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In search of black swans

How to support revolutionary ideas

Financial irrationality Modelling the real economy

Zitterbewegung anyone? The impact of the German language

Pressured environment Probing inside planets

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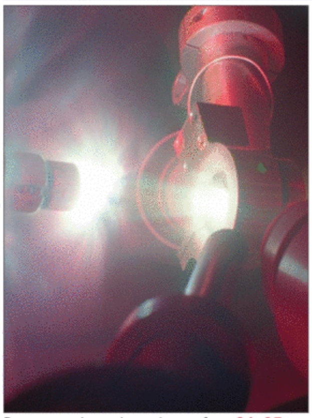
Eugene Kowaluk, University of Rochester

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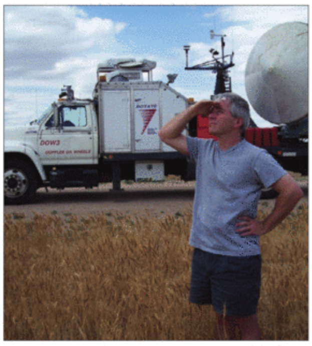
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Features

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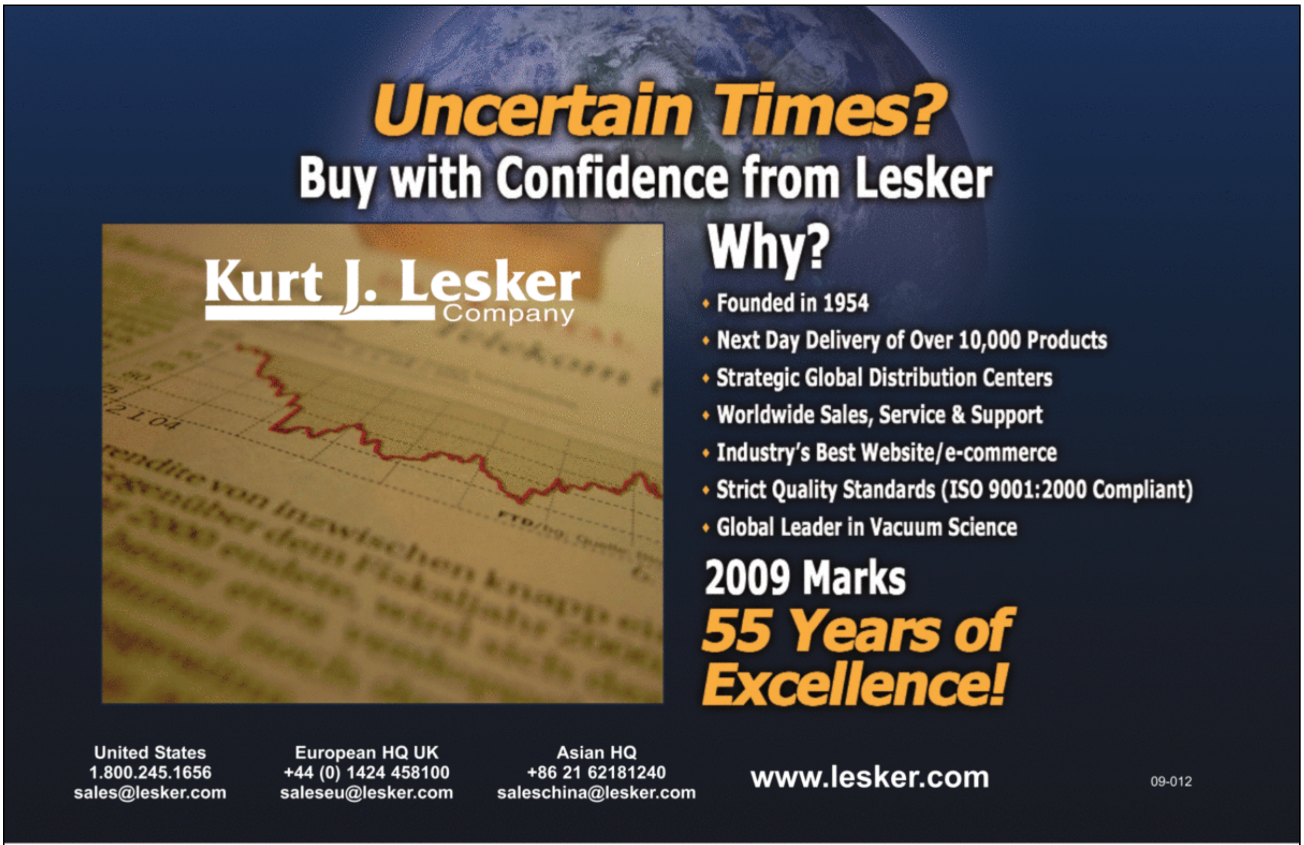
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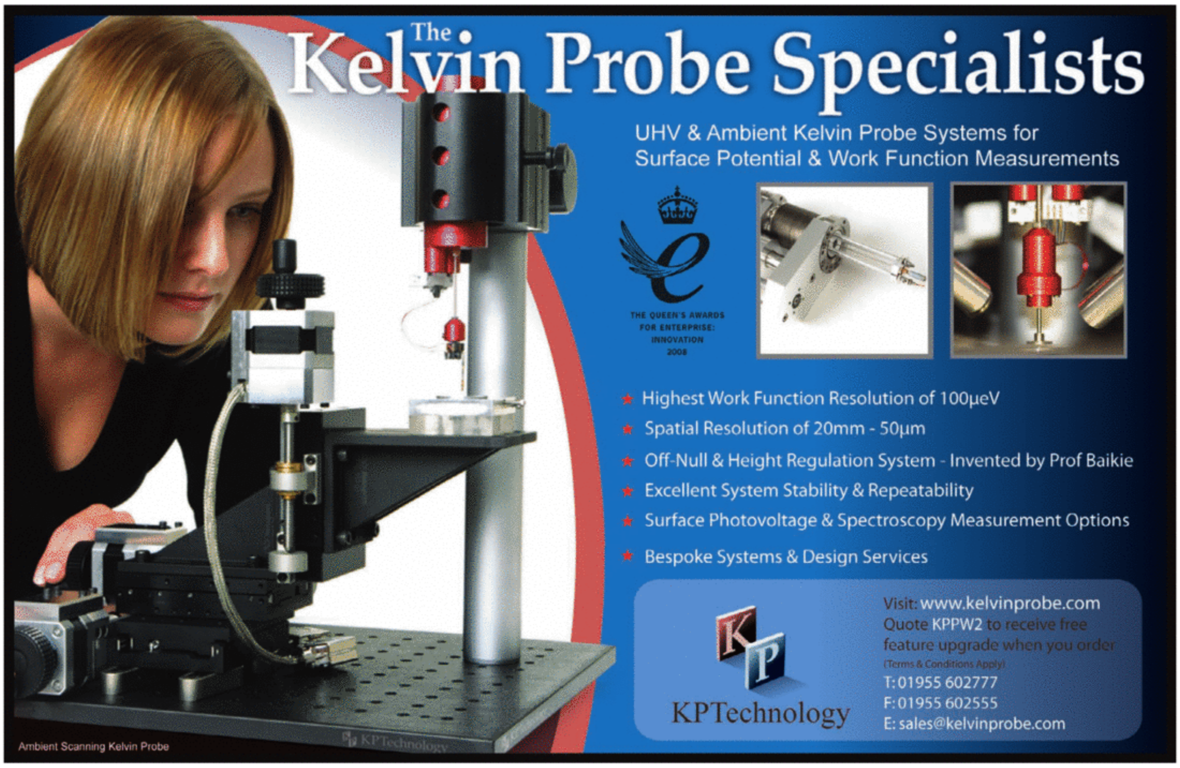
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For the record

I think physicists should go back to the physics department and leave Wall Street alone

Nassim Nicholas Taleb *from New York University quoted in the* New York Times
Taleb, a former trader and author of the bestselling book *The Black Swan*, says that the odds of predicting one-off events such as "Black Monday" are much greater than physicists' models predict.

