks

Medical physics

CERN converts accelerator for medical applications

CERN has announced that it is creating a new department to consolidate its activities in medical physics. Headed by Steve Myers, formerly CERN's director of accelerators and technology, the new department will also involve the lab's Low Energy Ion Ring (LEIR) being transformed into a biomedical facility, dubbed BioLEIR. Costing an estimated €15m, CERN will provide some of the cash but also seek money from elsewhere to fund the initiative.

CERN has a long history in medical physics, having developed Positron Emission Tomography scanners and also developed dedicated accelerators for particle therapy. The advantage of exploiting CERN's 78 m circumference LEIR accelerator, which is currently used to pre-accelerate lead ions for injection into the Large Hadron Collider (LHC), is that it is only in use for several weeks each year, leaving lots of spare beam time. LEIR also has an energy range that matches that of medical accelerators – around 440 MeV for carbon ions – and lies next to a hall used only for storage.



Tami Freeman

Grand designs
Steve Myers (left) and colleagues at CERN's Low Energy Ion Ring.

Some of this hall could be used to host two beamlines – one running at up to 440 MeV and another up to 75 MeV. Before this can happen, however, LEIR will have to be modified to let it accelerate different types of ions and require a new extraction system, all while still being used as a lead-ion accumulator for the LHC.

Protons and carbon ions are already widely used to treat tumours, while other ions such as oxygen and helium are under investigation, but according to Myers, there is still a lack of controlled experiments that directly compare the effect of different ions on cancer cells under identical conditions. Although existing clinical centres could in principle perform such studies, free accelerator time for research becomes extremely limited once patient treatments begin. "The big advantage here is that we don't treat patients," says Myers. "Our aim is to provide a service, so researchers don't have to do experiments at a clinical site, they can come here instead."

The revamped facility would work in the same way as particle-physics experiments are carried out at CERN: researchers propose experiments, which are peer reviewed by a panel of experts who select suitable projects, and CERN controls the beam-time allocation. Myers hopes to secure full funding for BioLEIR this year with the site up and running by 2016.

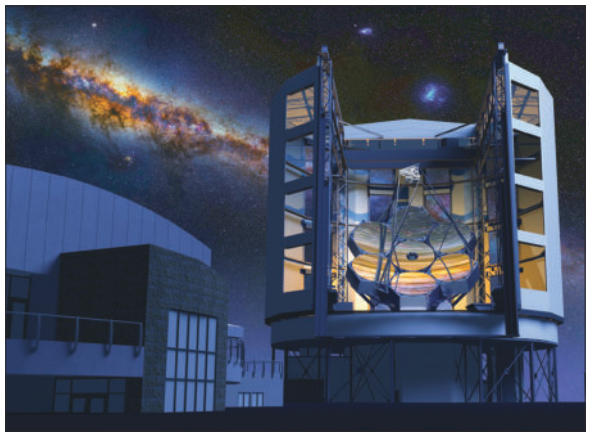
Tami Freeman

Brazil

São Paulo pushes for stake in huge telescope

The planned $880m Giant Magellan Telescope (GMT), to be built in Chile, could be boosted by astronomers from the Brazilian state of São Paulo, who are considering contributing $40m to the 25 m telescope. The proposed 4% stake in the facility from the São Paulo Research Foundation (FAPESP) would give its researchers 4% of observing time. When complete in 2019, the GMT will be based at the Carnegie Institution's Las Campanas Observatory in Chile and managed by a consortium of US, Australian and Korean institutions and will produce images up to 10 times sharper than the Hubble Space Telescope.

São Paulo is Brazil's richest state, with FAPESP being a major funder of research in the region. The state produces not only half the country's scientific output but also more than any other country in South America. Its decision to invest in the GMT could be seen as an insurance policy in case the Brazilian government fails to ratify the agreement to join the European Southern Observatory (ESO), which has stalled in legislative committees in the Brazilian government. The agreement would see the country put $371m into the ESO to assist with the costs of building the planned 39.5 m European Extremely Large Telescope (E-ELT).



GMTO Corporation

Joining the club
The state of São Paulo is planning to contribute $40m to join the $880m Giant Magellan Telescope, which is set to be built in Chile.

"Certainly it is [an insurance]," says Cássio Leandro Dal Ri Barbosa, an astronomer at the University of Paraíba Valley. "But it is much more than this. We will be paying for and will be using the [E-ELT], managing our share of time." However, Brazilian astronomers are hoping to get access to both the E-ELT and the GMT. "To have both is okay, but to have only the GMT is not okay," says Beatriz Barbuy, who heads the ESO committee of the Astronomical Society of Brazil. "By joining the ESO we will have access to a great variety of high-performance instruments, in optical and radio astronomy, that are not reachable elsewhere for us."

The ESO is optimistic that Brazil will ratify its membership of the organization, with its director-general, Tim de Zeeuw, expecting progress in the coming months. "Several of the steps in the ESO membership ratification process in the Brazilian parliament have already been completed and few remain," he told *Physics World*. However, Barbosa warns that Brazil has major elections this year and is hosting the World Cup. "Historically, nothing important is decided so close to elections," he says.

Indeed, the move by São Paulo comes as the observatory had its design approved by an international panel of experts on 19 February.

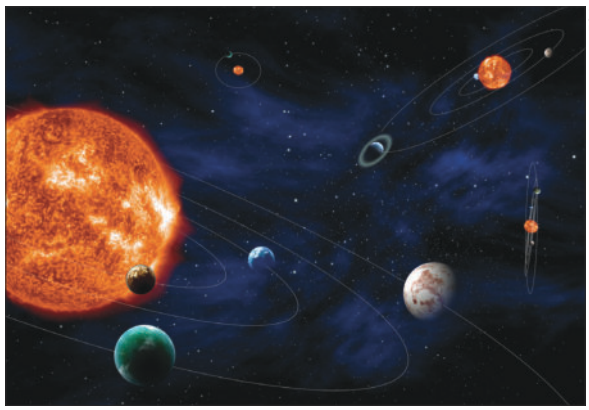
Gemma Lavender

Space

ESA selects planet-hunting craft for 2024 launch

The European Space Agency (ESA) has selected a craft to study planets outside our solar system for launch in 2024. The Planetary Transits and Oscillations of stars (PLATO) mission will identify and study thousands of exoplanetary systems with an emphasis on discovering and characterizing Earth-sized planets in the "habitable zone" of their parent star – the distance from the star where liquid surface water could exist.

PLATO is expected to operate from a point in space some 1.5 million kilometres further out from the Sun beyond the Earth known as Lagrange point L2. A space probe here can hover with little disturbance from stray signals from home and without having to use much fuel to keep it in position. During its six-year mission, PLATO will monitor relatively nearby stars, searching for tiny, regular dips in brightness as their planets transit in front of them. It will do this using 34 separate small telescopes and cameras and it is expected to study planets that orbit around a million stars. PLATO will also precisely characterize these stars, including their mass, radius and age.



ESA

Planet hunter
PLATO will use 34 telescopes and cameras to search for planets outside our solar system.

When coupled with ground-based observations, PLATO's measurements will allow a planet's mass and radius to be calculated, and therefore its density, providing an indication of a planet's composition. "PLATO, with its unique ability to hunt for Sun–Earth analogue systems, will build on the expertise accumulated with a number of European missions," says Álvaro Giménez, ESA's director of science and robotic exploration. "Its discoveries will help to place our own solar system's architecture in the context of other planetary systems."

The craft is ESA's third so-called "M-class" mission, joining Solar Orbiter and Euclid, which were chosen in 2011. Solar Orbiter will be launched in 2017 to study the Sun and solar wind from a distance of less than 50 million kilometres, while Euclid – to be launched in 2020 – will focus on dark energy, dark matter and the structure of the universe.

PLATO beat off stiff competition from four other missions that were vying for the launch spot, including the Exoplanet Characterisation Observatory and MarcoPolo-R – a mission to collect and return a sample from a near-Earth asteroid.

● See also "Planets galore" on pp33–37

Michael Banks

People

Physicist Rush Holt to leave Congress

Rush Holt, the physicist elected to the US House of Representatives in 1998, has announced that he will leave Congress at the end of the year. Holt, who earned his doctorate in particle physics from New York University in 1981 and was an assistant director of Princeton's Plasma Physics Laboratory from 1989 to 1999, says that he is unsure what his next move will be but that it will involve science.

Holt insists, however, that he is not planning to step down because of frustration with the current dysfunction of Congress. "I've decided to leave for a very positive reason," Holt told *Physics World*. "Most Americans would prefer to think that their representatives don't come from some lifelong political class. They would like to believe that their representative has a life before Congress and after Congress."

As well as making a contribution to climate-change policy, Holt has played a significant role in the debate over electronic voting machines, in addition to the issue of stop-and-search racial profiling. Indeed, his scientific background proved invaluable in several policy areas. "One of my proudest moments was getting $22m of new funding for science in the stimulus bill [in 2009]," he told *Physics World*. "That helped research all over the country, and helped the economy in the short term and long term. It was based on a pretty clear understanding that I had – and not everybody shared – that spending on scientific research is, in a very real sense, investment."

Stepping down
Rush Holt has been in Congress since 1998, but now says he will pursue other interests that may include science.

US House of Representatives

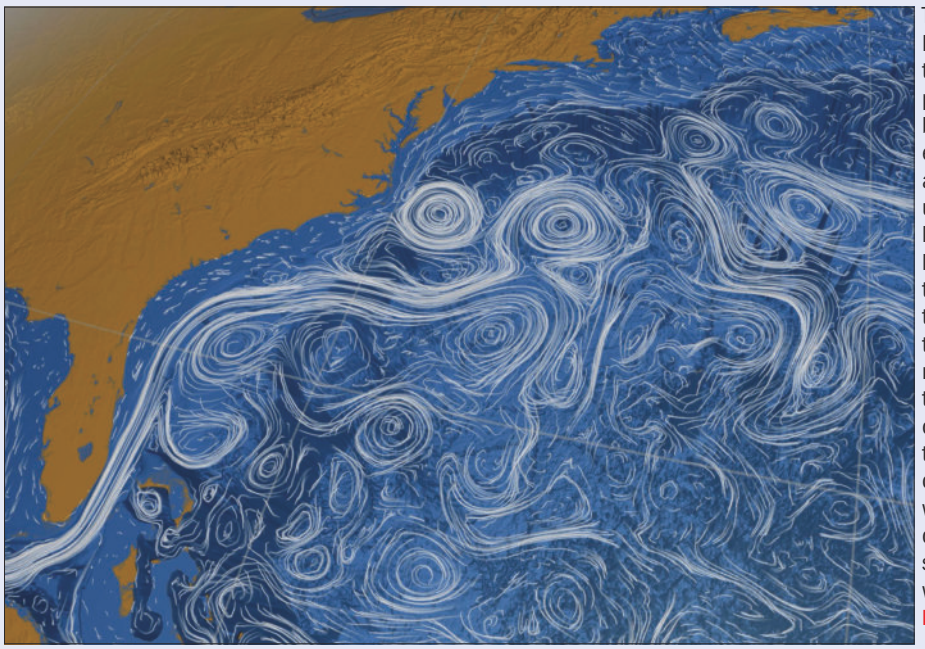
Fellow Democratic representative Bill Foster of Illinois, who will after Holt's departure be the only physicist in Congress, called Holt's retirement "a sad day". "We need more representatives like Rush to bring a voice for science and reason to Congress," Foster told *Physics World*. "Both Rush and I found ourselves continually asked by other members about a huge variety of technical questions, so I'm personally going to see my workload double." Foster, who is likely to be re-elected in November, is, however, not the only scientist in Congress, with Delaware senator Charles Coons having a chemistry degree and New York representative Louise Slaughter holding a degree in microbiology.

Yet Foster might not be the lone physicist in Congress for long. George Gollin, a particle physicist from the University of Illinois, has announced his plan to enter the Democratic primary to represent an Illinois constituency in the House of Representatives. Meanwhile, Princeton University plasma physicist Andrew Zwicker – a friend of Holt's – has joined chemist Frank Gibson, electrical engineer Upendra Chivukula and two legislators in the Democratic primary to succeed Holt.

Holt initially played down his links to physics when he first competed for a seat in New Jersey that Republicans had held for 30 years. "But I found after a few weeks on the campaign trail that people wanted to emphasize that I had an advanced degree in physics," he says. As for the future, Holt says it is "wide open" what his next move will be. "I expect science will figure in what I do," he says. "What science is, how it's done and who does it are all subjects that I'm deeply interested in and always will be."

Peter Gwynne
Boston, MA

Searching for beauty in data visualization



NASA

The first ever science exhibition at the British Library in London has begun, looking at the role that data visualization plays in the scientific process. The free exhibit – *Beautiful Science* – is being held in the library's Folio Society Gallery and explores scientists' ability to use plots, graphs and maps to get a better understanding of the underlying data. Running from 20 February to 26 May, the exhibition is sponsored by Winton Capital Management, which was founded by the physicist-turned-investor David Harding. Focusing on three themes – public health, weather and evolution – the exhibition features a range of images from the mapping of the 1854 London cholera outbreak by the physician John Snow to NASA's visualisation of the flow of ocean surface currents around the world from 2005 to 2007 (see left). "As big data is becoming a topic of such huge interest, we particularly wanted to show the important connections between the past and the present," says Johanna Kieniewicz from the British Library who is lead curator of the exhibition.

Michael Banks

Facilities

China to open underground neutrino experiment

Work has started on a huge underground neutrino lab in China. The $330m Jiangmen Underground Neutrino Observatory (JUNO) is being built in Kaiping City, Guangdong Province in the south of the country around 150 km west of Hong Kong. When complete in 2020, JUNO is expected to run for more than 20 years, studying the relationship between the three types of neutrino – electron, muon and tau.

Built by the Institute of High Energy Physics (IHEP) belonging to the Chinese Academy of Sciences (CAS), which finished the concept design for the detector last year, JUNO will require an 80 m high and 50 m diameter experimental hall located 700 m underground. JUNO's detector – filled with 20 000 tonnes of liquid scintillator – will use more than 15 000 photomultiplier tubes to detect the scintillation light that is created when a neutrino hits a hydrogen atom.

Although JUNO will be able to detect neutrinos produced by supernovae as well as those from Earth, the neutrinos that JUNO will mainly study will be created at two nearby nuclear power plants being built around 50 km from the experiment. "We need to detect neutrinos from the nuclear reactors, from a proper distance," says Yifang Wang, IHEP director, who heads the JUNO project. "It will be a big challenge to build such a large underground lab and a detector in five years."

IHEP

JUNO what it is? Site testing has begun for China's $330m Jiangmen Underground Neutrino Observatory.

The detector is expected to have an energy resolution of around 3%, allowing JUNO to determine the relative masses of the three kinds of neutrinos, known as the neutrino mass hierarchy. Several similar experiments around the world – including NOvA in the US, Hyper-K in Japan and the planned Indian Neutrino Observatory – will also work toward this goal. "That is an important part – to solve the mystery of why matter dominated over antimatter in our universe," says Jun Cao, a particle physicist at IHEP.

China's experience operating the Daya Bay neutrino experiment for the last three years will stand it in good stead for JUNO. "The success of Daya Bay has attracted more potential foreign partners for JUNO," adds Wang. Along with IHEP and 19 other Chinese institutions, interest in joining JUNO has also been expressed by more than 30 international institutions including most partners in Daya Bay from the Czech Republic, France, Germany, Italy, Russia and the US. "JUNO will help us build a leading research team, and make China one of the leaders in the field of particle physics," adds Wang.

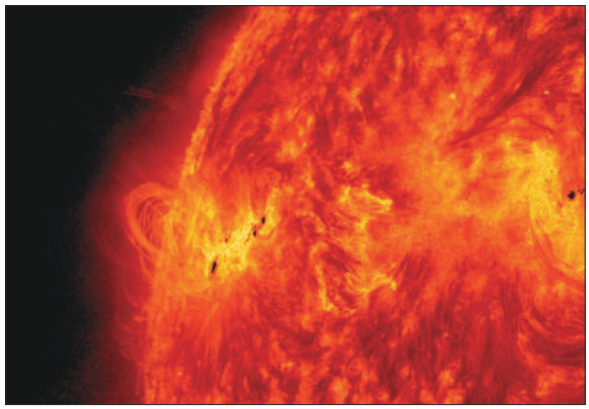
Jiao Li
Beijing

Solar physics

India aims for the Sun with Aditya spacecraft

The Indian Space Research Organisation (ISRO) has announced it will launch the country's first dedicated mission to study the Sun. Called Aditya-1 – meaning "Sun God" in Hindi – the $61m mission is expected to take off in 2016 or 2017 and will study the Sun for five years. The 400 kg satellite will be placed about 800 km above Earth's surface to continuously track the Sun for a period of five years.

Aditya-1 will carry a solar coronagraph that will work at visible and near infrared wavelengths together with polarimeters, a spectrograph and a charge-coupled device (CCD) camera. One of its main aims will be to improve our understanding of coronal mass ejections. These events – in which bursts of magnetic fields from the interior of the Sun emerge at the surface – are important as they can lead to a large increase in charged particles that hit Earth.



NASA/SDO

Solar surveyor India's Aditya-1 mission will study the Sun to see what effect it has on Earth.

Being India's first dedicated mission to study the Sun's corona, ISRO will have several technological challenges, including developing a highly polished mirror for the satellite as well as implementing a way of quickly reading out data from its CCD camera. "This mission will be particularly looking at the Sun and corona, which has the advantage that you avoid the interference of the Earth's atmosphere so you avoid all the scattered light contributions," says K Sankarasubramanian, a solar scientist at ISRO. "We can expect very crisp images of the solar corona from space."

Aditya-1 could also help astronomers to gain more insights into the Sun's influence on Earth. "We have seen over the years that the pattern of the climate has changed, so is there an effect of the Sun?" asks Dipankar Banerjee, a solar scientist at the Indian Institute of Astrophysics in Bangalore, which is a lead institution in building the craft together with ISRO's Udaipur Solar Observatory in Rajasthan. "We also want to study space weather as we have many satellites in space and telecommunication gets affected because of changes within the Sun."

Pallava Bagla
New Delhi

Sidebands

Evidence seen for cosmic inflation

The first evidence for the primordial B-mode polarization of the cosmic microwave background has been detected by astronomers working on the Background Imaging of Cosmic Extragalactic Polarization (BICEP2) telescope at the South Pole. The polarization signal is the first direct evidence for cosmic inflation and has been measured to a statistical certainty of 3σ. The primordial B-mode polarization is related to primordial gravitational waves that are thought to have abounded in the early universe. According to the BICEP2 collaboration, its results, which were announced as *Physics World* went to press, suggest that "the long search for tensor B-modes is apparently over, and a new era of B-mode cosmology has begun". For more detail see http://ow.ly/uFyhp.

UK splashes £290m on big science

The UK government has announced £290m to help build a trio of next-generation physics facilities. The money includes £100m for the planned £1.25bn Square Kilometre Array, which will be a ground-based radio-astronomy telescope consisting of more than 3000 radio dishes spread out across thousands of kilometres in both Australia and southern Africa. The UK government also announced it will spend £165m on the planned £1.25bn European Spallation Source, which will be built in Lund, Sweden. Planned to open in 2018, the facility will be the world's most powerful neutron source and cater for thousands of researchers every year in fields from condensed-matter physics to biology. The rest of the money will go to towards the European Space Agency's PLATO exoplanet mission that is expected to launch in 2024 (see p9).