We will not allow science to become a victim of the recession

UK Prime Minister **Gordon Brown** *in a speech at Oxford University last month*
Speaking to students, Brown pledged to protect science funding during the economic downturn.

As a physicist, I am concerned that some sceptics are ignoring the physical basis

Fred Singer *from the University of Virginia quoted in the* New York Times
More than 600 climate sceptics met at a conference in New York last month to challenge what is now a growing scientific consensus that without a change in our energy consumption the planet will dangerously heat up.

It was the Clangers who saved me

Space scientist **Maggie Aderin-Pocock** *from Astrium Ltd quoted in the* Daily Telegraph
Aderin-Pocock cites the classic kids' TV show *The Clangers*, which featured pink, mouse-like creatures living under a planet's surface, as what influenced her into becoming an astronaut.

He knew that the free world might depend on whether or not he did a great job

Baritone **Gerald Finley** *quoted in the* Guardian
Finley, who plays Robert Oppenheimer in John Adams' opera *Doctor Atomic*, says it is far more interesting for the audience to see the dilemmas the characters in the opera face rather than just a documentary of the events.

They are trying to create an artificial reality

James Kakalios *from the University of Minnesota quoted in* Forbes.com
Kakalios advised the creators of the recent film *Watchmen* about some of the science behind the movie. He thinks that the more a film can be supported by accurate science, then the more authentic it looks.

Seen and heard

Larripin Labs

In stitches

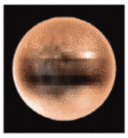
Calling all needlework lovers! Want to create a cross-stitch portrait of your favourite physicist? Well now you can, thanks to online retailer Larripin Labs. For only $10 you can choose between a head-and-shoulders pattern of Richard Feynman, Erwin Schrödinger or Michio Kaku. But do not expect to get sent an already completed item: $10 only gets you a PDF file, which includes instructions containing two charts showing you where to put the crosses and which colours to use to create your 15 cm by 10 cm cross-stitch masterpiece. If your favourite physicist is not included in the above list, do not worry, as LarripinLabs, which is supposedly the "home of the cross-stitched physicist", is also planning to add more patterns soon, as well as an astronaut series. Nice.

Flat-packed living

Most students enjoy leaving home to go to university, revelling in their new-found independence and freedom. That usually means living in a hall of resident or a shared student flat. But some of the 7000 students in the French city of Le Havre will soon be housed in metal containers that are normally used for freight. The so-called container-flats will be piled three to five storeys high and constructed before the start of the next academic year. Students will have to fork out €250 a month in rent to live in one of the 27 m^2 "apartments", each of which costs about €30 000 to build. Thankfully, the flats will be thermally isolated, heated, sound-proofed and even boast windows and a bathroom, so perhaps they are not so bad after all. Whether the wi-fi will penetrate the containers, as claimed, remains to be seen.

A year in the making

How long does it take to come up with a new definition of a word? A few weeks, or perhaps a month? Not for the UK's Science Council, an organization representing over 30 learned and professional scientific bodies, which has spent a whole year deciding on a new meaning for the word "science". It decided to redefine science in an attempt to provide a distinction between genuine science and pseudoscience. The final definition, according to the council's top minds, is that "science is the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence". There are some subtle distinctions to the definition in *The Chambers Dictionary*, which says that science is "knowledge ascertained by observation and experiment, critically tested, systematised and brought under general principles, [especially] in relation to the physical world". The biggest differences are that the Science Council says that science is the "pursuit" of knowledge rather than that "ascertained", as well as the inclusion of the "social" world. So *Physics World* readers, what do you think of the definition? Can you do better? But please don't take a year to decide!



Still a planet

The US is famous for its quirky local laws, and the state of Illinois is no exception. In the town of Zion, it is apparently illegal for anyone to give lighted cigars to dogs, cats and other domesticated animals. Now law-makers in that state have turned their attention to the status of Pluto – discovered in 1930 by Illinois-born Clyde Tombaugh – which in 2006 was downgraded to "dwarf planet" status by the International Astronomical Union. In a resolution passed on 26 February, the Senate decreed that Pluto should revert to full planetary status. So next time you are in Illinois, do not refer to the ninth planet as a dwarf or you could be singing the blues in the Joliet Correctional Center for running foul of the following: "Resolved, by the Senate of the ninety-sixth general assembly of the State of Illinois, that as Pluto passes overhead through Illinois' night skies, that it be re-established with full planetary status, and that 13 March 2009 be declared 'Pluto Day' in the State of Illinois in honor of the date its discovery was announced in 1930."

Frontiers

In brief

Molecular junctions make a switch

Physicists in the US have revealed how to make molecular junctions turn on and off using the tip of a scanning tunnelling microscope (STM). The researchers bonded the gold tip of an STM to a gold surface with a single "bipyridine" molecule. They found that when the molecule is bonded to the STM at an angle, the resistance is low and the junction is "on"; but when it is bonded vertically, the resistance is high and the junction is "off". Moreover, they were able to switch the junction on and off simply by pushing and pulling the STM tip (*Nature Nanotech.* doi:10.1038/nano.2009.10).

Quantum friction may not exist

Physicists in the UK claim that quantum friction does not exist. In the past, researchers had predicted that it would exist between surfaces moving past each other, as a result of the attractive "Casimir force" between the surfaces. However, previous calculations all used certain approximations. In the new study, the researchers say that they have found a way to calculate the Casimir force without approximations and that this equates to zero lateral force. If so, then it is potentially good news for nanomachines, which would have their motion hindered by the effect (*New J. Phys.* at press).

Harder than diamond

Researchers in China and the US believe that a mineral called lonsdaleite might actually be harder than diamond. Their calculations suggest that the very act of indenting lonsdaleite causes it to undergo a phase transition into a structure that is 58% harder than diamond. They came to this conclusion after finding that a related mineral called wurtzite BN is slightly harder than diamond, a new world record. Unfortunately, the production of lonsdaleite requires energies verging on those in meteorite impacts, which means the material may not see widespread applications in industry anytime soon (*Phys. Rev. Lett.* **102** 055503).

Ice exposes ancient supernovae

Researchers in Japan have found the signature of ancient supernovae in the Antarctic ice. By analysing cores of ice dating back centuries, the researchers found a high concentration of nitrate ions at certain depths that seems to correspond to the brightest supernova on record in 1006 and another 48 years later that created the Crab Nebula. The nitrate ions are thought to be produced when intense gamma rays from the supernovae strike the atmosphere and can make their way into the ice via circulating air currents (arXiv:0902.3446).

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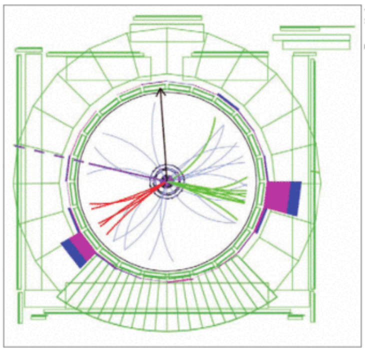
Top result for two Tevatron teams



Fermilab

Hit single This collision display from the CDF experiment shows a single top-quark candidate event.

Researchers using the Tevatron particle collider at Fermilab in the US have obtained unambiguous evidence that the top quark can be produced individually rather than in pairs. The discovery, which was made independently by both the CDF and D0 experiments, fills an important hole in the Standard Model of particle physics (arXiv:0903.0885; arXiv:0903.0850).