Japan prioritizes top projects

The Science Council of Japan has chosen 27 science projects that it deems "high priority" for construction in the coming decade. These include an upgrade to the J-PARC experimental facility in Tsukuba as well as the development of the Hyper-Kamiokande neutrino experiment, which would be located 650 m under the Nijuugoyama mountain, near the city of Hida in western Japan, to search for a fundamental matter–antimatter asymmetry in neutrinos. The 112-page document also calls building the Square Kilometre Array a high priority, as well as the LiteBIRD satellite – a craft that would measure the polarization of the cosmic microwave background.

Funding

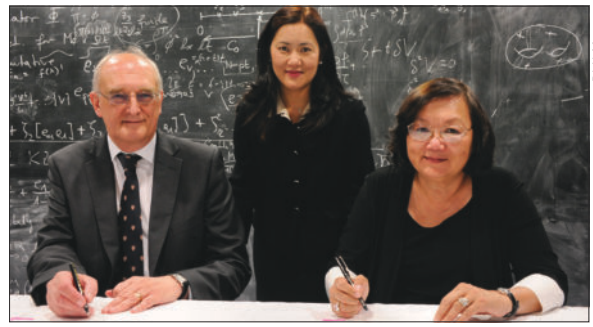
Cambridge chair divides physicists

A new chair designed to lure the world's brightest minds in cosmology to the University of Cambridge has generated a heated debate among physicists at the institution. Supporters of the Stephen W Hawking Professorship, set up in the Department of Applied Mathematics and Theoretical Physics (DAMTP), say that the £3.6m that accompanies the new position will allow the university to compete with the richest US institutions when hiring top scientists. Critics, however, argue that in agreeing to an unusual set of conditions attached to the donation, the university has placed financial gain ahead of meritocracy and has undermined its independence.

The position was made possible by a donation to the university by the US philanthropist Dennis Avery, heir to part of a fortune made in the commercialization of sticky labels, and his wife Sally Wong-Avery. A long-time friend of Hawking, Avery announced that he would fund the new professorship in January 2012. This was the latest in a series of donations to the university by Avery that include support for his *alma mater* Trinity Hall and a 2006 gift of £1m used to create a centre for theoretical cosmology within the DAMTP.

The new donation includes £1.2m that is being given to the university to set up an endowment fund that will provide some of the new professor's basic stipend. This salary, according to the deeds, must be "equal to or greater than the average salary and benefits received by other professors of similar years of service, or rank" within the DAMTP. The remaining £2.4m will be controlled by a group of trustees – three senior university officials and Avery's stepdaughter Natasha Wong. This cash will be used to top up the salary by as much as the trustees deem necessary to hire or retain the candidate of choice – up to a maximum of 2.6% of the capital (which today would mean about £67 000).

As a result of the endowment the salary is likely to be in the region of twice that for a professor at Cambridge. The holder of the chair is also appointed initially for seven years, and then for a further possible five or 10 years. After stepping down, the holder would be guaranteed a regular professorship until they retire.



Phil Mynott

Signing up
Cambridge vice-chancellor Leszek Borysiewicz (left), Natasha Wong (centre) and Sally Wong-Avery sign a memorandum of understanding regarding the new Stephen W Hawking Professorship.

Senior members of the university had begun negotiating the terms of the deal with Avery before he died unexpectedly in the summer of 2012. Faced with the stark choice of accepting the money with all of the strings attached or rejecting what would have been a welcome boost to departmental coffers, academics discussed the issue in a highly charged meeting of the university's governing Regent House on 14 January. The *Cambridge University Reporter* recorded DAMTP biophysicist Raymond Goldstein as saying at the meeting that the £3.6m was designed to "circumvent the normal salary structures of the university to guarantee a specific and outsized benefit to the chair holder".

On 25 February the university announced that 746 members of Regent House had voted in favour of the proposals and 606 against, with the professorship coming into effect on 1 March. However, the trust's rules seem to imply that no-one will be appointed while Hawking remains director of research at the DAMTP. Hawking will be supported by the trust's core endowment, although it appears he will not receive any supplementary salary from the donation.

Speaking to *Physics World*, DAMTP head Peter Haynes acknowledges that the terms of the donation "were not straightforward", but he believes that they can nevertheless be made to work "in a way that doesn't go outside the spirit of the regulations of the university". He admits that he does not "totally understand" why the fund was split into two. "You have to decide whether the enormous opportunities offered by the donation outweigh the potential complications," he adds.

You have to decide whether the enormous opportunities offered by the donation outweigh the potential complications

Edwin Cartlidge

Brazilian minister sets global goals

Marco Antonio Raupp, the mathematical physicist who is now Brazil's minister of science, technology and innovation, talks to *Physics World* about the challenges and opportunities for Brazilian research

What is your top priority for science funding?

Broadly speaking, organized science in Brazil began about 50 years ago; that is, we have been doing science for a relatively short time. On the other hand, Brazil is a huge country with enormous challenges, many of which demand the contribution of science. Thus we not only have to "make ends meet", but also meet the needs of basic research, and those of technological development and innovation.

Brazilian science has to be developed as a whole, implying that all areas of knowledge need funding. Of course, there are always specific priority needs, such as a few large research infrastructure projects. One example is the construction of the Brazilian Multipurpose Reactor, which is designed to enhance the country's capacity for producing radiopharmaceuticals and training people for nuclear research for peaceful uses. Another large project is the new Sirius synchrotron light ring, which will be among the largest in the world and let Brazil leap forward in materials research. A third project is to set up an ocean research institute, which will include buying a modern oceanographic research vessel. These projects will all be open to researchers from academia and industry.

How much is Brazil investing in research?

The most recent data available refer to 2011, when federal funding was R$17.8bn (£4.5bn) and state funding was R$8.6bn – totalling R$26.4bn of public investment in R&D. Companies, both public and private, spent R$23.6bn, bringing the overall total up to R$50bn. R&D spending in 2011 was 14.5% higher than the previous year, which in turn was 15.5% up on 2009. In fact, from 2000 to 2011 Brazilian investment in R&D quadrupled. Of course, we would like this growth to have been bigger, but considering the country's general conditions and its needs in other vital areas such as basic education and health, R&D investments have been evolving satisfactorily.

CC-BY Marcos Santos/USP Imagens

Targeting science Marco Antonio Raupp wants Brazil to increase its impact on the world.

We have already learned to do science and technology in universities and research institutes – we now need companies to also engage in R&D

What is the biggest challenge for Brazil's scientific community?

Over the last 50 years – supported by public funding – the Brazilian scientific community set up and organized, starting from a very small base, a science and technology (S&T) system of considerable size and complexity. Brazil now has 235 000 active researchers and, according to the Scopus database, they published 53 083 scientific articles in international journals in 2012, amounting to 2.45% of the world's total. In 1990, in contrast, they published just 3539 articles internationally, or 0.63% of the total. Meanwhile, in 2012, some 12 217 PhD students graduated – more than twice that of a decade earlier. As you can appreciate, these figures show a significant growth over a relatively short time and the challenge now is to improve the quality of the science to increase the impact of Brazil on world science. Another challenge is to enlarge the S&T system, which is today predominantly academic, so that it can reach the business sector. We have already learned to do S&T in universities and research institutes – we now need companies to also engage in R&D to enhance their competitiveness.

How will you improve the international impact of Brazilian research?

I believe this must come as the result of a sustained process – in other words, it is the evolution of the system as a whole that will result in greater international impact of Brazilian research. In this sense, one can see a series of developments under way, progressing year after year: number of PhD graduates; fellowships for Brazilian researchers to go abroad; foreign researchers in Brazil; publication of scientific articles by Brazilian researchers in international journals; and so on. An important recent step taken by the Brazilian government was to create the "Science without Borders" programme, which by 2015 will have offered 100 000 fellowships for Brazilian students and young researchers to go abroad. Brazilian research institutions are also increasingly incorporating an international dimension to their activities. In short, the Brazilian scientific community is aware of the need for greater participation in the world science scene and has been acting accordingly.

How can you ensure research spending drives innovation and economic growth?

By sound government policy and the involvement of the scientific community. Until the second half of the 20th century, Brazilian S&T was generally confined to academia, mostly because industrial development between the 1950s and 1970s tended to rely on foreign technology, leaving no "cross talk" between S&T. Nevertheless, through the concerted effort of public companies and universities, Brazil managed to achieve some important technological results in strategic developmental areas, such as technologies for offshore oil and gas production, aircraft manufacturing, and a very competitive agribusiness.

There is now, though, a clear awareness that S&T makes a vigorous contribution to Brazil's economic development. Towards this end, a legal framework is being built for science and technology, at the centre of which is the 2004 Innovation Law. Federal and state governments, meanwhile, have established a number of programmes for promoting and financing research, development and innovation activities.

At the same time, a new rapport is developing between industrial and S&T policies. This is officially reflected in the acknowledgment – embodied in President Dilma Rousseff's government policies – that science, technology and innovation are the thrust of sustainable development, whether in economic, social or environmental terms. Also, our researchers and research institutions are fully aware of the importance of carrying out projects in partnership with private companies.

Comment

physicsworld

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Paying the price

Sanctions imposed on Iranian researchers are hurting their physics community

Physics has always been a discipline that knows no borders. Sometimes, though, that international dimension has its drawbacks, which is that physics can be affected by political affairs over which physicists have little control. Visa restrictions are the most common problem, making it hard for some physicists to attend international meetings or take up posts at foreign institutions.

One country – Iran – has perhaps suffered more than most (see p17). Trade sanctions have been imposed on it for nearly 35 years, but in 2013 the US introduced new sanctions that prevent US nationals (even those not based in the US) from publishing, peer-reviewing or producing any article written by someone associated with the government of Iran, excluding academic or research institutions. In addition, US and EU sanctions mean that researchers in Iran are barred from accessing papers in certain journals, including some with only a vague link to nuclear science or technology.

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However, as currently drafted, the potentially wide interpretation of the rules is open to debate, which has led some publishers simply to decide not to accept any papers from Iranian researchers at all. Moreover, publishers can find it hard to determine if potential peer-reviewers are US nationals, particularly if they are not working in the US, which can delay the processing of papers that are accepted. Of course, researchers in Iran could use preprint databases, but for many Iranian scientists, publishing in peer-reviewed journals is what counts.

After looking closely at the rules and taking specialist advice, IOP Publishing, which publishes *Physics World*, does accept papers from Iran as it feels that banning authors from there could harm scientific communication. (The company is, though, abiding by the rule regarding US citizens not handling Iranian manuscripts and it does currently restrict access to certain journals.) Yet despite the odds, the 10 000-strong Iranian physics community is thriving and recent developments in Iran suggest future relaxation of the sanctions is possible, which could help them flourish further.

All eyes on Brazil

Our latest special report looks at the challenges for physics in World Cup host Brazil

Physics World has been expanding its editorial coverage around the globe in recent years, publishing special reports on China, Japan, India and Korea. Based on visits by editorial staff – myself included – those reports have let us "get under the skin" of what's going on in each nation. Our latest report (see http://ow.ly/uFbf2) is on Brazil, which has seen research spending more than quadruple since 2000. It includes an exclusive interview with the Brazilian science minister Marco Antonio Raupp, which also appears in this issue (p13).

Matin Durrani
Editor, *Physics World*

Critical Point Patenting science

Are you aware of cases where patents have hindered or prevented fundamental research? If so, **Robert P Crease** wants to know

Does patenting impede scientific research?

Those who favour patenting say that protecting intellectual property helps advance science and technology by promoting risk-taking. A mechanism is generally needed, they say, to protect ownership of an invention while its ramifications are explored and financed. That mechanism is called a patent. Patents also help drive scientific and technical progress by discouraging trade secrets, making legal protection contingent on prompt disclosure of technical advances, and permitting free use of an invention once its patent has expired.

Those opposed to patents claim they block competition and are a nuisance. Patents can keep researchers from using a promising method and may inhibit research in fields where other scientists or engineers are known to hold patents. They can have a chilling effect by dampening the desire of scientists to enter areas of research where the situation is unclear.

In 1972 the US Supreme Court ruled that "products of nature" (such as genes and bacteria), natural laws ($E = mc^2$ etc.) and abstract ideas (such as mathematical formulae) are "the basic tools of scientific and technological work that lie beyond the domain of patent protection". Allowing patents on these things would threaten to "inhibit future innovation premised upon them". This ruling affects only US law. But it was a grand claim for which the court offered no support; no references, say, to historians or philosophers of science. So was the court's concern for research anchored in scientific practice or was it based on mythology?

Physics patents

Famous patent cases involving physics include the US physicist Glenn Seaborg's patent on americium (US patent 3 156 523, filed 1946, issued 1964). His patent application, two pages long, is one of the shortest patent claims in history. The claim – covering "element 95" – has long expired. It did not, however, stop transuranic research, nor prevent americium from being incorporated into numerous industrial uses such as household smoke detectors.

In 1934 Leó Szilárd filed a British patent on a simple idea for a reactor, before the discovery of fission, but it was not issued. Ten years later, he and Enrico Fermi applied for another patent for a fission reactor, but its issue was delayed a decade due to secrecy (US Patent 2 708 656, filed 1944, issued 1955). The patent did not, however, impede reactor development. Nor has research involving lasers been impeded by patents.

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Impediment to progress? Do patents protect and advance science or get in its way?

Nicholas Christofilos's patent of the "strong-focusing" principle, used to control beams in high-energy hadron colliders, is famous thanks to his eccentric personality and dramatic story. Christofilos was a US-born Greek electrical engineer who founded a lift-installation company in Athens and worked on particle-accelerator design in his spare time. In the late 1940s he sent a manuscript outlining the principle to what is now the Lawrence Berkeley National Laboratory.

Berkeley's accelerator experts pronounced his ideas unsound, pointing out that they violated Maxwell's equations, among other things. Undeterred, Christofilos revised his idea, applied for US patents in 1949 and 1950 (US Patent 2 736 799, filed 1950, issued 1956), and sent another manuscript to Berkeley, which was thrown into a file without being read. So when Christofilos read of US physicists' "discovery" of strong focusing in 1952, he borrowed money from a Greek law firm with contacts in Washington and left for the US to press his claim. Red-faced atomic-energy officials granted him $10 000 in exchange for the right to use the strong focusing principle.

In 1972 the US Supreme Court (in *Gottschalk v. Benson*) decided that a software algorithm for transforming one number into another number was an unpatentable abstraction, and began to express concern about patents inhibiting basic scientific research. More recently, the court has rejected claims for isolated DNA (as a product of nature) and medical diagnostic correlations relevant for deciding medical treatments (as a natural law).

But patent law, like science, is always on the move. In the upcoming *Alice v. CLS Bank* case – involving a patent claim for computer programs and systems to control credit risk by creating and managing escrow accounts – the court will reconsider what terms such as products of nature, natural law and abstractions mean.

The critical point

Historians, economists and lawyers argue that broad patents – whose claims are framed to make it hard for people to make technical improvements without infringement – have negatively affected the development of many new technologies, including the car and aeroplane. But has fundamental scientific research been hurt?

Legal scholars I know doubt it for three reasons. One is that, in practice, patents are not granted on broad scientific principles. Another is that scientists engaged in fundamental research are often oblivious to patents. A third reason is that people who hold patents often do not enforce them, or license them cheaply to, researchers. No lab scientist I've talked to has heard of colleagues receiving "cease and desist" orders.

Still, I think it's possible that patents have negatively impacted fundamental research. One route might be through cost: budgets are a powerful force in experimental life, and manufacturers may charge more for patent-heavy equipment knowing that similar kit cannot be bought from other firms. Another possibility is self-censorship: scientists may avoid certain research because they fear patents might impede their ability to work, and lack the enthusiasm to do the required investigation.

Are these concerns real or imagined? Has fundamental research ever been retarded by patents? The answer is an empirical one involving actual scientific practice. If evidence exists, however, it is probably not found in documents, but rather in anecdotal information and informal discussions.

So let me ask you – do you know of cases where patents have kept anyone from conducting fundamental research? Please contact me at the e-mail address below and I'll review the issue in a future column.

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

Penalizing Iranian research

Abbas Ali Saberi calls for an end to sanctions that are hurting physics and physicists in Iran

"As a result of sanctions, we regret that unfortunately we are unable to handle your submission to this journal". I imagine not many of you have ever encountered this message after sending one of your papers to a journal, but it has now become all too familiar for researchers in Iran. That is because since the start of 2013, the US has asked scientific publishers to help tighten trade sanctions on Iran. Most journals therefore are not dealing with manuscripts written by Iranian scientists, meaning rejection even before peer review.

Although some of the sanctions have recently being eased, this has had no effective impact on research yet. Two of my colleagues in the physics department at the University of Tehran, for example, who work in optical physics, have recently submitted their research papers to an established European journal. They are still waiting for a proper response. The editors claim that they cannot find a referee to evaluate their work, with some referees apparently even refusing to review the paper as the authors are Iranian. Yet while papers from Iran are being turned away, many Iranian researchers are still acting as journal editors and referees.

Even simple misinterpretations and misconceptions of the sanctions can be just as damaging. Companies sometimes extend the sanctions to where they are not actually applicable in order to avoid any sort of punishment in dealing with Iran. This means, for example, that experimental physicists in Iran are unable to equip their labs even with the simplest instruments and tools, given that the sanctions do not allow overseas companies to do business here.

Yet the sanctions are just one of many unpleasant obstacles facing the physics community – another is visa restrictions. International collaboration plays a crucial role in the growth of any scientific community, and Iran's is no exception. But Iranian researchers face serious problems in obtaining visas for academic visits to other countries. Recent unnecessary measures adopted by foreign embassies in Iran in issuing visas for Iranian scientists, especially to physicists, have limited our contribution and participation in various scientific events, even those with aims that have nothing to do with technology or nuclear science.

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Censored International constraints on trade and travel are making it harder to do physics in Iran.

Are these restrictions not against the fundamental principles that scientists adhere to?

In 2007, for example, I was supposed to participate in a workshop and summer school on statistical physics and conformal field theory in Melbourne, Australia, together with two colleagues from Sharif University of Technology. Unfortunately, we could not attend the school since the Australian embassy did not issue our visa. The only reason I can think of for the refusal was that we were physicists. Then in July last year I was expected to start a two-year Humboldt fellowship at the University of Cologne in Germany, but nearly a year later and I am still waiting for the German embassy in Tehran to issue the visa. Yet it will not be my first trip to the country as I had already been a postdoc at Cologne for a year in 2011 and spent another three months as a visitor there in 2012.

Even when researchers are granted a visa, the situation can be just as difficult. For Iranian physicists working and studying in the US, their visas are "single entry", meaning they are forced to stay in the country for long periods – sometimes up to four or five years – without being able to visit their families or play an active role in promoting the physics community in Iran. In some cases, Iranian students who are attending a conference or workshop in the US or Europe are not even allowed to visit nearby laboratories or take part in specific activities and tutorial courses. Are these restrictions not against the fundamental principles of scientific and intellectual values that scientists adhere to?

Bouncing back

Despite all these pressures and constraints, the Iranian physics community has made substantial progress in research in the last couple of years, particularly in terms of the quality of papers published. According to Thomson Reuters' Web of Science database, by the end of 2013, almost 29 000 papers in physics had been published in total by Iranian physicists, including some papers with several hundred citations and 70 papers with more than 100 citations each. From those 29 000 papers, more than 12 000 papers have been published between 2011 and 2013. This signals that Iranian science has a growing impact in physics.

Education, also, has improved. Women make up about 60% of the total number of undergraduate students in physics, filling 35% of PhD positions in various fields of research in physics. For the last two years, women have also made up around 60% of the participants at the Annual Physics Conference of Iran and currently women form 51% of the 10 000 or so members of the Iranian Physical Society. Taking all these facts into account, it seems obvious that imposing sanctions on science – apart from being an unprecedented action in the history of science – has not yet had a significant impact on Iran's scientific progress but that is unlikely to remain the case.

I now urge scientific journals to stop their non-scientific policies regarding Iranian scientists and let science evolve as it should. We need to end these sanctions that do not allow our scientists to travel and I urge governments to reconsider their policies in order to facilitate and expedite their visa process for Iranian scientists and to offer more visas for our scientists. I hope that everyone realizes that these sanctions are damaging the capability and the future of Iranian research and I call on you to help with our cause.

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Feedback

Letters and comments that appear here may have been edited.
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It's all just physics

In reply to Max Tegmark's article "It's all just mathematics" (Features, February pp22–27).

Tegmark invokes Eugene Wigner's demand for an explanation of "the unreasonable effectiveness of mathematics in the physical sciences" as a partial rationale for his model of the universe as consisting, deep down, of pure mathematics. But is mathematics really unreasonably effective?

At its heart, mathematics is simply the science of patterns. Natural science, on the other hand, is the search for patterns in nature. When we identify patterns, we identify mathematics, and this mathematics becomes the shorthand by which we describe the pattern we have found. Biologists, who know that life is complicated, tend to be happy with even quite general abstractions. Physicists, on the other hand, zero in on the sorts of things where patterns are so regularly observed that we grant them the status of "laws of nature". We've got so used to finding patterns that we get very flustered when we can't; Einstein's resistance to quantum theory is a good example.

But of course, it may be, sometimes, that whatever is, just is. As far as we can tell, there are no hidden variables and the result of most quantum observations can only ever be known statistically. Perhaps the masses and coupling constants of the Standard Model of particle physics really are just randomly chosen, or they fell out of some annealing process with a very large number of local minima. Tegmark is not alone in rejecting such defeatism, but it seems to me that his "solution" verges on mysticism: he simply notes, somewhat tautologically in my view, that to be fully describable mathematically, the universe must be mathematical all the way down. Tellingly, his concluding argument seems to be that if he is wrong, we will eventually "hit a roadblock beyond which we can't understand our physical reality any better". Well, yes, but nature is under no obligation to make us feel good.

I agree that we should keep looking for hidden patterns and unifying principles – we wouldn't be physicists if we didn't. But I don't find his argument that the patterns must be there, because it would be too horrible if they weren't, to be all that convincing.

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The apparent connection between physics and mathematics is indeed compelling, but I wonder whether there is a much more mundane explanation than the one Tegmark offers. He refers to the concept of "abstract mathematics", but maybe there is merit in assuming that abstract mathematics does not exist; certainly, there is no proof of its existence. Mathematical concepts might then be viewed merely as shared attributes of physical entities and their patterns.

For example, the number three is not something that can exist in abstraction, but "threeness" exists as a shared attribute of a triplet of apples or bananas, a set of marks on a sheet of paper, bits in a computer or neuron connections in the brain. Similarly, an ellipse is a shared attribute of certain planetary orbits, conic sections and so forth. This far simpler view has the advantage that we do not need to ask about the origins of mathematics – it is simply part of our physical world. It is hard to imagine that numbers could exist in a universe with nothing to count! I would argue that there is merit in asserting not that physics is mathematical, but that mathematics is physical.

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I was enjoying trying to follow the thrust of Tegmark's article, and initially I missed a particularly interesting statement. But then I went back and read it again: "A hypothetical ideal supercomputer could calculate how the state of our universe changes over time without interpreting what's happening in human terms, simply by figuring out how all the particles would move or how the wavefunction would change."

Nature is under no obligation to make us feel good

The interesting thing about this statement is that almost all the physicists reading it will, like me, already be familiar with the basic idea. But while it is a useful way of thinking about the issues involved, it is nevertheless not a valid *gedankenexperiment*, because any such computer must necessarily be in communication with "our universe" (and therefore be part of it) in order to receive all the necessary "initial state" information, of which its own state is an integral part. Hence, Tegmark's simple description fails in the same way as does the classic question "The village barber shaves all those and only those who do not shave themselves. Who shaves the village barber?"

Later in the article, Tegmark introduces his Mathematical Universe Hypothesis – "our external physical reality is a mathematical structure" – and asserts that if it is false, then physics must eventually hit a roadblock. That contention might just be correct as it stands. But then he adds "We can't understand our physical reality anymore, because it lacks a mathematical description." Here I suggest that he is mistaken. For example, both he and I can think about these things, and we will probably agree that our thoughts are in some way associated with (or even that the relevant information is somehow the "content" of) the firings of a series of synapses in our cerebral cortices. But although we think that in some sense we understand this process – indeed, we acknowledge it as an inherent part of our physical reality – the chances of getting a mathematical description of it are currently best labelled as "remote".

This is not, of course, to deny that such a description might be arrived at in due course. But on the other hand, perhaps it won't, because somewhere down that road lies the concept (better known to theologians than to physicists) of predestination, which suggests that all of our thoughts and actions are in some way predetermined. Hence, a true "Theory of Everything" must therefore inescapably incorporate a complete answer to that conundrum as well – if the Mathematical Universe Hypothesis is true.

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Tegmark asserts that our reality isn't just described by mathematics, it *is* mathematics. As someone who attempts to model weather and climate by computer, I find this assertion concerning. My colleagues and I are striving to make our equations more and more realistic, and we are now at the stage where the models are beginning to include sophisticated cloud microphysics packages. However, I really

do need to know from Tegmark at what level of sophistication my mathematical equations will start producing real precipitation, not least to safeguard the multi-million pound supercomputing investments from water damage!

If his answer is that it will only actually rain when the equations are exact, then of course that will be a relief. However, isn't an assertion that vanishes into a puff of smoke, under the most infinitesimal of perturbations to the equations, rather unscientific – being what mathematicians would call "ill-posed"?

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Some thoughts on big G

In reply to Jon Cartwright's article "The lure of *G*" (Features, February pp34–37, http://ow.ly/ulHlw).

Cartwright's article gives an excellent summary of efforts to measure *G* and the variability of different measurements, which reportedly differ by 10 times their estimated uncertainties. But I wonder: measurements of *G* been made by moving instruments between various locations? This would give us a clue as to whether variability in *G* is due to instruments or location. No doubt people will say that *G* is supposed to be a universal constant, and should therefore be the same everywhere on Earth. It will, however, do no harm to check this assertion, and the process might well show up a factor not previously considered or thought of as significant.

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The publication of an incorrect statement of Newton's law of gravity should be unthinkable, but the fundamentally wrong presentation given in this article is now almost universal in education and the media. According to the article, "Newton's law of gravity states that the gravitational attraction between two bodies is proportional to the product of their masses, and inversely proportional to the square of the distance between them ($F = Gm_1m_2/d^2$)". But in fact this law applies to *particles*, and consideration of extended bodies requires great care. For example, a uniform spherical shell does not exert a resultant force on any object within it – a fact of great importance in geology and astrophysics. According to the form of Newton's law given in the article, such a shell would exert an infinite force on a particle at the centre. The usual excuse for the incorrect ideas now taught in physics is that they are "approximations", but I hope that it will not be claimed that infinity is a good approximation for zero!

John W Warren
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If there are dark-matter clusters of various densities passing through the Earth, then it seems to me that local variations from the actual *G* force would pull test results higher, depending on the dark-matter "weather" at that point on Earth at the time of each experiment. Overall variations in measurements of *G* could show a range of dark-matter density variations affecting the Earth as we transit the galaxy. Hence, repeated multiple tests of *G* done simultaneously around the world might give us some indication of a real-time dark-matter "weather report", including the direction and velocity of the flow of dark matter as it passes through the Earth.

midmoe
via *physicsworld.com*

I read the article on the measurement of *G* with interest, as it offers intriguing insights into a difficult problem. However, having just fallen down the stairs, injured my foot and cracked a couple of ribs, I now find it difficult to accept that gravity is the weakest of the four fundamental forces.

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A spot of bother

In reply to Robert P Crease's article "The spot in the shadow" (February p16, http://ow.ly/ulHSX).

I very much liked this article about the experimental verification (by François Arago) of a bright spot produced by diffraction of light from a circular obstacle. This paradoxical effect had been deduced by Siméon-Denis Poisson from Augustin-Jean Fresnel's wave theory of light, as an example of what he felt was the invalidity of the theory; hence, Poisson's objection ultimately led to a powerful support for the theory he was actually trying to demolish.

Crease's analysis of who deserves credit for the discovery is compelling until his very last sentence, in which he writes that "the rigorous answer to the question 'Who discovered the spot?' is the entire scientific community". One way to look at it is that if Nobel prizes had been awarded in those days, then the award surely would have gone to Arago, Fresnel and Poisson. Undoubtedly Crease is right to say that one aspect of any discovery is that it's not a discovery until the preponderance of the scientific community accept it, but to my mind, arguing that "the community" is

therefore the real discoverer interchanges cause and effect.

There are examples of discoveries that were accepted only decades after they were proposed, but that shouldn't take credit away from the individual(s) who made the initial argument. A famous case is Alfred Wegener's advocacy of continental drift. On the Internet and in some popular books on science, one finds the claim that geologists of Wegener's time were justified in rejecting the idea because there was no known mechanism to explain the phenomenon. I think this is poppycock: Wegener had evidence not only from continental shapes but also from congruent fossils and other deposits on matching continental coastlines. From later examples, I think the primary reason for the scientific community's rejection was that Wegener was not a geologist. There were other people besides Wegener who did propose much the same idea, so he didn't have unique credit; however, in the case of the "spot in the shadow", one can point to specific contributions made by each of Arago, Fresnel and Poisson. "The scientific community" seems to me much too woolly and amorphous as the prime recipient of credit.

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Newton's *Principia*

In reply to Patricia Fara's review of Colin Pask's book *Magnificent Principia* ("From Euclid to Einstein", February pp38–39, http://ow.ly/ullk9).

I fear that Fara – a historian – has reviewed my book under the misapprehension that it is a history, and an introduction to Newton and his work. It is not; it is about the magnificent *Principia*, what it actually contains and its significance, with supporting historical discussions as appropriate.

Stephen Hawking has called the *Principia* "probably the most important single work ever published in the physical sciences". In Einstein's opinion, "the whole evolution of our ideas about the processes of nature, with which we have been concerned so far, might be regarded as an organic development of Newton's ideas". For Steven Weinberg, referring to the way we approach science, "all that has happened since 1687 is a gloss on the *Principia*".

Yet amazingly few people of any background really know what is in the *Principia*. I set out to change that. As I put it in the book's preface, "My aim… is to take the third and final edition of Newton's *Principia* and explain how it sets out his (and now our) approach to science". And while there are scene-setting chapters about Newton and the state of science when he began work (and, after a tour of the *Principia*, chapters about its reception and later developments in mechanics), the main body of the book deals with Newton's development of science, especially mechanics. This is something the review largely downplays – perhaps not surprisingly, since Fara tells us that she finds physics boring.

In the book's epilogue, I list 34 results from the *Principia* that epitomize the brilliance and diversity of Newton's groundbreaking work. Here are three examples. First, Newton recognized that there are two masses: inertial and gravitational. He devised a method to compare them and reported on his experiments to show that they are equal – something later invoked by Einstein as a starting point in his General Theory of Relativity.

Second, Newton shows that orbits under an inverse square law of gravity are closed – a result now called Bertrand's Theorem.

If the law deviates from inverse square, the orbit rotates. Interestingly, Newton's formalism gives the rotation of Mercury's orbit when an extra force term is added as required by Einstein's relativity theory.

Third, we may wonder whether Galileo actually dropped objects from the Leaning Tower of Pisa, but we can read Newton's reports of experiments on various objects dropped from the top of St Paul's Cathedral. Using his mechanics he showed how to measure air resistance (and other fluid resistance in different experiments).

I make no apologies for my enthusiasm for Newton and his unrivalled *Principia*. If readers want a whole picture of Newton, the man and his works, I suggest they seek out Richard Westfall's magisterial biography *Never at Rest*.

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There are welcome insights in this review about Newton's strengths and weaknesses. Newton was not an advocate of Newtonianism, in that he did not endorse the mechanistic worldview of Enlightenment scholars. However, I would suggest that this was not because he postulated divine intervention in human affairs via comets with animated tails, but because he was a theistic scientist. His science emerged from a Christian worldview, which perceives God as continuously involved with his creation (not just intervening from time to time). Furthermore, Newton was not alone – most of the pioneers of science were like him. The Enlightenment was not a move to a better science, but a move to a different philosophical stance.

d tyler
via *physicsworld.com*

The mechanics of a skater's spin

In reply to the video "How do figure skaters exploit Newtonian physics when they spin?" (100 Second Science, 10 February, http://ow.ly/usDJo).

I won a gold medal in the Isle of Wight figure skating championships in 2008, so I can confirm that bringing the arms inward can indeed quicken the spinning speed – as it does in the "candlestick" spin, where the arms point straight up the spin axis and the spin is really fast. However, this doesn't necessarily happen, since the axis of rotation is not fixed and the body is non-rigid.

Physicists often highlight arm positions in spins, but much larger effects come from the momentum of the free leg with its extra kilogram or more of whirling boot and blade, at the far end, as in the sit-spin illustrated in the video (and above).

Shutterstock/Olga Besnard

Give it some leg There's more to spinning on the ice than arm position.

A normal spin is often entered on a backward right-inner-blade-edge so the skater travels clockwise around the intended spin axis. This considerable translation momentum is neutralized, off-axis relative to the skater's centre of gravity, by a step forwards and a kick sideways with the right-blade, left arm leading, right arm trailing, onto the left-blade-outer-edge which follows a decreasing circular trajectory, while the skater adjusts to semi-mechanical rigidity, having a backward momentum on the left upper-body and a forward momentum on the right.

This now anticlockwise angular momentum can be guided into a faster spin by bringing that whirling boot onto the rotation axis; work is done by muscles against centrifugation, so the spin energy increases. But get it wrong, and muscles dissipate rather than supply energy – like they do when descending stairs. A floppy spin is full of mechanical irreversibilities and rapid entropy production.

If you pull your arms carefully inwards against centrifugal forces, the spin quickens, but if the rotation axis changes, a retarding torque can arise from the changing direction of the blade on the ice together with the spin axis increasing its distance from the small moving blade-to-ice contact area. Also consider how much extra circulating blood may be in the hands due to previous spins – hand, arm and leg masses vary. Far from "straightforward biomechanics", the situation is full of variables – gyroscopic effects, backbone flexure, blade rocking, vestibular and visual feedback, ice condition and so on.

In Olympic skating you are watching the effects of very fine adjustments to many hidden variables. The best way to progress your understanding is to get some lessons and have fun. Also, have a good look at the reverse curvatures of figure skating blades and how they function.

g moore
via *physicsworld.com*

Graphene and science communication

In reply to the *physicsworld.com* news story "Ballistic electrons go further in nanoribbons" (6 February, http://ow.ly/ulJaS) by *physicsworld.com* editor Hamish Johnston.

Ballistic transport in graphene is an old story – in 2008 Xu Du and colleagues published a paper entitled "Approaching ballistic transport in suspended graphene" (*Nature Nanotech.* 10.1038/nnano.2008.199). My general advice for popular science writers is: don't rewrite the university news blindly – become familiar with the history of research first. The universities are trying to sell their research for grant agencies, so they often pretend that their research is more ground-breaking and fundamental than it really is.

Ragtime
via *physicsworld.com*

The electron mobilities reported in the Du *et al.* paper are nearly two orders of magnitude smaller than the highest mobility measured by De Heer and colleagues in their 2014 paper (*Nature* 10.1038/nature12952). Furthermore, the values measured by Du seem to be in line with theory (see figure 5 of De Heer's paper) and therefore are not anomalous. De Heer's anomaly *is* the news. Regarding my blind acceptance of a university press release, I spoke with De Heer for over an hour on the phone to ensure that I understood both the nature of his experiments and the relevance of the results. Regarding my ignorance of the history of the field, we have published more than 200 articles about graphene on *physicsworld.com*, many of which I have written or edited myself.

Hamish Johnston
Editor, *physicsworld.com*

If you've published so many articles about it, then in my opinion it would be more useful to illustrate how the mobility of electrons increases proportionally with their geometric frustration. The 3D bulk graphite is a rather poor conductor, but the 2D layers of graphene conduct well and 2D layers separated into nanoribbons are even more conducting. And when we measure the speed of electrons at the boundaries of these stripes (i.e. in a 1D arrangement), then the speed of electrons gets increased by around two orders of magnitude compared to 2D graphene.

You may attract the interest of readers with a sensationalist headline, but the pedagogical utility of such an article

will be minimal. And as for talking to De Heer "for over an hour on the phone", this is just what I'm talking about. Every researcher wants to present their findings as being as new and original as possible, and every journalist wants to announce ground-breaking stories. This apparently creates a conflict of interest, because readers who just want to understand these things seek continuity and connections.
Ragtime
via *physicsworld.com*

I am not fully current on the literature of graphene physics and that's why I read popular accounts of experiments in this field. I found this article to be very interesting and thought-provoking and I'd like to thank the editorial staff for publishing it. I'm not going to let the comments of Ragtime spoil my fun.
f wright
via *physicsworld.com*

Because you don't know the subject well, everything appears new and cool for you. If you don't want your delight spoiled by deeper understanding, you're essentially saying that you want to remain unfamiliar with the subject forever.
Ragtime
via *physicsworld.com*

Hey, Ragtime. I rather liked this article as well. I do not claim to be an expert, and I don't really need to be to benefit from reading *physicsworld.com*. I think actually talking with a principal investigator or senior scientist for an hour is way more than adequate due diligence on the part of the editor. I also have great professional respect for *Nature*, which published De Heer's paper, and for its editorial board and peer reviewers. For them to publish an article takes more than just some university press release! Give us readers and the editorial staff a break.
ASIWEL
via *physicsworld.com*

Dark-field competition

In reply to the *physicsworld.com* news story "Dark field illuminates X-ray imaging" (25 February, http://ow.ly/uIJnl), which concerns new research by Robert Cernik and colleagues (*Proc. R. Soc. A* 10.1098/rspa.2013.0629).