The top quark is the heaviest of the six known quark flavours. Discovered in 1995, also by CDF and D0, it completes the "three generation" structure of the Standard Model wherein the up and down quarks that make up ordinary nuclear matter have heavier copies: charm and strange, top and bottom. The top quark has only ever been produced in pairs with its antimatter partner, a process that involves the strong nuclear force. However, the Standard Model also predicts that the top quark is sometimes also produced singly via the electroweak force, for example when a proton–antiproton collision produces an excited W-boson that decays into a top and a bottom quark.

As the final decay states of top quarks mimic the signature of the Standard Model Higgs boson, the new results make it seem more likely that the Tevatron will be able to glimpse the Higgs while the Large Hadron Collider at CERN is being repaired. "We would not be able to claim evidence for a low-mass Higgs if we did not first observe the production of single top quarks," says D0 spokesperson Darien Wood.

The rate at which single top quarks are produced gives a direct measurement of V_{tb}. This is one of the elements in the 3 × 3 "CKM mixing matrix" that describes how quarks transform into different flavours via the weak force. V_{tb} now appears to be closer to one than to zero, which strongly disfavours the existence of a fourth generation of quarks.

Although the Fermilab researchers first reported evidence for the production of single top quarks in 2007, the past 18 months have allowed the experiments to record double the number of proton–antiproton collisions. The extra data have given each result a statistical significance of over five standard deviations. As a result of this discovery, the researchers have also excluded the mass range 160–170 GeV for the Higgs.

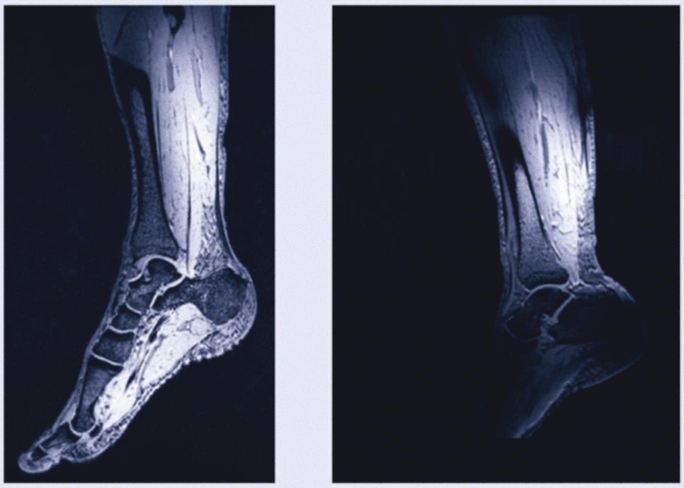
Fermi surface unmasked

For nearly three decades, scanning tunnelling microscopes (STMs) have been used to study the surfaces of metals and semiconductors, but now physicists in Germany have discovered that the instruments can be used to measure the behaviour of electrons lying much deeper inside. The researchers say their technique could offer a new way of measuring the "Fermi surface" between occupied and unoccupied electron energy states.

An STM works by placing a metal tip that is just one atom thick very close to the surface of a sample. When a voltage is applied between tip and sample, electrons tunnel into or out of the material. The size of the tunnelling current is related to the surface properties of the material, such as the locations of individual atoms.

Alexander Weismann and colleagues at the University of Göttingen, the Institute for Solid State Research in Jülich and the Martin Luther University in Halle were using an STM to study minute cobalt impurities on the surface of copper when they found an unusual pattern in the tunnelling current. The electrons injected from the STM tip should have rippled through the metal in wavefronts, which get scattered back to the surface only from impurities. However, Weismann and colleagues found that the interference pattern from the scattering corresponded to the underlying symmetry of the copper's crystalline lattice. The researchers think that this is because the ripples were focused along certain directions in the copper as defined by the shape of the Fermi surface (*Science* **323** 1190).

Team member Martin Wenderoth says that the technique could be used study local variations in the shape of the Fermi surface, as well as the layered magnetic structures that are used in giant magnetoresistance read heads for computer hard drives.



MRI gets new legs

You do not have to be a medical physicist to appreciate that the scan on the left is of higher quality than the one on the right. This improvement is possible thanks to a development by biomedical engineers based in Switzerland, who have designed a new way of using magnetic resonance imaging (MRI) to produce images of more uniform quality. In a standard MRI scan, a magnetic field is applied to the body causing the magnetic moments of the hydrogen nuclei it contains to align. A standing radio wave is then applied to the nuclei that knocks the moments out of alignment. Finally, as the hydrogen atoms relax, they emit radio waves, which can be mapped to form images of the interior of the body. One problem with the existing approach is that as the radio waves only have a short range, the coils used to produce them have to be positioned just a few centimetres away from the body. Now, in a radical overhaul of the process, David Brunner and colleagues at the University of Zurich have used a travelling radio wave instead. They transmit the radio signal with an external antenna and use a cylindrical conducting tube that lines the MRI machine to act as a waveguide. This means that there is more space inside the machine for the patient, and as the radio transmitter is well away from the patient, it is easier to image large areas of the body. The technique requires strong 7 T magnets, which also means clearer images (*Nature* **457** 994).

An eye on entanglement

Experiments that reveal the weirdness of the quantum world usually involve precise and highly specialized equipment. But now physicists in Switzerland and the UK have proposed a way of using human vision to observe entanglement. The experiment, which has yet to be performed in the lab, would involve entangling a pair of photons and then creating thousands of identical copies of one of the photons such that these could be seen by the naked eye (arXiv:0902.2896).

Proposed by Nicolas Gisin from the University of Geneva and colleagues there and at the University of Bristol, the experiment would involve taking a pair of entangled photons – created, for example, by passing light through a suitable "non-linear" crystal – and then sending one of the photons through a pumped optical medium to create thousands of identical cloned photons. Because the clones are coherent, the resulting pulse of light would be intense enough to be seen by eye.

But as the pulse is still entangled with the other original photon, measuring the pulse's polarization will reveal the polarization of the second photon. The team proposes to do this by passing the pulse through a polarizing filter, which would allow light with horizontal polarization to pass through while deflecting vertically polarized light. Two human observers – each looking along the two different paths – could then determine the polarization of each pulse. The polarization of the second photon could then be verified by passing it through a similar polarizing filter and into two sensitive detectors.

In previous experiments to observe entanglement in photons, the entangled pair was first forced into distinct polarization states and only then amplified so that it could be observed. Gisin adds that the experiment could even be extended to clone the second entangled photon and use four human observers to verify the entanglement.

Innovation

Seeking a biosensor powered by vibrations

Tiny sensors equipped with motors could be of great help to doctors by returning information from hard-to-reach areas inside the body. However, a large barrier to overcome is how to power these devices: standard fuel cells are too large and besides, once a sensor is inside the body, it would be difficult to "replace the batteries", *writes James Dacey*.

Now, researchers in Italy are proposing a solution wherein mobile electronic devices "harvest" the energy of natural vibrations inside the human body. Luca Gammaitoni and colleagues at the University of Perugia are developing a new type of sensor from piezoelectric materials that, when flexed by ambient vibrations, can generate tiny electric currents that could power a microscale motor.

The principle of converting ambient noise into useful energy is not a new idea, but previous attempts at harvesting it have targeted only vibrations at specific resonant frequencies. According to Gammaitoni, this approach is not appropriate for devices inside the body where most ambient vibrations are generated by nonlinear oscillations distributed over a wide spectrum of frequencies. Therefore, to demonstrate that their new "broadband" sensors are worth developing, the physicists set out to determine whether nonlinear oscillators yield a larger energy harvest than linear oscillators.

The team set up a pendulum where the swing of its steel weight was controlled by magnets on either side of the pendulum tip. Attached to the pendulum mass was a strip of piezoelectric material that was clamped at the base and that flexed every time the pendulum swung, thus generating internal electric currents. By varying the distance between the magnets and the steel mass, the researchers were able to set up both linear and nonlinear oscillations in the pendulum. The physicists claim that the nonlinear oscillations yielded four to six times more energy than the linear ones (*Phys. Rev. Lett.* **102** 080601).