I find it intriguing that these researchers are able to get credit for a technique that has long been developed and works a lot better than the one they proposed. I am talking about the X-ray grating interferometer developed by Weitkamp *et al.* (2005 *Optics Express* 10.1364/OPEX.13.006296). Aside from offering a much better signal exploitation, it also provides a dark field, a differential phase shift and an absorption image at the same time.
Christoph Baumbach
via *physicsworld.com*

The Weitkamp paper describes a very neat way to improve material contrast using phase imaging. However, the method described in the *physicsworld.com* article and in Cernik's paper is quite different. It describes the way in which energy dispersive diffraction patterns can be collected in the dark field to make 3D images that contain crystal structure information in each reconstructed voxel. This way of very simply projecting spatially resolved diffraction patterns onto pixelated energy-sensitive detectors is a new approach.
mclssbc
via *physicsworld.com*

Consistent morals

In reply to a *physicsworld.com* blog post about a talk by Amy Smithson, a non-proliferation expert, in which she criticized scientists who work on nuclear, chemical or biological weapons ("A question of responsibility", 16 February, http://ow.ly/ullWu).

Hurray for Amy Smithson! There should be more folks in science and technology who speak out about the ethics and morality of weapons work.
Howard Cohen
via *physicsworld.com*

I agree with the nub of her argument, but she makes it seem as if the American scientists do it out of "noble" patriotism and justifiable concerns for security, while the Pakistani and Russian scientists are evil mad scientists with shady motives. Surely they did not provide the US with Agent Orange to pour on civilians in Vietnam? Sadly, it is precisely this attitude of finger-pointing, us versus them, that perpetuates tragedies.
Ehsan Amini
via *Facebook*

This is a subject that has puzzled me for years. From a historical point of view, it is very interesting to study how different researchers in the Manhattan Project reacted to the use of the first A-bombs; from Edward Teller, who kept on working on nuclear weapons for the rest of his life, to Joseph Rotblat, who opposed them actively. Then there's Andrei Sakharov, who developed the first Soviet thermonuclear weapon, but then advocated the ban of nuclear tests. There's still a lot to do, when the Comprehensive Test Ban Treaty hasn't been ratified, and we see regimes that use chemical weapons. I fully agree with Smithson in that scientists should also be educated on the ethical side of their work. "Cool science" shouldn't be taken just as interesting science, but also responsible science.
Julio Herrera
via *physicsworld.com*

Scientists should also be educated on the ethical side of their work

New use for a Texas-sized hole

In reply to a *physicsworld.com* blog post about a proposal to build a successor to the Large Hadron Collider in Texas, using the partially completed tunnel of the ill-fated Superconducting Super Collider ("Rebirth of the SSC", 26 February, http://ow.ly/ullxa).

Go for it, guys! There is nothing like competition to spur people on. I judge the economics as involving much cheaper tunnelling costs, partly offset by the cost of lining the tunnel and installing pumps. But make sure you have triplicated power supplies to keep the pumps running in the event of lining failure. There will be a lot of expensive equipment down there.
Richard Shorter
via *physicsworld.com*

I seem to recall that the original collider project had an issue with fire ants. Now, crazy ants are making a beeline for north Texas (they make fire ants look like pets) and one of their favourite things is insulation on electrical cables. They would keep exterminators busy full-time. But I would love to see it. It would be a real shot in the arm for serious research and the jobs that go with it.
chris in dallas
via *physicsworld.com*

Dilemma resolved

In reply to a *physicsworld.com* blog post about BioLEIR, CERN's first major facility for biomedical research ("CERN creates new office for medical research", 25 February, http://ow.ly/ullHY and p8).

At last, an end to the question, "Why are we spending so much money on physics when we could be curing cancer?"
@lirugani
via *Twitter*

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Our wobbly galaxy

It is well known that the Milky Way rotates around a supermassive black hole, but researchers have found that our galaxy undulates up and down as well like a giant galactic merry-go-round. **Katia Moskvitch** reports on this surprising finding

Katia Moskvitch is a freelance science and technology journalist based in London, UK, e-mail emoskv@gmail.com

Black, heavy and calm, outer space seems motionless. Faraway stars flicker from time to time, as if lazily transmitting some cosmic Morse code. And on a clear night, the Milky Way looks as if it is painted on a huge, glossy black dome; the stars seem motionless, pinned into place.

Of course, we know that our home galaxy is not as still as it appears – its entire disc rotates horizontally about its centre. But in a surprising twist, recent observations by three independent teams of astronomers suggest that the Milky Way also undulates up and down. Thousands of stars in it constantly wobble vertically at speeds of about 20–30 km/s, stirring the galactic milkshake of stars and gas.

Just like any other spiral galaxy, the Milky Way looks like a pinwheel – a flat disc with spiral "arms" full of some 200–400 billion stars and a supermassive black hole at its centre. The motion of the Sun with respect to other nearby stars has been known for centuries, but it was in 1927 that Bertil Lindblad and Jan Oort came up with the first detailed model of our galaxy's motion, including its rotation.

We now know that individual stars orbit around the centre, making the whole disc rotate at about 220 km/s at the Sun's distance from the galactic centre. Also known is the random vertical motion of stars, much like a gas. But the bulk vertical up-and-down motion came as a surprise that no-one can yet explain. Perhaps the Milky Way is bumping into chunks of dark matter, or maybe some past collisions with other galaxies set it off ringing like a bell, suggests Mary Williams from the Leibniz Institute for Astrophysics Potsdam in Germany.

Williams leads one of the three groups to have suggested the Milky Way's peculiar vertical motion. Together with colleagues, she examined the movement of nearly half a million stars in a 3D volume around the Sun, using data gathered by the Radial Velocity Experiment (RAVE). A collaboration of researchers from more than 20 institutes around the world, RAVE ran for 10 years until April 2013 using data from the UK Schmidt Telescope of the Australian Astronomical Observatory.

The telescope measured starlight at infrared wavelengths between 840 and 880 nm. Using the resulting spectra, the researchers derived the stars' radial velocities, temperatures, elemental compositions and surface gravities (the latter being inversely proportional to the square of a star's radius). Based on the temperatures and surface gravities, the team isolated a group of about 70 000 stars with roughly the same intrinsic brightness, dubbed "the red clump".

As the stars in the red clump have the same brightness, the team estimated their distances from Earth by measuring how dim they are, much as a 60 W light bulb looks fainter when far away than close up. With this information, combined with the stars' radial velocities and extra information from other stellar surveys giving the transverse movement of the stars across the sky, the researchers put together a map showing the full 3D motion of the stars in space. (Figure 1 shows the vertical component.)

The result was unexpected. Not only do the stars rotate, they also move in-and-out and up-and-down in the galaxy. "These motions are suggestive of a wave, much like a sound wave," says Williams, whose work was published in October last year (*Mon. Not. R. Astron. Soc.* **436** 101).

Moreover, the stars do not all appear to be moving in the same fashion, either. Stars that are closer to


European Space Observatory

the centre of the galaxy than the Sun tend to drift away from the galactic plane, which goes through the middle of the galaxy's disc. However, stars that lie further out than the Sun move in towards the plane. The overall result is that stars move up and down depending on their distance.

"Our result has shown that the galaxy is all squishy and wobbly – it's not just spinning," says Williams, who also likens the stars' motion to dancers jumping up and down in the rotating "mosh pit" that sometimes forms in front of a stage at a rock concert. Reaching a definite conclusion was not easy, though, she adds. The results are incredibly complex, and you can only really see the vertical waves clearly on a 3D map.

Ripples of excitement

Just months before Williams and colleagues published their work, another team announced similar results. Led by astrophysicist Larry Widrow of Queen's University in Kingston, Canada, the team analysed data taken by the Sloan Digital Sky Survey (SDSS) of about 300 000 stars in the Milky Way. Widrow's team found a small but statistically important difference in the distribution of the number of stars – as well as their motions – above and below the galactic plane. It was, Widrow says, as if there were "localized ripples going through the disc".

One possible explanation for the ripples, according to Widrow, is based on there literally being more to the Milky Way than meets the eye. We know that it has a bright central bulge packed with stars, a flat rotating disc of stars, and a spherical halo of sparsely distributed stars that extends far beyond the galactic disc and contains more than 20 small satellite galaxies gobbled up by our own. But astronomers also believe that the Milky Way is surrounded by a halo of dark matter – an invisible substance of as-yet-unexplained composition that is thought to make up about 85% of all matter in our universe. According to computer simulations, dark matter can form massive lumps, which could have passed through our home galaxy's disc, churning things up and generating vertical waves in the motion of stars, says Widrow.

Williams' research confirmed Widrow's initial results with a larger data set, covering a larger region of the solar neighbourhood, extending roughly a quarter of the way to the centre of the Milky Way and about the same distance outward. The vertical flutter has also been confirmed by a third survey carried out by astrophysicists from the Rensselaer Polytechnic Institute in Troy, New York.

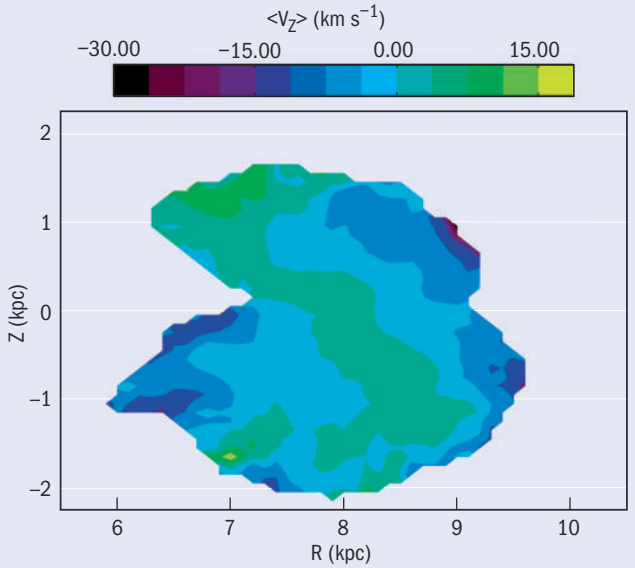
Published shortly after that of Williams, this third survey was based on observations made by the Chinese Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), located north-east of Beijing. "Although we were looking at a different part of the galaxy, we saw similar 'wobbly' patterns," says Heidi Newberg, who took part in the research. Given that three different surveys are all showing the same thing, Williams feels the results are incredibly exciting, giving her "a lot of confidence that what we are seeing is real".

A new wave of data

The next step is to use calculations and computer simulations to test different ideas about what makes the Milky Way flutter. Indeed, a new space craft

Dark matter can form massive lumps, which could have passed through our home galaxy's disc, churning things up

1 Throwing a wobbly



Leibniz Institute for Astrophysics Potsdam

Based on data from the Radial Velocity Experiment (RAVE) – a survey of almost half a million stars around the Sun – astronomers have found that the Milky Way not only rotates horizontally but also that individual stars move vertically up and down perpendicular to the plane of our galaxy. Shown here is a slice of the Milky Way cut along a radial line of the galactic disc, showing stars in the region near our Sun. Axes are coordinates, where R is the radial distance from the centre of the galaxy and Z is the distance above ($Z > 0$) or below ($Z < 0$) the plane. The Sun is located at (8.33,0.03). All distances are measured in kiloparsecs (kpc, where 1 kpc is roughly 3300 light-years). Colour indicates the stars' average velocity in the Z direction, $\langle v_Z \rangle$, and reveals a ridge inclined at 40° to the R axis where stars move upwards (green), whereas either side they move downwards (blue). The differences in stellar speeds resemble velocity maps for sound waves, supporting the theory that vertical waves exist in the galaxy.

will soon start bringing in a lot more observational results. The European Space Agency's Gaia satellite, which took off successfully late last year, is expected to produce a wealth of data on the structure of the Milky Way. It will measure accurate distances to about a billion stars, and give their proper motions and radial velocities.

This information will help scientists to carefully map out the bulk motions seen in the SDSS, RAVE and LAMOST surveys in far greater detail and over a larger region of our galaxy, providing in turn a much better idea about the structure of the Milky Way's galactic disc and the system of satellite galaxies and dark matter around it. "The final word will come with Gaia's [measurements] for a staggering amount of stars," says Williams. "With these we'll be able to accurately trace the motions of stars in this region and way beyond, and the vertical waves we're seeing [will be] starkly defined."

The results could give us a better understanding of how galaxies form, and help refine existing models of the Milky Way, which assume that our galaxy is in equilibrium. And if it turns out that dark matter is stirring things up, the wobbles could help determine whether unseen "dark" dwarf galaxies are orbiting the Milky Way, says Newberg.

All things considered, our galaxy seems to be much more than a plain old rotating spiral. ■

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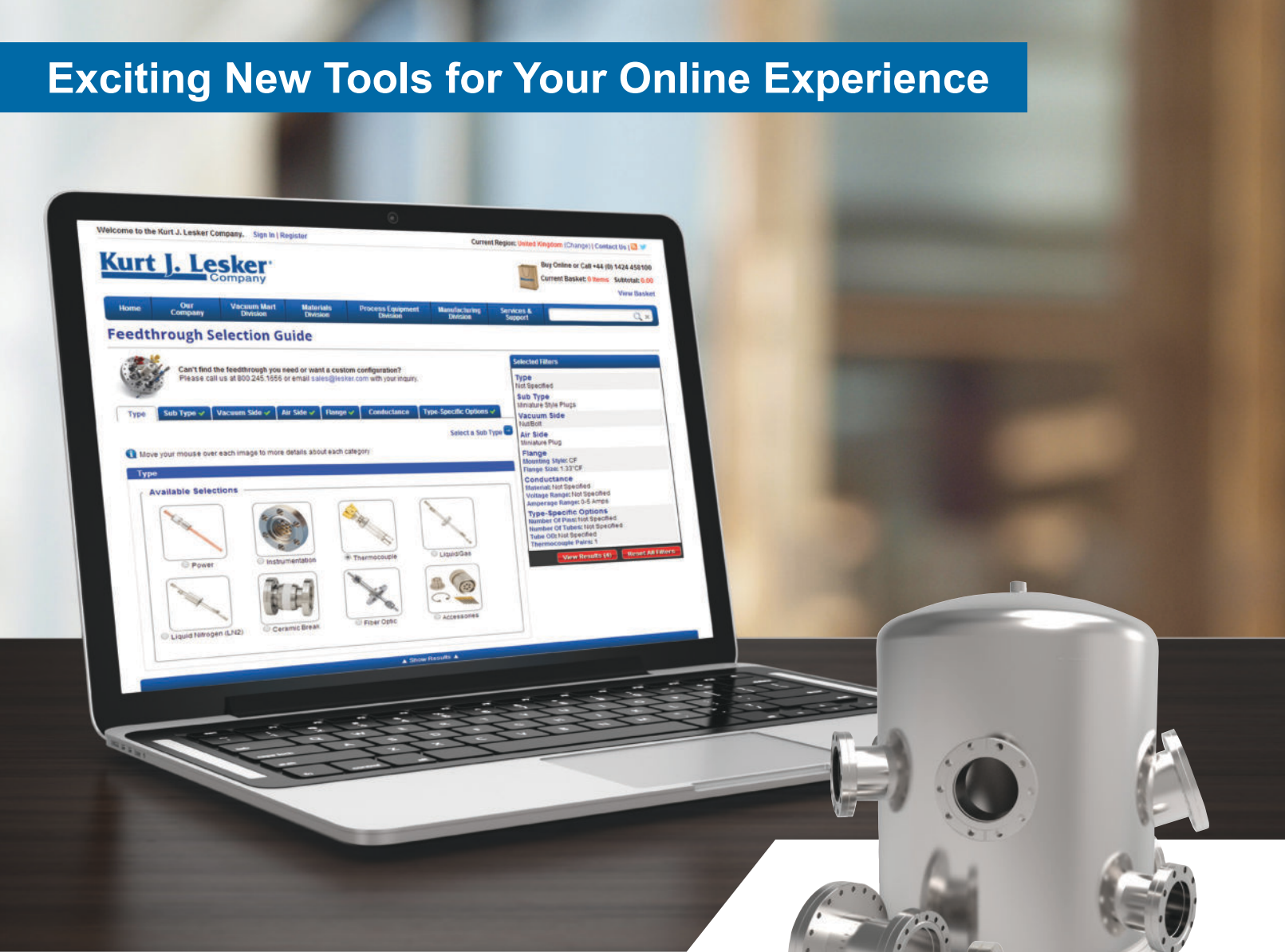

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The power of silence

Collaboration, engagement, outreach – the modern physicist is continually encouraged to keep talking and communicating. **Felicity Mellor** wonders if it would be better if we simply stayed silent

Felicity Mellor is senior lecturer in science communication at Imperial College London, where she is currently running a project funded by the Arts and Humanities Research Council on the "Silences of science", e-mail f.mellor@imperial.ac.uk

Isaac Newton craved it. So did Albert Einstein. Henry Cavendish and Paul Dirac positively exuded it. Silence, and its companion solitude, seems to be a recurring feature in the history of physics. Yet current research policy, in the UK at least, emphasizes silence's opposite. From assessing publications and rewarding collaborations, to requirements for public engagement, policy initiatives urge scientists to speak up. There is a danger that in the midst of all this enforced interaction, an important precondition for creativity in physics could be lost. With all these demands to talk, do scientists still have the chance to think?

The ideal of the solitary scholar has a long history in Western society. For all the rhetoric of openness and public demonstration that accompanied the establishment of the Royal Society in the 17th century, natural philosophy also continued to draw on the tradition of the isolated intellectual that had characterized much religious thought. Newton, in particular, cultivated the image of the hermit – dishevelled, shut away in his rooms, thinking about esoteric matters that few others could hope to understand. He published reluctantly, attempting to restrict his audience to only those he thought capable of appreciating his work. Indeed, it was only after much persuasion that he eventually agreed to his *Principia* being published in full.

A century later, Henry Cavendish was similarly reluctant to publish, with most of his research remaining hidden in his notebooks for decades after his death. Cavendish not only worked in isolation but was also famous for his silence when in company, refusing to speak even to his servants and communicating instead by notes. That did not, however, stop him making great advances in everything from the nature of gravity and electrical forces to thermodynamics and the chemistry of gases.

The recurring silences of physics tell us that, for many physicists, intellectual progress requires control over the communication networks of which they are a part

In the modern era, too, it is not difficult to find physicists whose working style was characterized by silence. Einstein spoke of never having lost "a need for solitude", while Dirac's colleagues joked that his name should be given to a unit for the fewest words it was possible to utter while in company, a measure that they put at one word per hour.

Of course, not all physicists are silent types. Niels Bohr, for instance, has been characterized in one biography by historian Robert P Crease and journalist Charles Mann as "The man who talked". If Einstein preferred "to think in apartness", as his biographer Abraham Pais put it, Bohr preferred to think through speech, developing his ideas by talking with others so that even the process of finding the right words became something to be pondered out loud. Yet Bohr's interlocutors also needed time away from all that talk. Werner Heisenberg retreated to the tiny island of Heligoland to escape from hay fever, and it was only then, reflecting on recent discussions with Bohr but not immersed in them, that he laid down the basis of his formulation of quantum mechanics. He was again away from Bohr when he wrote his uncertainty paper.