The patent for this new technique is held by Wisepower, a spin-off company set up by Gammaitoni and colleagues in Perugia. Wisepower will now turn its attention to the practical challenges of converting this principle into working devices. "We are looking to develop a prototype that could pave the way for microscale applications," Gammaitoni told *Physics World*. "But one of the big problems at the moment is getting the funding – at this time, Italy is not a great place for development. Right now we are open to investors from across the world."

News & Analysis

US nuclear repository in jeopardy

Physicists have expressed uneasiness about the future of nuclear-waste storage in the US after President Barack Obama's administration proposed slashing funds for a long-planned repository at Yucca Mountain in Nevada. If approved by Congress, the cuts seem likely to spell the death knell of the project, which has been in the works since 1987 and has so far cost the government \$9.5bn.

Although the administration has yet to suggest any alternative system for permanent waste storage, energy secretary Steven Chu has announced plans to set up a committee to consider possibilities. So has Senate majority leader Harry Reid, from Nevada, who has been a major critic of the Yucca Mountain repository. In the meantime, the 104 operating nuclear reactors in the US will continue to store a total of roughly 57 700 tonnes of nuclear waste on-site – a figure that rises by 2000 tonnes each year, according to nuclear physicist Thomas Cochran, a senior scientist at the Natural Resources Defense Council.

In addition to its political difficulties, the Yucca Mountain project has been plagued by scientific questions about the speed of water flow through the mountain and the security of transporting waste over hundreds of kilometres to the site. According to some researchers, the lack of an immediate alternative to Yucca Mountain is less disturbing than one might imagine.

Department of Energy

Under threat The US has spent \$9.5bn on the Yucca Mountain nuclear repository.

"There's no reason to put waste away permanently now," says the Nobel-prize-winning physicist Burton Richter, emeritus director of the SLAC National Accelerator Laboratory and chair of a Department of Energy subcommittee on the transformation of nuclear waste. "The idea was to keep the Yucca Mountain tunnel open for 75 years before sealing it. So why don't they just say 'Let's get some regional temporary repositories, move the waste there, and decide where it will go permanently later'?"

Cochran agrees. "The spent fuel can be stored safely on-site as long as there is an entity to manage the canisters and guard them," he says. The greatest hazard, he adds, is in operating the reactors themselves and in the "wet" storage pools where spent fuel is concentrated. As fuel ages and is moved to dry storage, it becomes progressively safer, although the process cannot continue indefinitely. "The biggest concern is that you'll get such a large build-up that you'll cut corners," he told *Physics World*. "Getting the material into a geologic repository is an attempt to address the issue that the temporary sites don't last as long as the waste".

The 2009 budget signed by President Obama on 11 March does not immediately scrap the Yucca Mountain plans, but it allots just \$68.6m to the Department of Energy's nuclear-repository programme – \$49m less than last year. Even if the repository survives, it will still have to undergo a thorough scientific grilling in a licensing process that began in October last year. This process has not yet been blocked, says John Keeley of the Nuclear Energy Institute, adding that the project will "live on with a faint heartbeat" for another year. Closing the site may also prove costly, since the government had promised nuclear-power utilities that it would start to accept their radioactive waste in 1998, and its closure could spark lawsuits seeking billions of dollars in compensation.

Peter Gwynne
Boston, MA

Environmental monitoring

NASA rocket failure delays Glory mission

NASA says it is too early to speculate if it will build another mission to measure carbon dioxide (CO_2) levels in the atmosphere after the space agency's \$270m Orbiting Carbon Observatory (OCO) failed shortly after take-off last month and landed in the Pacific Ocean.

The OCO was launched on a Taurus XL rocket from the Vandenberg Air Force Base in California. However, 14 minutes after the launch, the rocket malfunctioned and the "fairing" – the part on the top of the rocket that covers the satellite – had failed to separate, so the satellite could not drift away in orbit.

The satellite was meant to orbit the Earth at an altitude of 705 km and produce concentration maps of carbon sources and sinks throughout the world. It would have provided samples of CO_2 levels at about 34 000 locations as it orbited Earth once every 100 minutes.

NASA

A waiting game When it is launched, Glory will be the final member of NASA's Earth-observation suite called the A-train.

The OCO was to be the sixth satellite to join the "A-train" – a set of seven Earth-observing satellites that includes the CALIPSO and Cloudsat satellites looking at the levels of aerosols in the Earth's atmosphere and monitoring cloud formation. Both were successfully launched in April 2006.

The Glory satellite, which is designed to look at aerosol and carbon levels in the atmosphere, will be the last member to join this set of satellites. But as it will also use a Taurus XL rocket, its launch has been put off until NASA works out why OCO failed. "Once this has been understood, an investigation board will recommend action for Glory's launch," says Bryan Fafaul, Glory project manager.

"Although the failure is a significant loss in a specific area of carbon-cycle research," says Ronald Hooker, programme director of the Glory mission, "NASA's Earth-science programme will continue to provide unique data." All is not doom and gloom for CO_2 monitoring though: in January the Japanese space agency, JAXA, successfully launched Ibuki, which is the world's first satellite dedicated to monitoring greenhouse-gas emissions.

Michael Banks

Energy

China experiments with solar-thermal power production

Construction is due to start later this month on an experimental solar-thermal power plant in the shadow of China's Great Wall that will bring clean energy to 30 000 households by 2010. Built on the outskirts of Beijing at a cost of £10m, the 1.5 MW Dahan plant will cover an area the size of 10 football pitches, and will serve as a platform for experiments on different solar-power technologies.

Unlike photovoltaic solar panels, which produce electricity directly from sunlight, solar-thermal power is based on an array of mirrors that focus the Sun's rays onto a receiver. Several solar-thermal plants are already operating elsewhere in the world – notably in California's Mojave Desert and in Granada in Spain – but the Dahan facility will be the first of its kind in Asia. "The actual amount of power generated is small, but it is a big step for China to go into solar-thermal power generation using its own designs," says Christoph Richter, site manager of the German Aerospace Centre at the Plataforma Solar de Alméria, a solar-power research centre in Tabernas, Spain.

The Chinese design relies on 100 curved "heliostat" mirrors that track the Sun's movement across the sky and redirect light onto a receiver atop a 100 m-high central tower. Water flowing through the receiver is transformed into superheated steam, which can then drive electricity-generating turbines as in a conventional power plant. Surplus energy is stored as heat, with a tank of synthetic oil serving as a reservoir for the high-temperature (350 °C) heat needed to produce superheated steam, and a second system "downstream" to store heat at lower temperatures. Such two-stage thermal storage boosts the plant's efficiency, notes Zhihao Yao, a researcher at the Laboratory of Solar Thermal Energy in Beijing and member of the Dahan design team.


Chinese Academy of Sciences

Tracking the Sun China's 1.5 MW Dahan solar-thermal plant will use 100 mirrors to focus the Sun's light to generate electricity.

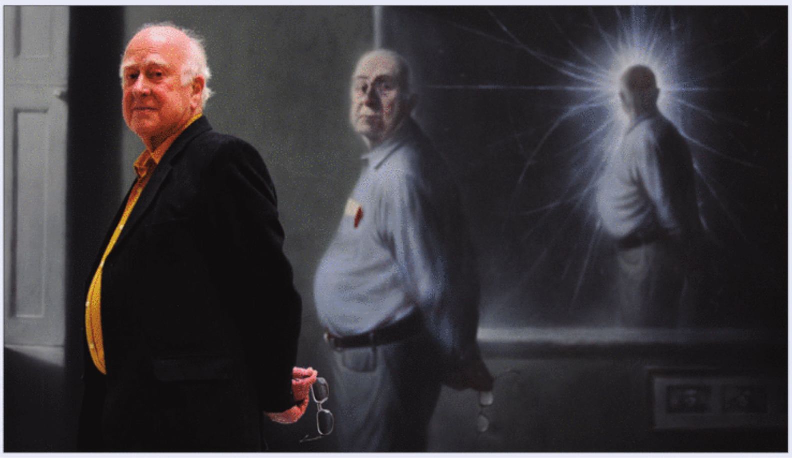
The oil used in the Dahan storage system is also cheaper than the molten salts used to store heat at the Spanish facility, in part because the salts' high melting point means that such systems must be drained when the plant is not in use.