As Heisenberg's example suggests, formative silences rarely, if ever, consist of absolute withdrawal. Historians of science have repeatedly shown that even those breakthroughs that seem to come from nowhere emerge from shared learning, external stimulation and networks of support. Even Newton, for all his curmudgeonly ways, corresponded with other natural philosophers, and Cavendish's excessive shyness did not prevent him from regularly attending scientific meetings. Despite their reclusive tendencies, both men also contributed to public affairs – Newton at the Royal Mint and Cavendish as an active committee member at the Royal Society and the British Museum. The myth of the lone genius has little basis in fact.

Controlling one's communication

Rather than being mutually incompatible, silence and communication form a delicate balance. As historian Mara Beller has said of Heisenberg's need to get away from Bohr, Heisenberg was striving not for intellectual isolation but to regain the "proper, uncoerced balance" in his communications. The recurring silences of physics tell us not that individual genius is the sole source of creativity, but that, for many physicists, intellectual progress requires control over the communication networks of which they are a

Dave Cutler

The most successful physicists have been able to strike a balance between coming forth and holding back

part. Communication, yes, but on the physicist's own terms, in the manner that suits each individual best.

So how much control do scientists today have over their level of communication? Not much, by some accounts. Peter Higgs has recently claimed that he would not have been able to complete his Nobel-prize-winning work in the current research environment. The peace and quiet that he enjoyed in the 1960s is, he thinks, no longer a possibility.

One example of this shift from a balance between silence and communication to a near-exclusive focus on the latter can be found in the ways in which institutes of advanced study have been conceived. Writing in 1931, Abraham Flexner, founding director of the Institute of Advanced Study in Princeton, envisioned his institute as a place that "should be simple, comfortable, quiet without being monastic or remote". It would provide "the tranquillity and the time requisite to fundamental inquiry into the unknown". Located in extensive grounds close to, yet entirely separate from, the university, Flexner's institute facilitated collaboration within a context of retreat.

By contrast, the new generation of advanced study institutes that have appeared in the UK over the last decade sit within universities and emphasize collaboration and social impact over withdrawal and speculative contemplation. Durham University's Institute of Advanced Study, for instance, aims at "bringing together some of the world's finest researchers from all disciplines" to work with the university's own staff. It also "serves as a top-level forum, enabling key decision makers and experts to discuss pressing policy problems". Likewise, the University of Warwick's Institute of Advanced Study aims to "promote collaborative research projects", especially through "international engagement" and "links with the university's strategic partners".

These are laudable aims, but it is striking that the need for periods of withdrawal and solitude are no longer acknowledged as a means of facilitating intellectual advances. History shows us that the most successful physicists have been able to strike a balance between coming forth and holding back, between public discussion and private contemplation. Yet reticence and silence seem to have no place in the modern research agenda. Delete the silences from speech, and one is left with incoherent babble. Delete the silences from scientific research and perhaps the result will be nothing but noise.

Detlev van Ravenswaay/Science Photo Library

Planets galore

With almost 1700 planets beyond our solar system having been discovered, climatologists are beginning to sketch out what these alien worlds might look like, as **David Appell** reports

And so you must confess
That sky and earth and sun and all that comes to be
Are not unique but rather countless examples of a class.
Lucretius, Roman poet and philosopher, from *De Rerum Natura*, Book II

The only thing more astonishing than their diversity is their number. We're talking exoplanets – planets around stars other than our Sun. And they're being discovered in *Star Trek* quantities: 1692 as this article goes to press, and another 3845 unconfirmed candidates.

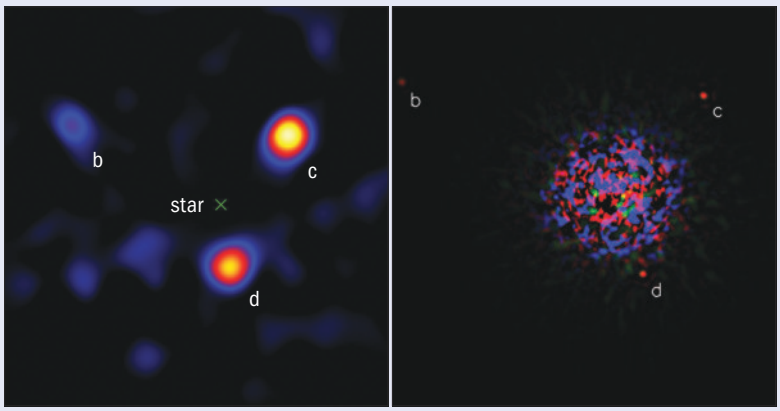
The menagerie includes planets that are pink, blue, brown or black. Some have been labelled hot Jupiters, black Jupiters or puffy Jupiters; there are hot Neptunes and mini-Neptunes; exo-Earths, super-Earths and eyeball Earths. There are planets that orbit pulsars, or dim red dwarf stars, or binary star systems.

Astronomers are in heaven and planetary scientists have an entirely new zoo to explore. "This is the best time to be an exoplanetary astronomer," says exoplanetary astronomer Jason Wright of Pennsylvania State University. "Things have really exploded recently." Proving the point is that a third of all abstracts at a recent meeting of the American Astronomical Society were related to exoplanets.

This explosion is largely thanks to the Kepler space observatory. Discoveries of exoplanets had been

David Appell is a science writer living in Salem, Oregon, US, www.davidappell.com

How to find exoplanets



NASA/JPL-Caltech/Palomar Observatory

National Research Council Canada

Caught on camera The HR 8799 planetary system was detected through direct imaging.

- **Radial velocity surveys** detect a planet by observing the wobble in a star's motion caused by the orbiting planet. Light from the component of the wobble along our line of sight is Doppler-shifted as the star approaches us or recedes from us. We detect this as a shift in the lines of the star's emission spectra to smaller or larger wavelengths. Hundreds of observations can eventually detect a radial velocity – defined as the line-of-sight velocity of the star with respect to Earth – as low as 1 m/s. By comparison, Jupiter shifts our Sun's centre of mass by 12 m/s.
- **Transit surveys** detect a small decrease in a star's light when an exoplanet happens to have an orbit that takes it between its star and Earth. The amount of light blocked indicates a planet's size, with large Jupiter-like planets blocking more than 1% of a Sun-like star's light and Earth-sized planets only 0.01%.
- **Direct imaging** of a faint exoplanet beside its immensely brighter star typically works if it has a wide orbit of tens of astronomical units.
- **Gravitational microlensing** of a star that happens to pass in front of another is usually a smooth microlensing event, but if the event is perturbed – as evidenced by a blip on an otherwise smooth curve showing the amount of magnification over time – this indicates that an exoplanet is orbiting the foreground lensing star.
- **Astrometry** is a method whereby a star's position is plotted precisely and any perturbations point to an orbiting planet.
- For more details on detection techniques, see "Brave new worlds" (March 2009 pp26–30).

slowly mounting since the first two candidate exoplanets were confirmed in 1992. But Kepler's launch in 2009 changed the game entirely. The observatory boasted a specially designed one metre wide photometer that could continuously monitor the brightness of more than 150 000 stars. Thanks to this kit, Kepler was able to detect the minute variations in a star's output as an exoplanet happened to pass between (transit) its star and Kepler. In May 2013, when the second gyroscope-like reaction wheel that kept Kepler pointed at a particular star failed, the telescope's spectacular run was sadly curtailed. Yet astronomers are still busy analysing its data and, as we go to press, data from Kepler have led to the discovery of 964 confirmed exoplanets and 3845 that are unconfirmed.

But it is not only astronomers who are having their fun. Climatologists, who were previously restricted to modelling Earth, Venus, Mars and Titan, now have hundreds of new worlds to play with. Feeding data from Kepler into their climate models, these scientists are beginning to sketch out what these other worlds might look like and, in particular, whether they could support life.

When climate gets strange

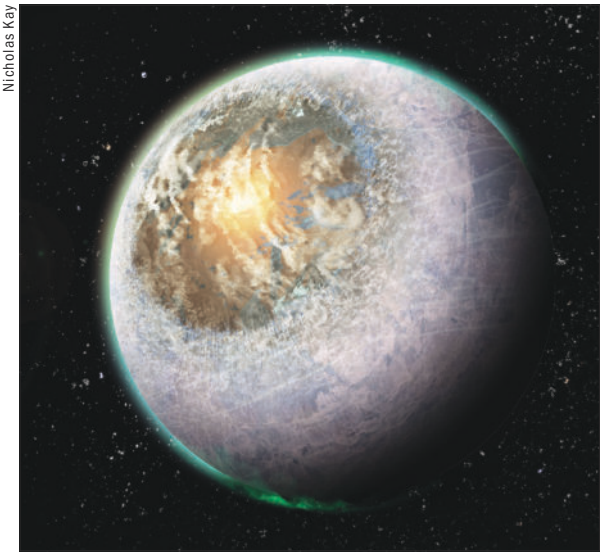
Some of the newly discovered exoplanets would have a hard time supporting life as we know it. The oddball planet HD 80606 b in Ursa Major, for example, has an orbital eccentricity (the amount by which it deviates from a circular orbit) of 0.93 – just slightly lower than Halley's Comet. Orbiting its Sun-like star, planet HD 80606 b would receive at its furthest point about as much sunlight as the Earth does, but when it is at "periastron" – its closest approach to its star – it would get a massive 828 times more. When astronomers observed the planet's eclipse by its parent star, its temperature rose from about 800 K to 1500 K in just six hours.

All that astronomers need to begin estimating an exoplanet's climate are its orbit – defined by the distance from its star and the duration of its year – and the luminosity of its parent star. Both pieces of information are yielded by the two main methods for detecting exoplanets: radial velocity surveys and transit surveys (see box, left). And knowing a planet's mass and radius, astronomers can determine the planet's average density, giving some idea of what it's made of. Meanwhile, clues to the planet's atmosphere, if it has one, can be gained from the starlight it blocks when the planet passes in front of its star, or from the planet's own emissions that are blocked when it passes behind its star.

Raymond Pierrehumbert, a climate scientist at the University of Chicago, has explored the possible climate of Gliese 581 g, a candidate exoplanet that sits 20 light-years from Earth in the constellation Libra. One of six exoplanets thought to be orbiting its star, Gliese 581 g was discovered in 2010 by the Lick–Carnegie Exoplanet Survey led by University of California, Santa Cruz astronomer Steven Vogt and R Paul Butler of the Carnegie Institution of Washington. The discovery was based on combined radial velocity measurements from the Keck 1 telescope in Hawaii and the 3.6 m telescope at the European Southern Observatory in Chile. While four of the six exoplanets are confirmed, the existence of Gliese 581 g is controversial because the data can be interpreted to mean either that Gliese 581 g exists, or that the confirmed planet Gliese 581 d has an eccentric orbit rather than circular. "It will take many more data points than the 400 gathered already to resolve this eccentricity ambiguity," says Vogt, who believes the radial velocity data support the unconfirmed planets, but who expects to spend many years doubling the number of data points before resolving the issue.

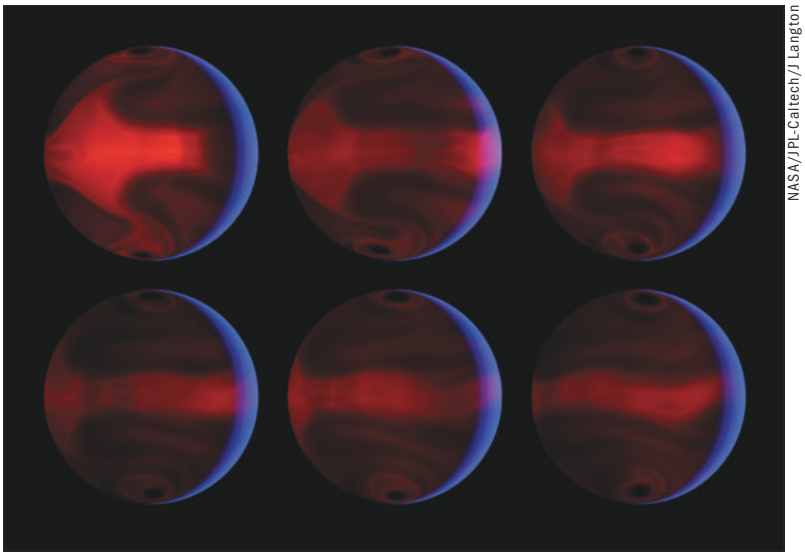
Despite this ambiguity, Gliese 581 g hit exoplanet headlines in July 2012 when it was ranked first in a list of the five potentially most habitable exoplanets, put together by researchers at the Planetary Habitability Laboratory, which is part of the University of Puerto Rico at Arecibo. The planet is looked on so favourably because, if it does exist, it lies smack-bang in the middle of its star's "habitable zone" (see next section).

Pierrehumbert explored the range of possible



Nicholas Kay

Eye in the sky Artist's impression of Gliese 581 g as an "eyeball Earth" that is frozen all over except for a single giant ocean.



NASA/JPL-Caltech/J Langton

What a scorcher! The simulated weather patterns of eccentric planet HD 80606 b, 4.4 days (top left) to 8.9 days (bottom right) after its closest approach to its star.

environments of Gliese 581 g by making different guesses for the planet's composition and putting them into climate calculations. Key parameters are what the surface is made of (rock, water or ice?) and the atmosphere (airless, life-essential nitrogen or an abundance of carbon dioxide (CO_2), with its large greenhouse effect?). Because the planet's orbit is, in theory, circular and only 0.15 astronomical units (AU) from its star, tidal forces are huge and it is likely tidally locked, always displaying the same side to its star (as the Moon does to Earth).

One scenario is that Gliese 581 g is a rocky planet without an atmosphere, which would make it cold and barren – and therefore little different from our Moon. But if the planet has a pure nitrogen atmosphere with a surface pressure of 10^5 pascals – nearly the same as that of the Earth – over a dry rocky surface, the temperature would be a survivable –4 °C at the substellar point (the surface point directly under the star). The planet's night side would, however, be about –50 °C – inhospitable for life as we know it. Different estimates of the planet's albedo (reflectance), the presence of water (brought in by comets, as is thought to be the case for Earth) and the amount of CO_2 in its atmosphere would lead to much higher temperatures. In fact, with a dense enough atmosphere, the planet would have a strong water vapour/CO_2 greenhouse effect producing a warm, liquid water ocean, with the potential to support life.

But the most interesting possibility for Gliese 581 g is an "eyeball Earth" – a low enough albedo that open water occupies a circular region near the planet's substellar point (the "pupil" of the eyeball), with the rest of the planet's surface frozen over (the "white" of the eyeball). The size of the ocean would depend on the atmosphere's CO_2 concentration, and the temperature at the ice edge would be the freezing point of the ocean. Using a global climate model with 10^5 pascals of surface pressure and a 20% CO_2 atmosphere, Pierrehumbert found the planet would have a maximum temperature of 37 °C with a large circular ocean of width 90° in both latitude and longitude. Depending on the planet's radius (known to be between 1.3 and 2 times Earth's), the region of open water would be about half the size of all of Earth's oceans. The night-side temperature would be frozen darkness at about –63 °C.

Even if Gliese 581 g does not exist, other similar exoplanets do. So could such an eyeball-Earth exoplanet ever be confirmed? One clue would be to scan the planet using infrared photometry and detect a step-change in the planet's albedo, corresponding to the transition between ice and open water. If the planet is tidally locked, our view of it would change during its orbit, from the warm ocean to the cold night side.

Habitable zones

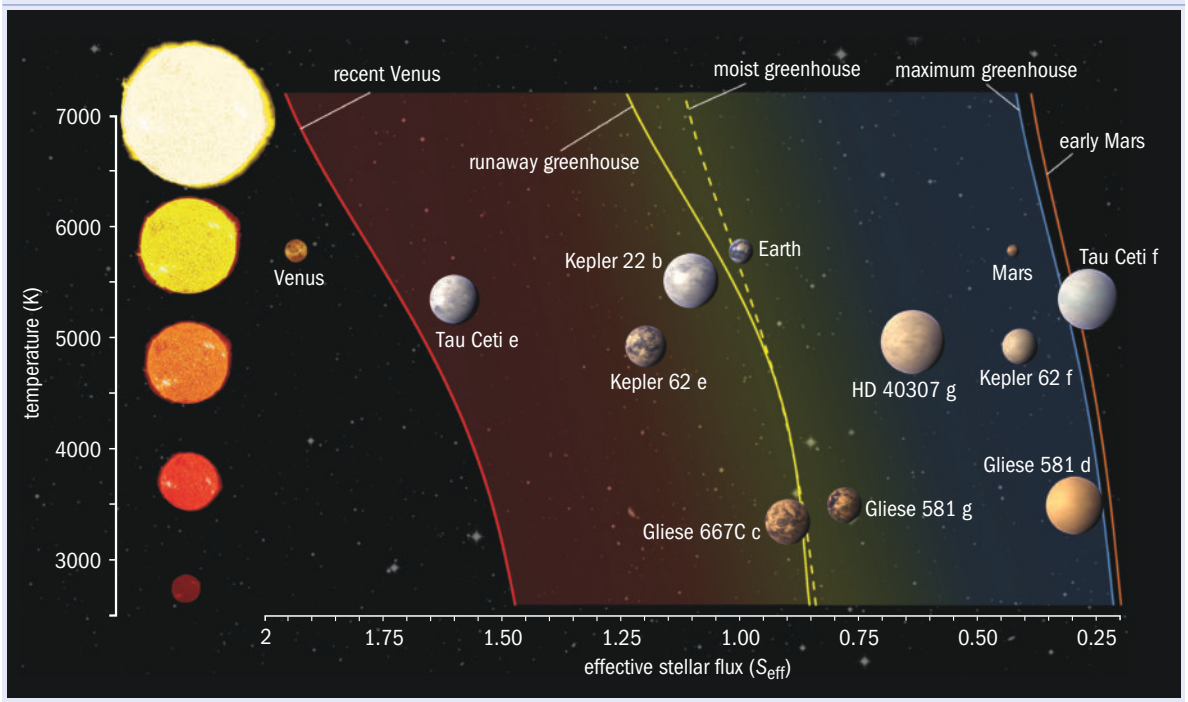
We've mentioned the habitable zone, or "Goldilocks zone", but what would this be like in reality? Within this realm, where temperatures are not too hot or too cold, it is possible for a rocky planet to maintain liquid water on its surface – a key requirement for the survival of life as we know it.

In a paper published in *Proceedings of the National Academy of Sciences* last November (10.1073/pnas.1309107110), James Kasting and colleagues at Pennsylvania State University tried to pinpoint the inner and outer limits of the habitable zone, expanding on groundbreaking work Kasting first did over 20 years ago. Using sophisticated models of a rocky planet with surface liquid – and making assumptions that the atmosphere contains water vapour, nitrogen, carbon dioxide and oxygen – he and his team found that the inner edge of the habitable zone is closer to its star than previously calculated.

What the paper also shows is that, when a watery planet is too close to its star, there are two very different mechanisms by which the planet's water can be lost to space. First, if a planet is so close to its star that its temperature exceeds 647 K, the planet would lose its water dramatically by undergoing a "runaway greenhouse" effect and its entire ocean would evaporate into its atmosphere.