Keeping costs down is important. "In China, the cost for using their own coal is unbeatable, unless you factor in the environmental damage," says Richter. Another snag is the large amount of land needed. David Faiman, director of Israel's Ben-Gurion National Solar Energy Center, notes that China's energy demand increased by about 430 terawatt-hours in 2007, and simply keeping up with this expansion would require devoting about 3000 km^2 of the Gobi desert each year to solar-thermal power. Still, the fact that China is investing in solar power on any scale is a "favourable sign", he adds.

The next step for the Chinese will be to enlarge the Dahan plant to 5–10 MW. This will happen by 2015, deputy project leader Li Xin told *Physics World*. A separate 1000 MW plant is being planned for the Chinese province of Inner Mongolia, with support from Solar Millennium, the German firm that built the plant in Granada, but this commercial-scale facility is still a few years away.

Margaret Harris

Peter Higgs appears on canvas


Callum Bennetts/Maverick Photo Agency

A portrait of Peter Higgs, the 79-year-old physicist after whom the Higgs boson is named, was unveiled last month at the University of Edinburgh. The oil painting, commissioned by the University of Edinburgh where Higgs has spent the bulk of his career, was painted by Scottish-based artist Ken Currie. The painting shows Higgs holding a pair of glasses and looking both towards the unseen artist and – as seen in the mirror behind – to a debris of colliding particles. "It is a great surprise to me that the university wanted to paint my portrait," said Higgs speaking at the unveiling of the painting. "I would not have predicted it 30 years ago." If discovered, the Higgs boson would complete the Standard Model of particle physics by explaining how particles get their masses.

Michael Banks

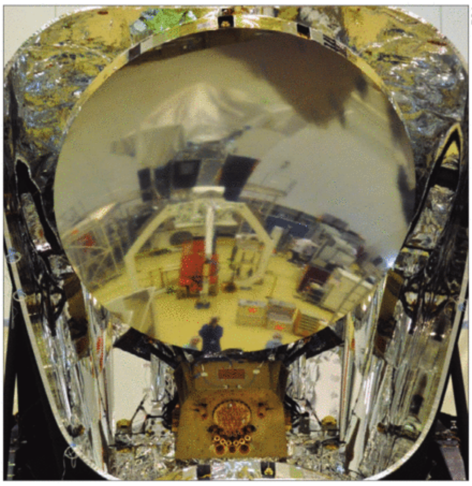
Mapping the cosmos

Two new European-led satellites to map the geometry of the universe and study the formation of the earliest galaxies are to be launched later this month. **Daniel Clery** reports on what the missions hope to uncover

For the last seven years, NASA's Wilkinson Microwave Anisotropy Probe (WMAP) has kept a lonely vigil in an area in space some 1.5 million kilometres further out from the Sun beyond the Earth. Known as Lagrange point L2, it is where a space probe can usefully hover, little disturbed by stray signals from home and without having to use much fuel to keep it in position. But WMAP will soon have company: two groundbreaking missions from the European Space Agency (ESA), due to be launched on the same Ariane-5 rocket later this month, will take up their positions next to NASA's craft.

First to arrive, roughly two months after the launch, will be Planck – a microwave observatory like WMAP. Planck will reveal more about the geometry and contents of the universe by finely measuring the comic microwave background (CMB) radiation – a remnant of the Big Bang. "Planck will provide a big jump in knowledge," says Nazzareno Mandolesi of the Institute of Space Astrophysics and Cosmic Physics in Bologna, principal investigator for one of Planck's two instruments, which will together measure the CMB at frequencies between 27 GHz to 1 THz.

More than a month later, Herschel, named after the German-born astronomer who in 1781 discovered Uranus, will join the group in a much wider orbit around L2 than Planck. This far-infrared and submillimetre telescope will study the universe's coolest objects, from the era when the first stars and galaxies were formed to the present day. "Herschel is the first really big infrared telescope," says astrophysicist Michael Rowan-Robinson of Imperial College London. "For the first time we will get a proper sense of star formation in [other] galaxies."



ESA

Double vision The European Space Agency's Planck and Herschel satellites will launch on the same rocket later this month and cost a total of €1.1bn.

Cosmic echo

The Planck mission has a more focused goal than Herschel: to map out the CMB in the finest detail yet. The CMB was created 400 000 years after the Big Bang, when primordial protons, neutrons and electrons formed neutral atoms that allowed photons to finally move freely. The photons have continued to do ever since, being stretched to microwave frequencies due to the expansion of the universe.

NASA's Cosmic Background Explorer (COBE) set the field alight in 1992 when it revealed that the CMB is not uniform but has slight variations that carry information about the early universe. "It transformed the field completely," says astrophysicist Pedro Ferreira of the University of Oxford. Researchers set to work on a raft of new instruments, ground-based, airborne and in orbit, including WMAP and Planck.

The value of Planck and other CMB experiments is that they provide some of the only hard data about the very early universe. Cosmologists believe that the nascent universe underwent a period of extremely rapid growth called inflation and Ferreira says that Planck will be able to "distinguish between different theories of inflation and decide what theories are actually viable".

The Degree Angular Scale Interferometer, sited at the South Pole, found the first evidence that the CMB photons are polarized; and Planck will measure that polarization in more detail than was possible before. The big challenge for Planck will be to detect a so far unobserved type of polarization known as "B-modes", which date back to the period of inflation and are determined by the density of primordial gravitational waves. "This is a signal that has gone unobstructed since the Big Bang," says Ferreira. If they could be detected, thinks Ferreira, such waves might tell us what mechanism generated them in the universe's first moments, what caused inflation, and even if there was something before the Big Bang.

Eye in the sky

Herschel has two goals: to study star formation in our galaxy; and galaxy formation across the universe. It is hard to see star-forming regions at visible wavelengths because they are usually shrouded in gas and dust that block visible light. Infrared light pierces this veil and Herschel has the resolution to reveal the details of how clouds of cool atoms and molecules coalesce into stars.

As water vapour in the atmosphere absorbs much of the infrared radiation from space, astronomers have long been trying to get telescopes above the atmosphere. IRAS, a US–UK–Netherlands mission in 1983, was the first to map the entire sky, followed by ESA's Infrared Space Observatory (ISO) in the 1990s and NASA's current Spitzer Space Telescope.

All of these missions, however, are limited by their cooling systems. Because any warm object emits radiation in the infrared, these telescopes and their detectors must be chilled close to absolute zero using liquid helium. Helium is heavy to hoist into orbit, which limits the size of any mirror that can be launched to less than 1 m, in turn restricting angular resolution. Moreover, helium eventually boils off, thereby limiting mission lifetimes to just a few years.

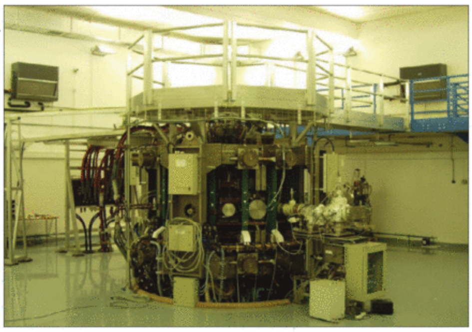
As Herschel is viewing slightly longer wavelengths than previous infrared missions, it can get by with its mirror and telescope just being "passively" cooled to 80 K by the coldness of outer space, leaving just the detectors bathed in liquid helium. This allows Herschel to have a mirror that is 3.5 m across, the largest yet deployed in space. The satellite will investigate light with wavelengths of 55–670 μm.

On a larger scale, Herschel will look back to the early universe to see galaxy formations that are invisible to the likes of the Hubble Space Telescope because of gas and dust. "We will find out how all the galaxies we see today came into being," says Matt Griffin of the University of Wales, Cardiff, principal investigator on one of Herschel's three instruments. It will also probe the planet-forming regions around stars in our Milky Way, the gas giants of our solar system, and comets and objects in the Kuiper Belt.

Fusion

COMPASS tokamak points towards ITER

Physicists in the Czech Republic have started operations in what is now the most advanced fusion facility in central Europe. The Compact Assembly (COMPASS) tokamak, located at the Institute of Plasma Physics (IPP) in Prague, originally belonged to the UK Atomic Energy Authority (UKAEA) but was sold to the IPP for £1 in 2001. Physicists and engineers have spent the last two years installing the tokamak, and the Czech government has spent €12m to upgrade the infrastructure plus the aging control and data-acquisition systems.


Institute of Plasma Physics

Star power The COMPASS tokamak in Prague will mimic plasmas expected to be produced at ITER.

The tokamak consists of a D-shaped vacuum chamber, which will eventually be used to fuse deuterium and hydrogen nuclei together. As it has the same geometry as the ITER fusion reactor that is currently being built in Cadarache in France, experiments performed on COMPASS can mimic plasmas expected at ITER. In particular, researchers at the IPP will use COMPASS to operate "H-mode" plasmas, which will be used in ITER, allowing them to investigate problems involving potentially dangerous bursts of the plasma into the reactor wall. "We plan to study the suppression of these discharges, which will be directly relevant to ITER," says Radomir Panek of the IPP.

The COMPASS tokamak will be further upgraded next year to allow the plasma to be heated to temperatures of 30×10^6 K. At the UKAEA, microwaves were used to heat the plasma, but researchers in Prague will install a new system that will inject hydrogen or deuterium atoms into the plasma. The atomic beams get ionized and confined in the centre of the COMPASS plasmas, where they heat the plasma by transferring energy to it as they collide. Once operational, COMPASS is expected to cost the IPP about €250 000 per year to run, although researchers there are looking to collaborate with physicists from other labs.

Michael Banks

European Union

Bureaucracy blights funding in Europe

The process of applying for money from the Framework programme of the European Union (EU) is a "stain" on the EU's reputation and a "radical overhaul" of the administration is needed. That is the view of an independent panel of scientists charged with evaluating the €18bn Sixth Framework programme, which lasted from 2002 to 2006 and funded collaborative research performed within more than one country. The panel says that grants handed out by the programme take, on average, over a year to get approved, with a quarter of proposals taking more than 450 days before being signed.

The 13-strong evaluation panel was led by the biologist Ernst Rietschel, president of the German Leibniz Association. Although its report says that the Sixth Framework's achievements have been "substantial", the panel calls for changes in the Eighth Framework programme, which is expected to start in 2014. These include shortening the time of receiving grants by 50% and reducing the need to audit ongoing projects.

> The time taken to get funding is a constant complaint of researchers

"The time taken to get funding is a constant complaint of researchers," says Sean McCarthy from Hyperion, a firm in Ireland that trains researchers to write proposals for Framework programmes. "But on the one hand you have politicians who argue taxpayers' money must be monitored and properly spent, and on the other researchers who want simplicity."

The EU is currently in the throes of the Seventh Framework, which runs from 2007 to 2013 and has a budget of €50bn. Every year the programme receives 16 000 proposals involving over 80 000 researchers. "Each proposal can take up to 13 hours of work to assess," says McCarthy.

Michael Banks

Science and religion

Physicist bags Templeton prize

A French theoretical physicist and philosopher of science who did his PhD with Louis de Broglie has won this year's £1m Templeton Prize, which is awarded for "progress toward research or discoveries about spiritual realities". Bernard d'Espagnat, 87, won the prize for his work on the philosophical implications of quantum mechanics by laying the theoretical groundwork for experimentally testing the violation of "Bell inequalities". He is the seventh physicist in the last 10 years to win the prize, which was set up in 1972 by the late philanthropist Sir John Templeton.

Born in 1921, D'Espagnat has spent his career working on the discrepancies between quantum mechanics and the common-sense view of how the world works. He studied at the Ecole Polytechnique before doing a PhD in particle physics at the Institut Henri Poincaré in Paris under De Broglie. After a spell with Enrico Fermi at the University of Chicago, he moved to CERN, where he helped create the lab's famous theory division.

When D'Espagnat returned to Paris in the 1960s he worked on ways to experimentally test Bell inequalities, which – if violated – would show that entangled particles can have an instantaneous influence on one another. "We had to make the test to check if quantum mechanics was indeed true," says D'Espagnat. Many physicists had previously thought that quantum mechanics was incorrect, or incomplete, since it violated the principle of "locality" – that an object is only influenced by its immediate surroundings.

The proof finally came in 1981 when experiments on polarized photons by Alain Aspect, with whom D'Espagnat worked closely, showed that Bell inequalities were indeed violated. D'Espagnat, who was raised as a Roman Catholic, subsequently wrote a book, which became a best-seller in France, that explained to non-specialists the implications of Bell inequalities for our understating of the physical world. The book was published in English in 1983 as *In Search of Reality: The Outlook of a Physicist*. D'Espagnat told *Physics World* that he plans to give a third of the prize money to his family, a third to charity and the rest for research.

Michael Banks

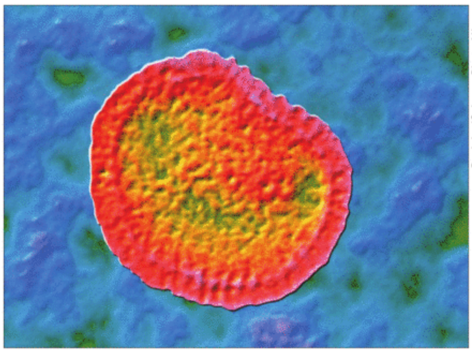
Statistical physics

Flu fighters use the Web to track virus

Physicists in Italy have begun analysing data from a new Web-based project that seeks to model how flu spreads through a population. The project, known as Influweb, involved some 2000 ordinary Italians replying over the last six months to a weekly e-mailed questionnaire about their state of health and current geographical location. The project will be able to pin down the spread of flu in real time and with a spatial resolution on the level of a person's postcode.

The spread of flu is traditionally monitored using information provided by doctors who visit patients ill in bed or see patients in their surgery. One problem with this approach is that it can take over a week for the data to be processed. Moreover, such methods do not sample enough people. "We found that 90% of people with symptoms never see a doctor," explains physicist Daniela Paolotti from the Institute for Scientific Interchange (ISI) in Turin, who is a joint co-ordinator of Influweb along with Vittoria Colizza.

What the ISI researchers hope to obtain is much more accurate data that will allow them to test and refine their theoretical models of the spread of flu and other epidemics. This should, in principle, allow them to make better predictions of how widespread a particular outbreak will be and when it will peak. Traditional monitoring techniques have so few data that they only become statistically relevant if summed over a large geographical area. The Influweb team now has six months worth of data, including information on groups such as pensioners and children.



Pasieka/Science Photo Library

Cold snap Researchers in Italy are using data uploaded to the Web by patients to model how flu spreads.

Influweb is inspired by similar Web-based projects that have been running in Belgium and the Netherlands since 2003 and in Portugal since 2005. The former scheme, which has information on 60 000 people, has been able to predict a week earlier than other techniques when a particular epidemic will peak. The Influweb project will, however, try to exploit that breathing space by alerting hospitals of an imminent epidemic so that they can, for example, put extra ambulances on stand-by.