Kasting and colleagues find that, for Sun-like stars

1 The Goldilocks zone – not too hot, not too cold



Chester Harman/PHL at UPR Arecibo/NASA/JPL/*PNAS* 10.1073/pnas.1309107110

The habitable, or "Goldilocks", zone is the shell-shaped region around a star in which a planet could have liquid water on its surface. That zone is shown here as a function of the temperature of the planet's star (five examples are shown on the left) and of stellar flux in comparison to what we receive on Earth, S_{eff}. In a conservative scenario, the habitable zone is restricted to the "moist greenhouse" and "maximum greenhouse" limits. An optimistic scenario, which uses estimates of how long Venus and Mars kept liquid water on their surfaces, extends the habitable zone to the "recent Venus" and "early Mars" limits.

with an effective radiating temperature of 5780 K, a runaway greenhouse effect occurs if a planet's effective stellar flux, S_{eff}, is 1.04 or more (figure 1). (This quantity is a measure of how much radiation a planet receives from its star and is a planet's stellar flux divided by the solar flux at Earth's orbit. $S_{eff} = 1$ is the flux we receive on Earth, with higher values meaning more radiation is received than on Earth, and lower values less.) In our solar system, this effective stellar flux is equivalent to the planet being 0.98 AU from the Sun and in fact Venus, which orbits at 0.72 AU, is thought to have undergone a runaway greenhouse effect. Once the ocean is gone, the planet's water would be lost in a few tens of millions of years, as the photo-disassociated hydrogen atoms escape to space.

The second method by which a planet can lose its water is that, before the entire ocean evaporates, the atmosphere becomes fully saturated and water vapour rises so high into the stratosphere that it cannot condense. When those atoms in a water molecule are then disassociated by incoming photons, the light hydrogen atoms escape into space. This "moist greenhouse" happens, in Kasting's 1D model, if the planet's surface temperature is above 340 K for an Earth-like atmosphere, equivalent to the planet's S_{eff} being greater than 1.01. In our solar system this equates to 0.995 AU from the Sun, just inside Earth's orbit, which would seem to indicate that Earth is in danger of this fate.

However, Kasting explains that his 1D energy balance model is limited in its predictions. "The model is too conservative for two reasons," says Kasting. First, it ignores how clouds, which can both trap and reflect heat, change with temperature. Second, it assumes that relative humidity in the lowest part of the atmosphere is 100%, when in reality it is less. "A 3D climate model is needed to better quantify these effects," he adds, which is in fact what other researchers have now done. Recent work using a 3D climate model by Jérémy Leconte, of the Institut Pierre Simon Laplace in Paris, and colleagues puts the inner edge of the habitable zone at a safer $S_{eff} = 1.10$ (0.95 AU) for Earth-like planets, and that of Eric Wolf and Brian Toon of the University of Colorado at Boulder found an inner limit of $S_{eff} = 1.15$ (0.93 AU).

As for the cold outer boundary of the habitable zone, it is the distance at which surface water cannot get above its freezing point, despite full-on greenhouse warming. Kasting and colleagues calculate this theoretical "maximum greenhouse" limit to be at $S_{eff} = 0.35$, which equates to 1.69 AU in our solar system. However, we know that early Mars had liquid water flowing on its surface at least 3.8 billion years ago – a time when the Sun's luminosity was 25% lower than today – which suggests an empirical limit of $S_{eff} = 0.32$, which is 1.77 AU in our solar system today.

Until and unless we obtain good data on the planetary atmospheres that show some kind of a bio-signature, we will not know if they are habitable environments

Favourites for habitability

Given the wide range of parameters that can make a planet habitable, which exoplanets do astronomers think have the best chance of supporting life?

At NASA's exoplanet conference at its Ames Research Center three years ago, the Kepler team announced it had found its first confirmed planet in

a habitable zone, Kepler 22 b, some 600 light-years from Earth in the constellation Cygnus. It orbits its Sun-like star in 290 days, and although its semi-major axis is a familiar 0.85 AU, the shape of the exoplanet's orbit is unknown, so we also do not know how much time it spends in its star's habitable zone. With $S_{\rm eff} = 1.09$, it likely has a surface above freezing over at least part of its orbit, and could be an ocean world with a small rocky core.

The solar system around the star Kepler 62, which is some 1200 light-years away in the constellation Lyra, has at least five planets, two of which are particularly enticing as twin Earths. The masses of this pair – Kepler 62 e and Kepler 62 f – are unknown, but we know they have radii between 1.25 and 2.0 that of Earth. Both are in the habitable zone of their parent star, with $S_{\rm eff}$ values of 1.16 and 0.41, respectively – the latter within the habitable-zone limits given by climate models. The planets' albedos are unknown, but a Monte Carlo simulation that assumed they are a random number between 0 and 0.5 found the planets' estimated equilibrium temperatures to be –3 °C and –65 °C.

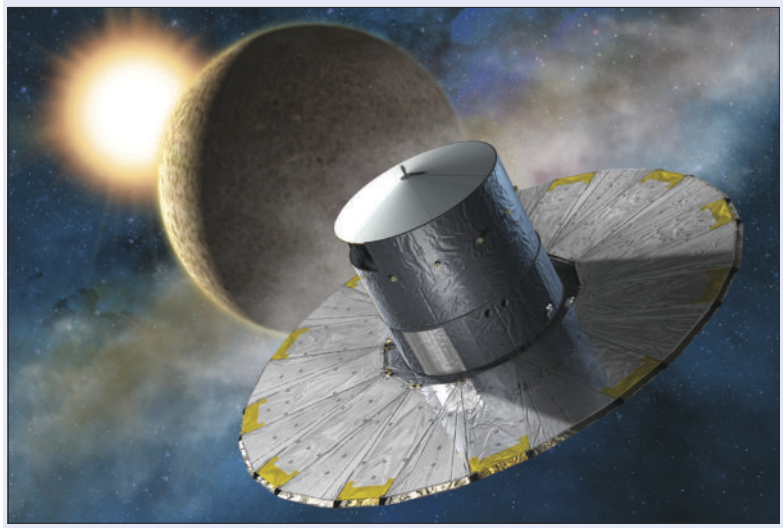
Dimitar Sasselov of the Harvard–Smithsonian Center for Astrophysics and colleagues at the Max Planck Institute for Astronomy in Heidelberg, Germany, calculate that the planets may be completely made of water, or they may be solid with a shallow ocean; the latter offers the possibility of hydrothermal vents, which on Earth support organisms known as "extremophiles".

With a little luck and the right atmospheric composition, either or both of Kepler 62 e and f could be habitable. However, we will not know if any of these planets are fit for life until astronomers look more closely. "Until and unless we obtain good data on the planetary atmospheres that show some kind of a bio-signature, we will not know if they are habitable environments," says Ravi Kopparapu, a research associate in Kasting's group at Pennsylvania State.

Unless the inhabitants of an exoplanet are beaming radio waves or laser light our way – what scientists who search for extraterrestrial life call "technosignatures" – astronomers will look for actual habitation by spectroscopically examining an exoplanet's light spectrum. A telltale sign could be the presence of accumulated gaseous molecules that are a by-product of biological metabolism, such as oxygen, methane, nitrous oxide and ammonia. Specifically, the ratios of these gases should be far from thermodynamic equilibrium – as they are on Earth.

Kepler 62 e and Kepler 62 f are too far away for astronomers to sift through their light looking for chemical elements from their atmospheres – their distance is large enough that not enough photons would be collected. But they have attracted the attention of SETI (Search for Extraterrestial Intelligence) researchers, whose SonATA programme – SETI on the Allen Telescope Array in northern California – is concentrating on the Kepler telescope's discoveries of exoplanets in the habitable zone. The programme will focus on frequencies where the Earth's atmosphere is most transparent, which includes many frequencies that have never before been observed.

Future missions



ESA

Star surveyor Artist's impression of Gaia, which is right now monitoring our galaxy's stars.

Last December saw the launch of the European Space Agency (ESA) Gaia mission, also known as "the one billion star surveyor". This five-year mission's primary goal is to investigate the formation and evolution of the Milky Way by mapping 1% of our galaxy's stars; monitoring the position of these stars will also bring to light any wobbles in their position that would indicate exoplanets (see box on p34). Estimates suggest that Gaia will discover tens of thousands of new exoplanets.

Looking further ahead, in 2017 NASA plans to launch the Transiting Exoplanet Survey Satellite (TESS) telescope, which will look for transiting exoplanets and is expected to discover up to 10 000 candidates. There are also plans to adapt existing ground-based telescopes here on Earth to search for new exoplanets. The SPHERE system designed for the European Southern Observatory's Very Large Telescope and the Gemini Planet Imager developed for the Gemini South telescope, both in Chile, will allow these telescopes to look for large, giant planets. A different approach will use the spectrographs HARPS-N at Italy's Galileo National Telescope in the Canary Islands and ESPRESSO at the ESO's Very Large Telescope – planned for 2016 – to detect exoplanets' frequency spectra.

Many hopes are being placed on the NASA-led James Webb Space Telescope (JWST), planned as a successor to the Hubble Space Telescope, to study the formation of stars and planets. Its large-aperture, infrared telescope will be ideally suited to doing atmospheric spectroscopy. But the JWST has already been 17 years in the planning, is well over budget and, with shades of the infamous Superconducting Super Collider, has nearly been cancelled once already. The US has now capped its cost at $8bn, with launch slated in 2018.

Then there are proposals such as the New Worlds Mission to build an unprecedented "star shade". Shaped like a multi-petalled flower, the shade would fly 50 000 kilometres in front of the JWST, blocking a star's light by as much as 10 billion-fold, allowing astronomers to view exoplanets without the glare of the star over-exposing their readings. Also, ESA has drawn up plans for a mission called PLATO to launch in 2024, which is hoped to discover exoplanets around Sun-like stars (see p9).

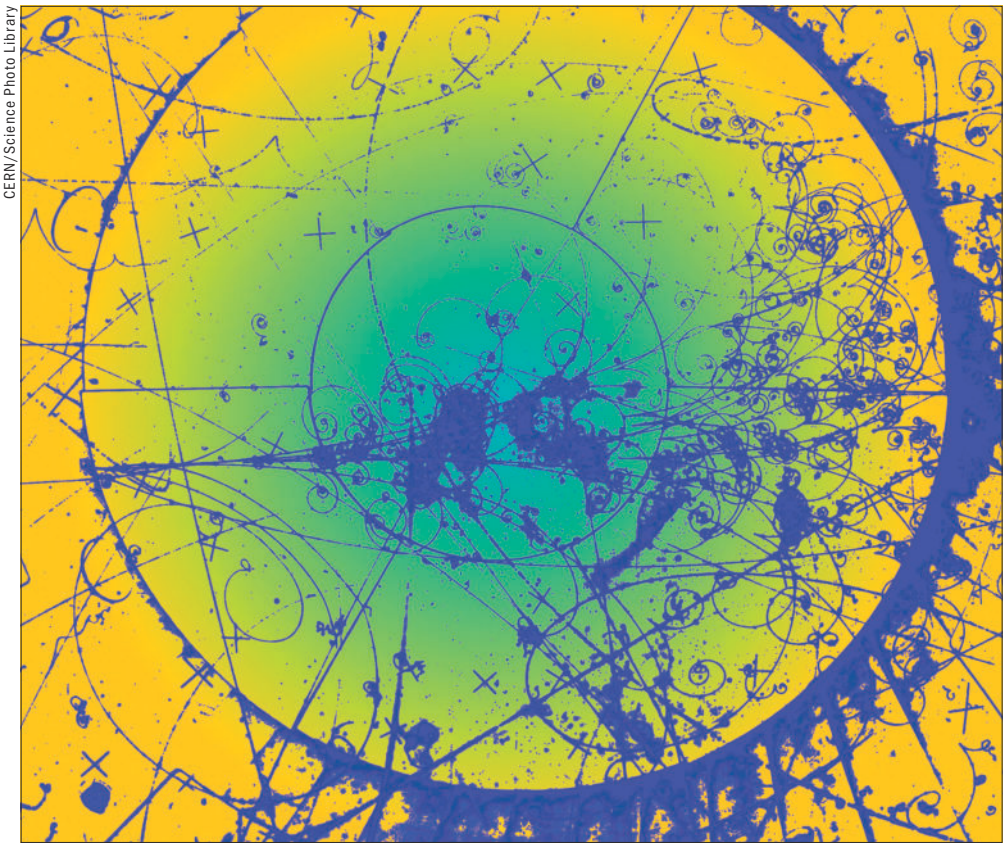
What else is out there? It is perhaps the ultimate question.

This is a truly unique time for astronomers – new vistas are bringing revelations of new worlds almost as fast as they can catalogue them, while others are characterizing these realms, allowing us to begin imagining what they look like. Can imagination keep up with reality? Like few other times in history, our human understanding of the cosmos is fulfilling, and even surpassing, our human dreams of the cosmos. ■

Reviews

Brian Clegg

Hunting for neutrinos



CERN/Science Photo Library

Rare beauty
Bubble chamber particle tracks from CERN showing a muon neutrino interacting with a neutron.

The Neutrino Hunters: the Chase for the Ghost Particle and the Secrets of the Universe
Ray Jayawardhana
2014 Oneworld/ 2013 Scientific American £11.99pb/ $27.00hb 256pp

The hunt for the Higgs boson may have dominated headlines for the last few years, but Ray Jayawardhana's book *The Neutrino Hunters* makes it clear that the neutrino is, if anything, even more worthy of publicity. The neutrino's importance is not related to the headline-grabbing technical error of 2011, when it appeared that neutrinos had exceeded the speed of light, but rather because these ubiquitous particles – around 100 trillion of which pass through your body from the Sun every second – give astronomers a unique ability to see into otherwise impenetrable parts of the universe. Moreover, their strange ability to change form shakes up the Standard Model, our best current understanding of fundamental particles.

The hunt for neutrinos began in 1930, when the Austrian physicist Wolfgang Pauli predicted the existence of a neutral particle that is emitted during beta decay. In this nuclear process, an electron is given off as a radioactive atom decays, but there is a hole in the system's total mass/energy after the reaction. Something has gone missing and Pauli predicted that it was an unknown, ghostly particle. Pauli had mixed feelings about this. As he commented to his friend Walter Baade: "I have done a terrible thing. I have postulated a particle that cannot be detected."

Pauli's initial speculation was more than a little brave. At the time there were only three known (apparently) fundamental particles: protons, electrons and photons. To propose another just to explain a little missing energy seemed extreme. Pauli called his hypothetical particle the neutron, but the name was soon taken by James Chadwick to apply to the nuclear particle he had discovered, so Pauli's conjecture was renamed the neutrino (or "little neutral one") by the Italian physicist Enrico Fermi.

As the title of *The Neutrino Hunters* suggests, the people who searched for evidence to back up Pauli's hypothesis, and later for explanations of the new particle's behaviour, are the book's main characters. Some of the searchers are well-known figures, but others are fresh and hence particularly interesting. Consider the Italian physicist Bruno Pontecorvo, who was the first to suggest that neutrinos could be detected. He realized that although neutrinos mostly pass straight through matter, very occasionally an atom will absorb a neutrino and be transmuted to a different element. This new element might then decay, allowing the interaction to be detected. A rare event indeed, but Pontecorvo recognized that nuclear reactors and stars pump out so many neutrinos that such events should be detectable.

Soon after making this proposal, Pontecorvo dropped off the radar, only to emerge years later in the Soviet Union (August 2012 pp44–45), but others went on to build the giant detectors required to observe neutrino-related decays. From the early vats of cleaning fluid to the science-fiction film-maker's dream that is the IceCube neutrino observatory – a series of 86 elegant chains penetrating over a kilometre deep into ice near the South Pole – these vast detectors, usually deep underground, are as much the stars of the search as are the humans.

Another important but rarely mentioned figure is the US physicist Frederick Reines, who between 1953 and 1956 managed to pin down actual neutrino events, demonstrating that Pauli's ghostly particle truly existed. And then there was Ettore Majorana, the most enigmatic of the hunters. His idea that a neutrino could be its own antiparticle may explain why our universe is primarily matter rather than antimatter (and also shakes the Standard Model once more), but his science was over-

shadowed by his sudden unexplained disappearance during a sea crossing in 1938.

Stylistically, Jayawardhana displays an element of "writing by numbers" in the early chapters. It is common in popular science books to start a chapter with a personal cameo from a key character's life, but in the opening chapter the anecdote has nothing to do with the topic of the book. References to science fiction are another popular science mainstay, but where it's obvious that an author such as Michio Kaku employs this tactic because he loves the genre, in this case a reference to Isaac Asimov's rules of robotics is mishandled, since Jayawardhana attributes them to Asimov's *Foundation* series rather than the Susan Calvin/US Robots and Mechanical Men stories where they originated.

Soon, however, Jayawardhana settles down to a solid, readable style. The book's content, meanwhile, is excellent, piling in plenty of interesting detail and interlacing stories of neutrino detection (and their implications for fundamental physics and cosmology) with entertaining facts.

Neutrinos' strange ability to change form shakes up the Standard Model of particle physics

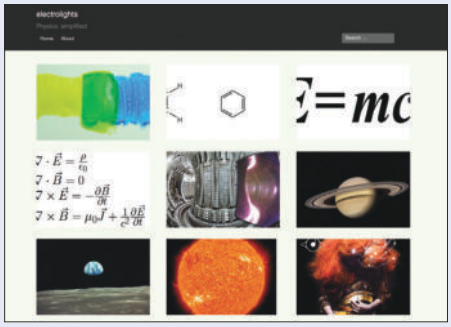
For example, we learn that the physicists building the CUORE observatory at Gran Sasso in Italy needed to shield their experiment with lead to keep out stray radioactivity. But freshly mined lead is itself radioactive, so the team made use of nearly 10 tonnes of lead ingots from the wreck of a ship that sank off Sardinia 2000 years ago.

The only criticism I have of the book's science is that Jayawardhana sometimes oversimplifies. So, for instance, he mentions that the Japanese Super-Kamiokande detector might be improved by dissolving a little gadolinium in its vast tank of water as this "would enhance the detector's sensitivity to relic neutrinos". What is never explained is *why* the metal would make any difference to the ability to distinguish the "relic" neutrinos – which are left over from supernova explosions – from other types.

Neutrinos have long been underrepresented in popular science writing, with the only serious competition coming from Frank Close's *Neutrino* (December 2010 p45). Close is better on the science, but *The Neutrino Hunters* gives an excellent picture of the hunt itself and of its implications for physics and cosmology, as we find out more about these fascinating, elusive particles.

Brian Clegg is a science writer based in Wiltshire, UK, and the author, most recently, of *Dice World* (2013 Icon Books), www.brianclegg.net

Web life: *electrolights*



URL: http://electrolights.wordpress.com

So what is the site about?

The *electrolights* blog aims to "explain day-to-day phenomena in simple terms and [show] that physics, though mind-boggling sometimes, is really about the basic things in life". The blog is aimed at non-experts, especially students, and is written in a straightforward style reminiscent of the *Simple English Wikipedia*, which is designed to be understood by children, adults who are trying to learn English and people with learning difficulties.

What are some of the topics covered?