Although Paolotti has not obtained enough data this winter to make full predictions, she is optimistic for next year. "We are confident that next winter will yield even more participation and that we will gain predictive capacity," she says. The ISI researchers are also co-ordinating a €5m four-year European-wide extension of Influweb, known as Epiwork. Funded by the European Union and co-ordinated by Alessandro Vespignani from the ISI, Epiwork began in February and involves 12 organizations from seven European countries and Israel.

"I believe this project is a cutting-edge approach to data collection," says Zoltán Toroczkai, a physicist at the University of Notre Dame in Indiana, who is also involved in modelling epidemics. "It will be extremely useful in tackling a problem that has not really been exploited in the current modelling, namely the dynamical coupling between people's mobility in geographical space and the spread of an epidemic."

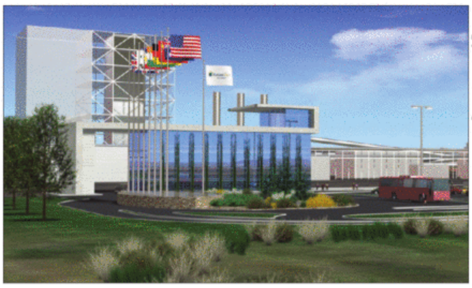
Michele Cantanzaro

Energy

US pays price for $500m budget blunder

An "inexcusable" $500m accounting error led to former US President George Bush's administration scrapping plans for a carbon-capture and storage demonstration plant last year, according to a report by the science and technology committee of the US House of Representatives. The project was axed because costs appeared to have ballooned from $1bn to $1.8bn, when in fact they had risen to only $1.3bn. The report says the pull-out "severely" damaged the country's reputation as an international science partner and "left the country with no coherent strategy for carbon-capture".

First announced by President Bush back in 2003, FutureGen was designed as a coal-fired power plant that would not emit any carbon dioxide by capturing and storing it underground in a technique known as carbon capture and sequestration (CCS). To be built in 2013, the plant was to have been constructed by the FutureGen Alliance – a public–private partnership set up to design, build and operate the plant.



Department of Energy

Costly error The FutureGen carbon-capture demonstration plant was axed after an accounting mistake.

However, in the budget for the 2008 financial year, the Department of Energy (DOE), led by Samuel Bodman, cancelled a $1.1bn grant for the project because of the apparent huge cost overrun. "Unfortunately, the [DOE] withdrew their support for FutureGen before the alliance could complete a new cost estimate in June 2008," Lawrence Pacheco, a spokesperson for the company, told *Physics World*.

The mistake arose because the initial $1bn estimate was made using constant 2004 dollars, whereas last year's DOE cost estimate factored in inflation through until 2017. But an audit carried out by the US Government Accountability Office in February concluded that FutureGen's price-tag had actually increased by only 39% to $1.3bn in constant 2005 dollars.

The project could, however, be revived thanks to President Barack Obama's $787bn stimulus package, which includes an extra $1.6bn for the DOE above its 2009 budget of $4.0bn (see *Physics World* March p13). The FutureGen Alliance now plans to meet with energy secretary Steven Chu to kick-start the project. The Nobel-prize-winning physicist has already stated his support of CCS demonstration plants.

Michael Banks

Space

NASA missions: late and expensive

Most large NASA missions have an average delay of almost a year and are launched over budget, according to a report by official US spending watchdogs. The Governmental Accountability Office (GAO) found that of 13 missions for which NASA provided figures, 10 were delayed by, on average, 11 months and cost 13% above the original estimates. Two of the other projects came in on schedule and under budget, while one was delayed but stayed on budget.

The mission with the biggest overspend is NASA's $347m Glory satellite (see p6), which is designed to look at aerosol and black carbon soot levels in the atmosphere. First conceived in 2003, it will cost 53% more than originally planned. "We experienced difficulties in the development of instruments, which impacted on the launch readiness and the costs," says Bryan Fafaul, Glory project manager. Also hard hit has been the Mars Science Laboratory, which was recently delayed by two years and is now estimated to cost $2.3bn, up by $700m from its initial estimate of $1.6bn.

Of the 13 projects, the only two that come in on schedule and under budget are the $300m Wide-field Infrared Survey Explorer (WISE) and the Dawn spacecraft. WISE is set to launch in November to perform an "all-sky" survey in the 3–25 μm wavelength range and has cost 1% less than planned, while the $465m Dawn spacecraft was launched in 2007 – 2% below initial estimates – to visit the dwarf planet Ceres and a large asteroid.

NASA did not give the GAO data for five missions, including the James Webb Space Telescope, the Hubble Space Telescope's successor, which is expected to launch in 2013, as well as the Ares crew launch vehicle and the Orion exploration capsule, which are expected to take astronauts to the Moon. The GAO has not, however, made recommendations about what should be done to reverse the current trend.
Michael Banks

Analysis of NASA projects

Mission	Cost change	Launch delay (months)
Aquarius	6%	10
Dawn	−2%	0
Fermi Gamma-ray Space Telescope	5%	9
Glory	53%	6
Herschel	13%	20
Kepler	25%	9
Lunar Reconnaissance Orbiter	0%	6
Mars Science Laboratory	26%	25
National Polar-Orbiting Operational Environmental Satellite System Preparatory Project	19%	26
Orbiting Carbon Observatory	18%	5
Solar Dynamics Observatory	1%	17
Stratospheric Observatory for Infrared Astronomy	3%	9
Wide-field Infrared Survey Explorer	−1%	0

Ethics

Physicist accused of misappropriating NASA funds

Government investigators have accused an Iranian-born physicist of defrauding US taxpayers by transferring millions of dollars of grants from NASA and other agencies into his own bank account. Samim Anghaie, founder and director of the University of Florida's Innovative Nuclear Space Power and Propulsion Institute (INSPPI), has been accused of receiving funds worth a total of $3.4m, which his family then spent on cars and land.

Papers filed in court after an FBI raid on Anghaie's INSPPI offices assert that he received funding from NASA, the US Air Force and the US Department of Energy on the basis of 13 fraudulent proposals for research contracts. The contracts all went through New Era Technology, a company Anghaie set up in 1988 with other family members.


University of Florida

Under investigation Samim Anghaie.

Responding to the charges, the university has placed Anghaie, who has published more than 500 journal papers and has served on top-level advisory boards for NASA and the Department of Energy, on paid leave. "The university is collaborating with representatives from NASA and the FBI," says Steve Orlando, a spokesperson for the University of Florida.

The institute's grants have already run out, and Orlando says that the university is waiting for the affair to be settled before deciding the institute's future. The staff member and graduate student who worked with Anghaie at the INSPPI have now moved to new positions in the university.
Peter Gwynne
Boston, MA

Sidebands

CERN

CERN marks 20 years of the Web
Researchers at the CERN particle-physics lab near Geneva celebrated the 20th anniversary of the invention of the World Wide Web last month. The main speaker was Tim Berners-Lee, who in 1989, when a software engineer at CERN, wrote a now-famous proposal to his manager Mike Sendell outlining his vision of "information management" at the lab. Berners-Lee's proposal is considered one of the foundations from which the Web was built and led to the creation of the coding language HTML. Speaking at the event, Berners-Lee, who originally studied physics at Oxford University, said that "CERN has come a long way since 1989, and so has the Web, but its roots will always be here".

Finland publishes space strategy
Finland's national space strategy should concentrate on Earth observation and satellite positioning, according to a report submitted to the Finnish government last month by the country's space committee. Climate-change research topped a list of activities that would benefit from better-funded space technology, but the report also urged the country's industries to invest in space-related applications, citing a radio receiver built for Europe's Planck satellite (see p8) by the Danish space-technology firm DA-Design.

China outlines lunar programme
China plans to launch a robotic Moon lander by 2013 according to Ye Peijian, the chief designer of Chang'e-1 –China's first Moon orbiter, which was launched in October 2007. Peijian also says that China will launch a mission in 2011 to test "soft" landing techniques and risks, and that the country will send a sample-return mission to the Moon by 2020.