Although some posts do indeed focus on the physics of everyday things, such as compact discs, the subject matter of others is decidedly more esoteric, with black holes, double-slit experiments and the theory of relativity all covered. Posts about conventional physics often put a fresh spin on the topic. For example, a May 2013 post about "Weighing the Earth" does a nice job of framing the difference between weight and mass, noting that "to weigh something, anything, means to determine the force being exerted on that thing by another body...You can't have a body in isolation, in *complete* isolation, away from any other planet, star or galaxy, in the depths of vacuous space and talk about its weight". However, it continues, "that isolated body will have a mass, regardless of it being on its own or not". Another great example is a February 2014 post about addition and subtraction, which reveals that even the most straightforward mathematical operations have unexpected depths.

Who is behind it?

The author of *electrolights* is Swetam Gungah, a London-based mathematical physicist who has made his career in the financial industry and is currently director of business development at S&P Capital IQ. A staunch advocate of science outreach, Gungah also occasionally writes for the Institute of Physics-supported blog *physicsfocus* and gives talks around the UK about the importance of physics and other STEM (science, technology, engineering and mathematics) subjects.

Can you give me a sample quote?

From a July 2012 post entitled "Bright", which begins with the causes of the seasons and then moves on to discuss the challenges of using solar energy: "In a matter of days...the Earth will be at its furthest from the Sun. Yet, in the Northern hemisphere, summer temperatures will be in the mid-20s Celsius. Isn't it strange that it's hotter in the Northern hemisphere when the Earth is actually furthest from the Sun? Shouldn't it be cooler instead? Had things been plain and simple, that's how you would expect the temperature to vary: the closer one is to the Sun, the warmer one should be. ..But things aren't that plain – though they can still be simple – and therefore it is the *tilt* of the Earth that determines the season, not its distance from the Sun. Had the Earth not tilted at 23.5° from the vertical, the seasons would have been pretty much non-existent. A minimal and boring hot/cold variation would have prevailed throughout the year depending on how far the Earth was from the Sun as opposed to how much it was leaning off its axis of rotation."

Jeff Hecht

Edible lasers and death rays

Jack Fields/Science Photo Library

Playing with light
US physicist Arthur Schawlow with a laser ray gun. Schawlow set out to prove that "anything will lase", as Stephen Wilk's new book recounts.

How the Ray Gun Got its Zap: Odd Excursions Into Optics
Stephen R Wilk
2013 Oxford University Press
£18.99/$34.95hb
256pp

"Optics is light work" was one of Arthur Schawlow's favourite slogans, and it didn't just appear on the T-shirt he wore while giving lectures at Stanford University. Schawlow, who shared the 1981 Nobel Prize for Physics for developing laser spectroscopy, was a playful physicist who concocted novel experiments to amuse as well as educate. So it's probably inevitable that there's a Schawlow story in *How the Ray Gun Got Its Zap*, Stephen Wilk's collection of "odd excursions into optics".

The Schawlow story Wilk picks is a gem, though. In the decade after the first laser was demonstrated in 1960, so many different materials were made into lasers that Schawlow concluded "anything will lase if you hit it hard enough". To prove this, he and Theodor Hänsch (then a young postdoc, later a Nobel laureate himself) decided to fire pulses of light at brightly coloured Jell-O brand gelatine desserts, in the hope of making an "edible laser". None of the 12 flavours they bought in the supermarket would lase, but they eventually succeeded by adding a dye, sodium fluorescein, to unflavoured gelatine. Schawlow called the result "almost non-toxic", but declined to eat the experiment afterwards.

After recounting this tale, Wilk, an optical engineer, goes in search of the truly edible "gin and tonic laser" he heard about as a doctoral student. Eventually, he traces the story to an experiment at Eastman Kodak labs, where two researchers found that very fast flashlamps could indeed excite blue laser pulses from an unidentified brand of tonic water. It didn't make a good laser, Wilk observes, but it does make a fun story.

Wilk's interest in such fun stories makes his book an entertaining tour of history's optical oddities. The most intriguing mystery of ancient optics concerns Archimedes: did the great proto-physicist really mastermind the burning of a fleet of Roman ships by focusing sunlight onto them with polished shields? The surviving written evidence is scanty, and scientists and engineers have tried to resolve the question for centuries. A long list of experiments shows disconcertingly wide variations. The results ranged from modest heating to conflagration, often in keeping with what the experimenters hoped to find, so the question may be among the great unanswerables. All history has to say is that whether or not the Greeks burned some of their ships, the Romans ultimately won.

Many of the book's essays answer odd questions raised by curious minds, such as why we think the Sun is yellow despite the fact that sunlight is, by definition, white light. That's a puzzler to ponder, and Wilk points out flaws in three common explanations before concluding that the Sun looks yellow to the eye because the atmosphere scatters blue light across the sky. But that's not quite the whole story, he adds, because when the Sun is high in the sky, too little blue light is scattered to make the Sun look yellow. The impression of a yellow Sun comes when it is low enough in the sky to glance at briefly, but not so low that it looks orange or red to the eye – colours that we know to be wrong.

Another, similar, essay concerns the number of colours in a rainbow. As a child, Wilk was told there were seven, but as he writes, "My old Crayola crayon box held 64 colours." To resolve this paradox, he digs back to – what else? – a three-volume 1858 treatise on the Greek poet Homer. This work devoted a full 42 pages to Homer's use of colour, and thereby launched an ongoing debate over how the ancients described it. The division of the spectrum into seven colours is sometimes linked to an attempt to mirror the seven notes of the musical scale, but Wilk traces it instead to a decision Isaac Newton made while writing his definitive treatise *Opticks*. In some places Newton listed only the colours red, yellow, green, blue and violet, but in others he added "orange" and "indigo". Orange was soon ensconced as a definitive colour, but the distinction between blue and indigo is so subtle that indigo is often lost – except when an "i" is needed to

make the colour mnemonic "Roy G Biv" pronounceable.

The book's title comes from a wonderful chapter in which Wilk traces the history of fictional "death rays" back more than 200 years, to an 1809 novel in which the author Washington Irving – best known for *The Legend of Sleepy Hollow* – armed his interplanetary invaders with beams of concentrated sunlight. The "heat rays" of H G Wells' better-known Martian invaders did not arrive until 1896. "Disintegrator rays" soon followed, and death rays of various types became standards of pulp-era science fiction, comics and films. In most cases, these rays killed on contact, leaving dead bodies but not the blood and guts of the deadly mechanized warfare that began with the First World War. Quoting the science-fiction critic Peter Nichols, Wilk notes that their invention "may have resulted from a certain squeamishness, since it allows for a maximum of destruction with a minimum of bleeding pieces to sweep up afterwards". As a card-carrying laser and SF geek, I couldn't ask for more.

It's an old-fashioned cabinet of wonders in book form, offered in the spirit of intellectual fun

How the Ray Gun Got Its Zap is not a big-picture, big-issue or deep-thought book. It's an old-fashioned cabinet of wonders in book form, offered in the spirit of intellectual fun. It sent me down to the kitchen to see if my violet laser pointer would stimulate bright fluorescence from any of the leftover Christmas food colouring. The only glimmer of hope was from red cinnamon nonpareils, but I may put some coloured Jell-O on my grocery list.

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Between the lines

Shutterstock/Zinaida Ok

Quantum pioneer
A new book by A Douglas Stone sets out to reclaim Einstein for quantum mechanics.

Einstein's quantum side

The fact that Albert Einstein won his Nobel prize for explaining the photoelectric effect, and not for his special or general theories of relativity, is often regarded as an anomaly. The usual explanation for the Nobel committee's decision is that the scientific establishment of the early 20th century was far too conservative to reward a truly revolutionary theory, so instead, it honoured Einstein for work that was both less controversial and less significant. The solid-state physicist A Douglas Stone, however, takes a different view. In his book *Einstein and the Quantum*, Stone sets out to reclaim Einstein for the other side of modern physics, noting that "for most of us quantum mechanics *is* the theory of everything". The result is a remarkable thing: a book about Einstein that feels fresh, focusing as it does on the master's ideas about statistical mechanics and blackbody radiation rather than, say, space-faring twins and $E = mc^2$. It helps that Stone, a first-time popular science author, is wonderfully quotable, producing such instant gems as "A good experimentalist can also be lucky. A good theorist, on the other hand, has to be right." But really, it's the physics of Stone's book that enchants, as he ushers us through the subtleties of the ultraviolet catastrophe, quantum ideal gases and even Bose–Einstein condensation. Thanks to a few technical passages, the book is probably best suited to readers who are already familiar with the basic principles of late classical and early quantum physics. However, in many cases, Stone's explanations are better and more intuitive than those found in traditional textbooks; for this reason, *Einstein and the Quantum* would make excellent "further reading" for undergraduate courses in thermodynamics, modern physics or the history of science. Stone also has a knack for summing up complex ideas in a way that even novices will understand. At one point, he compares Max Planck's predicament concerning blackbody radiation with that of an undergraduate who turns to the back of their textbook to find a correct answer "but can't quite figure out how to get that answer based on the principles they are supposed to have learned".

● 2013 Princeton University Press £19.95/$29.95hb 344pp

Back to first principles

In any conversation about the philosophy of science, the word "reductionism" is seldom very far from the lips. In the words of Alastair I M Rae, this idea that a system can be understood by "reducing" it to its component parts – and that any physical laws that apply to the parts will also apply to the whole – forms "a central, if often unstated, assumption underlying almost every scientific statement". Despite its importance, however, the term is probably used more often than it is understood. Rae's book *Reductionism* – one of a series of short "beginner's guides" to topics that range from anarchism to volcanoes – aims to address this deficit. In addition to reductionism itself, the book also covers related ideas such as falsification, Occam's razor and the principle of emergence. The last of these ideas suggests that complex phenomena (such as the shapes in a painting) "emerge" from simpler ones (such as individual brush strokes), and it is sometimes regarded as a philosophical challenger to reductionism – at least in the colloquial sense that "the whole is greater than the sum of its parts". Rae, however, is a fully paid-up member of the reductionist fan club, believing that even very complex emergent phenomena, such as human consciousness, can be reduced to basic chemistry and physics, at least in principle. Physicist readers may wish to skim the book's first few chapters, which tell a familiar (if rather comforting) story about how chemical properties "emerge" from the behaviour of individual atoms and electrons. Later chapters on biology and the application of reductionism to quantum measurement will be of greater interest, and Rae's decision to conclude by discussing high-temperature superconductivity – an emergent phenomenon dear to his own heart – is a nice touch.

● 2013 Oneworld £9.99/$14.95pb 224pp

Careers

Serving an ageing population

Gerontechnologist **Lawrence Normie** describes his work on devices that improve the lives and health of older adults

GeronTech

Home help Lawrence Normie has put his defence engineering knowledge to work in assistive technology.

Is it possible, within a few minutes before the event, to predict a fall in someone who has a medical condition affecting their balance and stability? And can these predictions be made reliably enough for preventive measures to be taken? As a "gerontechnologist" working at the Israeli Center for Assistive Technology and Aging, GeronTech, these are the kinds of questions I am attempting to answer. The problem is an urgent one. Each year, falls due to age-related postural and walking instability lead to thousands of serious injuries among people over the age of 60. For people over the age of 75, the statistics are especially disturbing: in around one-third of falls by over-75s that result in a hip fracture, the prognosis is death within 12 months.

Faced with this problem, dozens of groups in academia and industry are attempting to develop ways of preventing falls. Many commercially available devices can already detect falls when they happen, usually via a combination of a tri-axial accelerometer (similar to those found in gaming-console motion sensors) and a digital signal controller programmed with algorithms representing typical acceleration profiles of falls. But being able to predict – and then prevent – a fall *before* it happens is much harder. This is partly because falls among older people have so many causes. For example, they may occur because of a sudden drop in blood pressure, a problem with the inner ear's balance mechanism (vestibular disorder) or the effects of degenerative neurological disorders such as Parkinson's disease. Medications prescribed to manage various age-related diseases can also disturb balance and stability.

The solution we are developing at GeronTech, in common with those of other groups, employs inertial sensors (MEMS accelerometers and rate gyroscopes) along with a suite of physiological sensors that monitor heart and breathing rates, blood oxygen saturation, skin conductivity and muscle tone (via an electromyogram). Eventually, we hope to add piezoelectric sensor arrays embedded in the patient's shoe insoles, in order to monitor relative load distribution on the legs and feet.

We do not expect eventually to incorporate all of these physiological sensors into a commercial device, since they would be inconvenient, cumbersome and uncomfortable to attach every day. Instead, we hope to identify sufficient correlations between salient kinematic and physiological parameters that we can "train" a fall-prediction algorithm to function using data from the less-intrusive inertial sensors alone. For instance, during the moments preceding a fainting or vestibular disturbance episode, we might expect to identify subtle yet characteristic changes in gait and posture that indicate high risk of an imminent fall.

> Gerontechnologists work to improve quality of life among older adults by developing technological solutions

A new and growing field

In general, gerontechnologists work to improve quality of life among older adults by developing technological solutions to problems they experience in daily life. Some of us also work on adapting the environment to be accessible to, and more inclusive of, older citizens and people with disabilities. Familiar examples of "inclusive design" include curb-kneeling buses that enable people in wheelchairs to board, audible signals at pedestrian crossings and large, simplified-format ATM screens for people with impaired vision.

As a formal discipline, gerontechnology is barely 20 years old. It is also highly multidisciplinary, as biomedical, mechanical, electronics and computer engineers work together with ergonomists, industrial designers, psychologists, ethicists and physicists to solve problems. For these reasons, there is no formal qualification that one can obtain to be called a gerontechnologist, and my own route into the field was far from direct.

After completing a BSc in pure and applied physics at the former University of Manchester Institute of Science and Technology (now part of the University of Manchester), I became a systems engineer in the radar guided missiles group at Marconi

Defence Systems. The company supported me through a part-time Master's course in microwaves, communications and modern optics at University College London, and after just over four years I joined a defence consultancy, CAP Scientific. While at CAP I quickly fell into the role of cross-group "house doctor" and troubleshooter for technical problems related to radar, sonar, optical and other types of military sensors.

After immigrating to Israel at the end of the 1980s, I initially joined the naval radar group at Israel Aerospace Industries. But eventually, I decided I'd had enough of the defence industry, so I started a hi-tech industrial consulting partnership with a friend from the UK. As is common in consultancies, my assignments varied a lot, but over the years I became increasingly involved in rehabilitation engineering – a field that concerns the development of technologies to help patients recover their motor, sensory or cognitive function. So when I spotted an advertisement in 1998 for a director to help develop and lead a new centre for assistive technology and ageing, it seemed like a good way of combining my know-how on rehab engineering and the business and marketing experience I had acquired as a consultant.

Varied skill set

As the executive director of a small non-profit research centre, my resources are limited, so my daily responsibilities extend considerably beyond management and administration. Virtually all of the projects we work on, including those where we collaborate with other research institutions, require my hands-on involvement. This makes my job both incredibly interesting and very challenging, as I need to constantly keep abreast of gerontechnology's diverse knowledge areas.

A typical work week entails writing, editing, or reviewing scientific manuscripts, mentoring engineering and industrial design students, writing grant proposals, participating in technical committee meetings, updating the centre's website and – if I am lucky – finding enough spare time to work at the bench on various electronics or electronic encephalography projects. I also spend several weeks each year working as an independent expert for the European Commission's framework programmes for trans-European collaborative research and development, which have allocated considerable sums of money in gerontechnology-related grants over the past decade.

Both my undergraduate training in physics and my postgraduate degree in electronics contributed to the skill set my job requires, and my experience of systems analysis and technical project management has been very useful, too. Perhaps more surprisingly, much of my work in the defence industry has also proved relevant. For example, in addition to the falls prediction system described above, I am developing a nine-degrees-of-freedom inertial sensor body-area network for measuring and logging movement disorder patterns in people with Parkinson's disease. This involves techniques that are similar to those used in the design of inertial guidance systems for aerospace platforms such as guided missiles, since it requires a thorough understanding of (among other things) how to apply Euler angles and quaternions to describe the equations of motion for rigid bodies. In this respect, I like to say that I am turning swords into ploughshares.

To new physics graduates (or postgraduates) considering a career in gerontechnology, I would recommend finding a suitable academic position at one of the many universities, either in Britain or overseas, that have multidisciplinary units working on relevant projects. If you are already enrolled at an institution that operates such a programme, so much the better. A graduate physicist who chooses to work in the field will find that they have considerable flexibility and latitude to specialize in a wide variety of sub-disciplines, many of them well suited to the analytical problem-solving type of training given in physics courses.

For physicists like me who entered gerontechnology mid-career, the academic option may not be feasible. Nevertheless, the world's ageing population means there is a growing demand for a physicist's skills among private research institutions, start-up companies and even some large consumer electronics and telecommunications firms that engage in gerontechnology R&D. If you have acquired management, marketing and perhaps also legal experience along the way, opportunities in the field are even broader. The gerontechnology field is still young and flexible enough to accommodate the skills of a physicist in numerous roles, as we seek to meet the challenge of ageing well.

Further information

If you want to know more about gerontechnology, I recommend the following organizations:

- The **International Society for Gerontechnology** (ISG)

Founded in the early 1990s by a group of like-minded engineers, scientists and psychologists, the ISG convenes a biennial international conference, organizes regular master classes for PhD students and publishes a quarterly peer-reviewed journal, *Gerontechnology*, of which I am an associate editor. (www.gerontechnology.org)

- The **Gerontechnology (ISG) LinkedIn group**

I administer this group, which currently has more than 900 members, on behalf of the ISG (you don't need to be a member of the ISG to join). The group provides a platform to exchange information and opinion (usually based on current and topical news items from the academic and clinical literature) and also hosts notifications about meetings and conferences.

- The **Association for the Advancement of Assistive Technology in Europe** (AAATE)

Like the ISG, the AAATE holds regular conferences and workshops, and it also publishes a peer-reviewed journal, *Technology and Disability*. (www.aaate.net)

Lawrence Normie is executive director of GeronTech in Jerusalem, Israel, www.gerontech.org, e-mail lrnormie@gerontech.org.il

Once a physicist: Tom Brake

Tom Brake is the member of parliament for Carshalton and Wallington and deputy leader of the UK House of Commons

Why did you decide to study physics?
I had an aptitude for maths and physics, and I got interested in astronomy. I went to school in France, and I did a dissertation on astronomy for my International Baccalaureate, which is what I studied rather than A-levels. Then some lecturers from Imperial College London came over to France and explained why Imperial College was the best place in the UK to do physics, so a friend of mine and I decided that that was what we wanted to do.

What did you do after graduation?
When I graduated in 1983, the options for physics graduates seemed to be accountancy, IT, defence or further study. I opted for the IT stream in part because that's what my father did, so I had an appreciation for what was involved; I suppose there was also the intellectual challenge of making systems work. Later, my role became more about managing people, and that was something I really enjoyed.

What sparked your interest in politics?
The early 1980s were a very political period for the UK. Margaret Thatcher had a straightforward effect on people: they either loved her or they hated her. I fell into the latter category, although looking back on what she achieved, my views have mellowed slightly. But it felt like a very difficult time for the UK, and that motivated me to get involved.

There were also a couple of policy issues that I was concerned about. One was the environment. Back then, the main environmental challenges we faced were things like acid rain and the potential environmental disaster associated with a possible nuclear war. That's not something people think about nowadays, but in the 1980s it was a realistic prospect, and the environmental consequences would have been horrendous.

The other big issue for me was Europe. Because I'd lived and studied in France, I felt an affinity for Europe, and since Europe was and is the UK's biggest trading partner, it's important that we have a good, strong relationship. I joined the Liberal Party (now the Liberal Democrats) because I thought it had the best policies on the environment and Europe, along with a pragmatic approach to other issues.

How (if at all) has your physics background helped in your career?
Insofar as my physics studies led me into working in IT, and to adopting a methodical, rational approach to resolving problems, I think it has helped. I'd like to think that that attitude has fed through into the way I do politics, at least in terms of making sure there are always clear priorities and targets, and understanding that things have to be measured before you can tell whether a policy's been effective.

Any advice for today's physics students?
In the UK, we require a very large number of science graduates to support research and manufacturing, and I think there's a real potential, from a jobs point of view, for people to get involved in the sciences. So I'd encourage them to do that. But if any students or graduates are worrying that studying physics at university might preclude them taking up a political career in the future and becoming a government minister – well, I can demonstrate that they should have no such concerns!

Next month in Physics World

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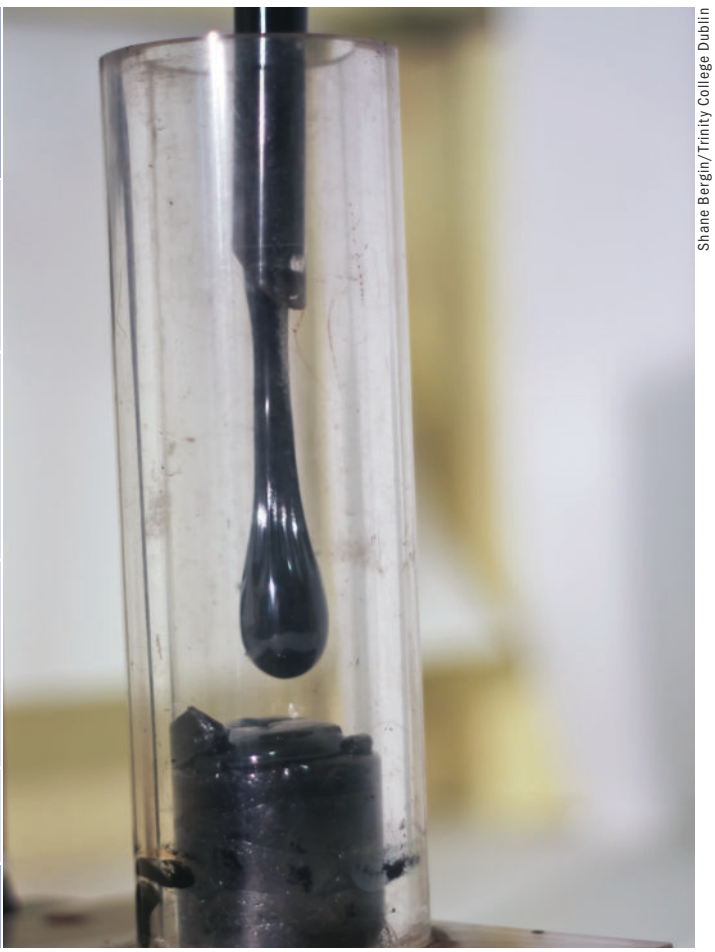

Shane Bergin/Trinity College Dublin

Careers and people

Movers and shakers

Two groups of optical scientists have been awarded shares in the 2014 Rank Prize for Optoelectronics. **Alf Adams**, **Eoin O'Reilly**, **Gordon Osbourn** and **Eli Yablonovich** were honoured for their work on strained-layer laser structures, while **Leo Hollberg**, **Svenja Knappe** and **John Kitching** received the award for developing an atomic clock on a chip.

The Hawaii-based W M Keck Observatory is searching for a new leader after its current executive director, **Taft Armandroff**, announced that he will step down in June in order to take up a post at the University of Texas at Austin, US.

Frédérick Bordry, who was previously head of the technology department at CERN, has become the centre's new director of accelerators and technology.

Theoretical physicist **Alessandra Buonanno** of the University of Maryland, US, has been named as the next director of the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Potsdam, Germany. She will take over from founding director Bernard F Schutz in September.

Italian particle physicist **Tiziano Camporesi** has been elected as the new spokesperson for the CMS experiment at CERN's Large Hadron Collider, replacing American Joe Incandela, who had led the collaboration since 2011.

Meera Chandrasekhar, a physicist and educator at the University of Missouri, US, has received one of the country's most prestigious teaching prizes, the $250 000 Baylor University Robert Foster Cherry Award for Great Teaching.

A trio of UK-based climate scientists – **Peter Cox** of the University of Exeter, **Gabriele Hegerl** of the University of Edinburgh and **Doug Parker** of the University of Leeds – have received Wolfson Research Merit Awards from the Royal Society, along with mathematical physicist **Ernesto Estrada** of the University of Strathclyde, nanoscientist **Anatoly Zayats** of King's College London and 16 scientists from other disciplines.

Ronald Ekers, a Fellow at the Australia Telescope National Facility, has won the American Astronomical Society's Grote Reber Gold Medal for his contributions to radio astronomy.

The American Astronomical Society has given its highest honour, the Henry Norris Russell Lectureship, to the Harvard University astrophysicist **George Field**, for "a lifetime of contributions to our basic understanding of diffuse plasmas in the universe".

Cosmologist **Carlos Frenk** and planetary scientist **John Zarnecki** have received the Royal Society of Astronomy's highest honour, the Gold Medal, for lifetime contributions to astronomy and geophysics, respectively.

A metallurgist dubbed "Mr Rare Earth" for his expertise on this group of metals has won the 2014 Acta Materialia Materials and Society Award. **Karl Gschneidner**, a materials scientist at Iowa State University in the US, was honoured for bringing attention to an impending squeeze on the supply of rare-earth elements (February 2011 p17).

Crystallographer **Frank Hawthorne** of the University of Manitoba, Canada has won the Mineralogical Society of America's Roebling Medal for his work on the structure and chemistry of minerals.

Physicist **Tim Holt** has received the Fraunhofer Medal for his role in establishing Glasgow's Fraunhofer Centre for Applied Photonics as the first UK branch of Germany's Fraunhofer Society. Following Holt's retirement in December 2013, **Simon Andrews** was named as the new executive director of Fraunhofer Research UK Ltd.

Atomic physicist **Deborah Jin** of the US National Institute of Standards and Technology in Boulder, Colorado, has won the 2014 Comstock Prize in Physics for her studies of quantum degenerate gases and quantum chemistry in polar molecules.

University of Maryland geophysicist **Vedran Lekic**, whose research interests include using neutrinos to map the decay of radioactive elements far below the Earth's surface, has received the Charles F Richter Early Career Award from the Seismological Society of America.

Nanoscientist **Laura Na Liu** of the Max Planck Institute for Intelligent Systems in Stuttgart, Germany, is among 10 early-career researchers to receive the Heinz Maier-Leibnitz Prize from the German Research Foundation (DFG) in 2014.

The Royal Swedish Academy of Sciences has selected **Peter Molnar**, a geophysicist and seismologist at the University of Colorado at Boulder, US, as the recipient of its Crafoord Prize in Geosciences 2014.

Geoff Pryde of Griffith University in Queensland, Australia, has won the Australian Academy of Science's top award for early-career researchers, the Pawsey Medal, for his work on optical quantum computing.

Nanophysicist **Federico Rosei** of the INRS Énergie Matériaux Télécommunications Research Centre, Quebec, has received the E W R Steacie Memorial Fellowship from Canada's Natural Sciences and Engineering Research Council.

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The art of falling fluid

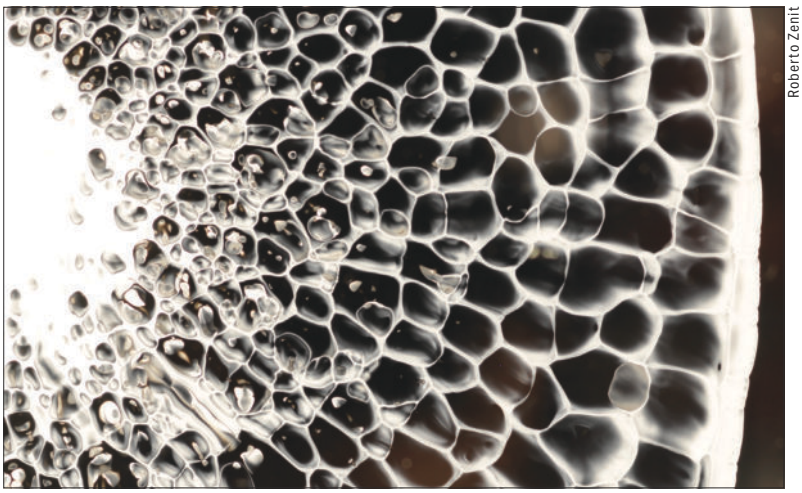
When Jackson Pollock first dripped paint onto horizontal canvases to create works such as *Autumn Rhythm* (1950, MoMA), he became the founding spirit of a major art movement, Abstract Expressionism. Art historians have studied the intricate, looping patterns in Pollock's work ever since but, on occasion, his paintings have also attracted attention from scientists.

One approach, originated by Richard Taylor, has been to subject Pollock's work to fractal analysis (September 2013 pp37–41). In 2011, however, a trio of researchers – physicist Andrzej Herczyński, art historian Claude Cernuschi and mathematician L Mahadevan – examined the fluid dynamics of the paint itself. They studied how it behaved as Pollock dipped an implement into a can of paint, then wielded the tool to allow the paint to fall onto the canvas below. They concluded that Pollock controlled the paint as it descended under gravity, rather than letting it pour randomly. The process, the researchers suggest, should be called "streaming" rather than "dripping" because it produced continuous well-defined lines, not spatters.

These insights were given added meaning in 2012, when art historian Sandra Zetina and physicist Roberto Zenit of the National Autonomous University of Mexico (UNAM) reported a fluid-dynamics study of another iconic artist, David Alfaro Siqueiros. A leader of the Mexican muralist movement, which carried great artistic and social weight from the 1920s to the 1940s, Siqueiros was one of the trio of great Mexican painters known as "Los tres grandes" (Diego Rivera and José Clemente Orozco were the others). Siqueiros was a true revolutionary: a devoted communist, in May 1940 he tried but failed to assassinate Stalin's enemy, Leon Trotsky, and he sought novel technology for art with the same revolutionary fervour. For example, in his painting *Collective Suicide* (1936, MoMA), Siqueiros used a quick-drying automotive paint developed by the Ford Motor Company to produce attractively complex abstract patterns. These patterns resulted from Siqueiros' "accidental painting" technique, in which he put a layer of paint atop another layer of a different colour. The colours automatically interpenetrated to produce what Siqueiros called "the most magical fantasies and forms that the human mind can imagine".

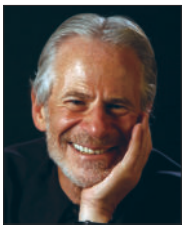
Zetina and Zenit hypothesized that these forms arise from the Rayleigh–Taylor (RT) instability in fluids. Named after the British scientists Lord Rayleigh and Geoffrey Taylor, this phenomenon arises when a horizontal layer of fluid supports another layer of denser fluid. This situation is inherently unstable, like a big boulder insecurely perched on a small rock. The slightest irregularity at the interface of the two fluids will cause gravity to pull the denser fluid into the less dense one. This produces complex turbulent extrusions that take on fantastic shapes in both fluids.

To test the theory, Zetina and Zenit simulated Siqueiros' method in a controlled manner by putting a layer of white paint on a layer of less dense black paint (see above right). As their video (http://ow.ly/sGn6S) of the resulting evolution shows, what emerges is a beautiful, unpredictable pattern that resembles those in *Collective Suicide* and obeys the mathematics of RT instability.



Roberto Zenit

The slightest irregularity at the interface of the two fluids will cause gravity to pull the denser fluid into the less dense one, producing complex turbulent extrusions



What does this have to do with Jackson Pollock? Remarkably, despite their different national origins, Pollock encountered Siqueiros and his methods early in his career. In the same year that Siqueiros created *Collective Suicide*, he also ran an experimental workshop in New York to introduce his novel methods to other artists – including a 24-year-old Pollock. The attendees probably saw *Collective Suicide*, but during the workshop, they did more than just experiment with RT instability. As one of them wrote, "We sprayed [paint]…used it in thin glazes or built it up into thick globs…we poured it, dripped it, spattered it, hurled it at the picture surface."

According to Helen Harrison, director of the Pollock-Krasner House and Study Center in East Hampton, New York, this early exposure to paint in motion was important in developing Pollock's technique. In her book *Jackson Pollock* (Phaidon Press, 2014), Harrison notes that Pollock knew of Siqueiros' unconventional approaches before the 1936 workshop. Nevertheless, she observes, Pollock's brother Charles put great weight on the influence of that workshop, which he considered "a key experience in Jackson's development" that "must have stuck in his mind to be recalled later, even if unconsciously, in evolving his mature painting style".

Physical analysis illuminates the ways that both artists used a natural effect – fluids falling under gravity – to produce their works. However, it does not explain everything, since the artists also made creative choices. Siqueiros declared, correctly, that his patterns were made by the paint itself, and so accepted the resulting unpredictability. Pollock, on the other hand, based his approach on apparently haphazard but actually well-controlled streams of paint falling through air. As he put it, "I can control the flow of paint: there is no accident." And by itself, the physics of fluids cannot answer another important question: why are we pleased by Siqueiros' turbulent patterns and Pollock's looping ones? The answer may have to wait until we can complement physical analysis with a true neuroscience of aesthetics – if this ever becomes possible.

Sidney Perkowitz is a physics professor emeritus at Emory University in Atlanta, Georgia, US. His recent books include *Hollywood Chemistry* and *Slow Light*, www.sidneyperkowitz.net

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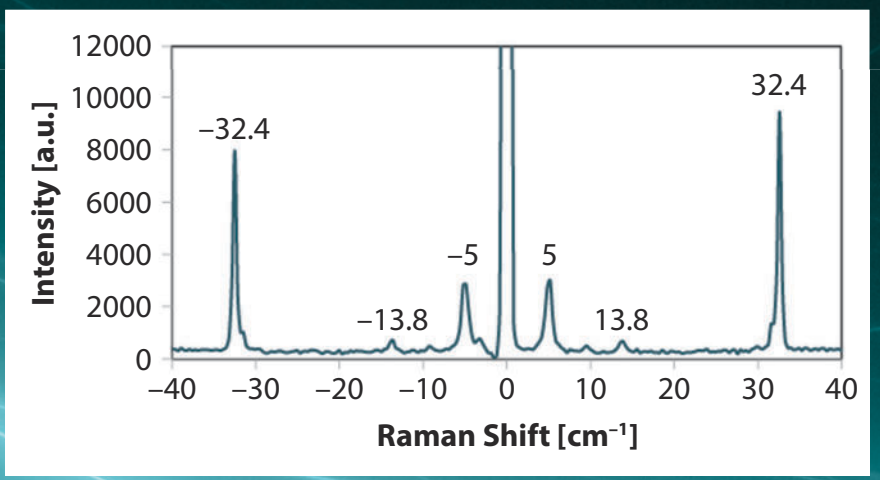

Raman spectrum of several layers of MoS_2 flakes measured at 633 nm with BragGrate™ Notch filters and single stage spectrometer

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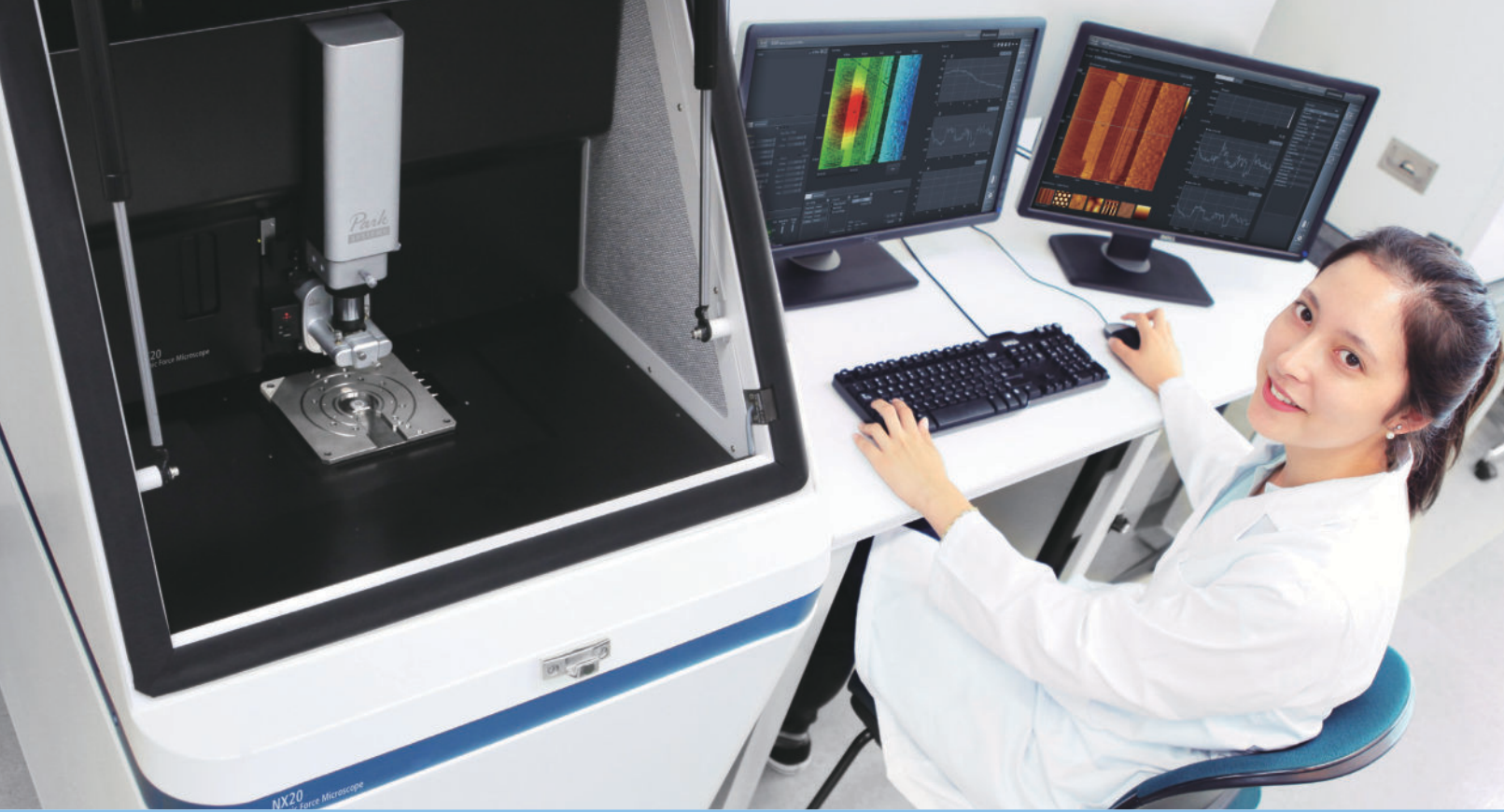

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