Oxford Instruments honoured
The UK-based firm Oxford Instruments, which makes cryogenic equipment and superconducting magnets, has won this year's Private Limited Company (PLC) award for "best technology company". The PLC awards, sponsored by Price Waterhouse Coopers, the *Financial Times* and the London Stock Exchange, are given to smaller firms listed on the stock market.

Unleashing science in India

As India heads to the polls this month, **Pallava Bagla** describes how the world's second most populous country is pushing to the forefront of science – from space missions to nuclear technology

With a population of over 1.1 billion people, of whom 714 million are entitled to vote, elections in India are complex affairs. In the next general election, which begins on 16 April, there will be more than 828 000 polling stations, where some 1.3 million electronic voting machines will be used in what will be the world's largest electronic election. The machines themselves were built and designed in India.

Despite the new technology in the polling booths, scientists in India have traditionally been shackled by age-old regulations barring them from holding equity stakes in the private companies that commercialize their inventions. But on 24 February, in a bid to win support from the country's 400 000 government scientists, the Indian science minister, Kapil Sibal, unveiled a new policy that sweeps away these old laws.

Calling it a "historic decision that will unleash the entrepreneurial potential of Indian scientists", Sibal said these measures were part of a much-needed reform process. Equally full of praise was Raghunath A Mashelkar, president of the Pune-based Global Research Alliance and a former president of the Indian National Science Academy, who called it an "absolutely path-breaking achievement". He said it would open the floodgates for wealth generation by embracing the concept of "knowledge as equity".

Big budgets

Today, India spends in excess of $2.5bn on science and technology, with almost three-quarters of this coming from public funding; the country also produces over 5000 PhD students every year. Scientists in India published some 5932 papers in physics journals in 2007 – roughly half the total published by UK scientists and about a sixth of the figure for the US.

Thankfully for scientists, there has been nearly complete bipartisan support for science among the ruling elite. The United Progressive Alliance – a centrist coalition led by the economist Manmohan Singh that has governed India for the last five years – has traditionally been a great supporter of science. So has the right-of-centre opposition – the National Democratic Alliance, led by Lal Krishna Advani.

Pallava Bagla

Blast off After launching its first mission to the Moon in 2008, India now has plans to send astronauts into space.

In the run-up to the elections, the government announced the creation of eight new institutes of technology, 30 new central universities, five new institutes of science education and research, as well as 20 national institutes of technology. But although the Indian economy has surged forward over the last two decades – it is currently growing at almost 8% per year – not everything is rosy.

In its last budget, the government allocated almost no extra money to science, while the elections themselves have led to some projects stalling. In particular, the Indian Space Research Organisation (ISRO) in Bangalore had hoped to get approval for its proposed manned space activities, which could see two or three astronauts entering low Earth orbit by 2015. These plans, which would cost about $3bn and make India the second country in Asia to send astronauts into space on its own merit using home-grown technology, may now have to wait until after the elections to get approval.

That delay is frustrating, as the ISRO, and indeed the whole nation, is still riding high on the success of its maiden lunar mission: Chandrayaan-1 – a $100m remote-sensing project that blasted off on 22 September last year – which ISRO boss Madhavan Nair calls "path-breaking". The ISRO has, however, approved a second, robotic mission to the Moon to be launched in 2012, for which the government has sanctioned about $125m. The agency also has plans to undertake missions to study the Sun and an asteroid, and to send an unmanned satellite to Mars – all before 2014.

Space is not the only final frontier for India. If all goes to plan, the country could soon have its very own Indian Neutrino Observatory (INO) tucked 2 km below the Deccan Plateau in southern India some 250 km south-east of Bangalore in the Nilgiri hill ranges. When ready in 2012, this will be the single most expensive basic-science research facility ever to be built in India, costing $167m over a seven-year period.

The observatory will be fully funded by India, with the Department of Atomic Energy in Mumbai footing the bulk of the bill. But Anil Kakodkar, chairman of the Indian Atomic Energy Commission, thinks the INO is not "outrageously expensive" for the nation. Vinod Chohan, a physicist at CERN in Geneva, agrees, saying that "India is well off to be able to permit this". When complete – assuming clearance is given by the local forestry department – the INO will have a massive 50 000 tonne detector made from layers of magnetized iron and glass that will be used to detect neutrinos and antineutrinos produced when cosmic rays interact with the Earth's atmosphere.

Global player

Over the last few years, scientists in India have begun to realize the importance of participating in global science projects. The country has already invested $40m in the Large Hadron Collider (LHC) at CERN and has earned the status of "observer state" in this largely European experiment. India's biggest contribution has been to test many of the collider's superconducting magnets and to also build the jacks that support the entire LHC ring. "It is a thriving collabor-

The Indian Institute of Science: a century of success

Founded 100 years ago on 27 May 1909, the Indian Institute of Science (IISc) is perhaps India's leading science and engineering research centre. Located in Bangalore in the south-west of the country, the centre grew to prominence following the arrival of the Nobel-prize-winning physicist Chandrasekhara Venkata Raman as its first Indian-born director in 1933. Other famous alumni include the nuclear physicist Homi Bhabha, who founded India's atomic-energy programme, as well as Vikram Sarabhai and Satish Dhawan – the architects of the Indian space programme.

The centre has made a huge impact on Indian science and technology. The country's aerospace industry can trace its roots back to the centre, while Bangalore's reputation as India's "Silicon Valley" is also based in part on the IISc's early work in computer science and engineering. Moreover, many local firms involved in defence, space science, metallurgy and materials emerged as off-shoots of the institute's activities.

The IISc currently has about 2000 full-time researchers and 2600 PhD students, whose work covers everything from nanoscience and high-energy physics to mathematics and biology, while some 250 new PhD students join the centre each year. It was first conceived in 1896 and proposed to the government in 1898 by the great Indian industrialist Jamsetji Nusserwanji Tata, the founder of what is known as the Tata Group, which produces everything from cars and steel to chemicals and tea. He intended the centre to be a "university of research" established through a family endowment,

but despite this far-sighted philanthropic gesture – at a time when a university education was beyond the reach of most Indians – he declined to have his name associated with the centre. (The famous Tata Institute of Fundamental Research in Mumbai was set up much later, in 1945, by his nephew.)

Sadly Tata did not live to see his centre built as he died in 1904. Indeed, the British government rejected Tata's original idea of including research into the humanities and medicine, which would have given the IISc much more of a university character. Moreover, the donation of 400 acres of land by the Maharaja of Mysore province led to the institute being located in Bangalore, rather than present-day Mumbai, as Tata had intended.

The centre's first director was the British chemist Morris Travers, who started with research in areas that would support the local chemical, food and electrical industries. Initially, all faculty staff were British and, although the students were all Indian, it was not until the late 1920s that Indians began to take up the majority of full-time posts. Modern research only really began to flourish with the arrival of Raman, who was director until 1938 and remained at the IISc until 1948, carrying out work in optics, crystallography and acoustics.

Following its independence from Britain in 1947, India's quest for industrial growth led to the IISc focusing heavily on engineering. Indeed, the 1950s saw many engineers move from the IISc to the newly founded Indian Institutes of Technology (IITs), which themselves grew out of the centre's activities. The IISc later branched out into research into everything from biosciences to aerospace, with many of India's most famous scientists working there.

As for the future, the IISc's current director – the biophysicist Padmanabhan Balaram – says that he intends to create a new interdisciplinary research centre. Two possible fields – energy and materials, and synthetic biology – have already been identified, although the IISc is still waiting for government cash. The institute has also recently set up new centres in Earth science and neuroscience. Balaram even thinks that the IISc might run undergraduate degree courses for the first time. Other plans include the construction of an additional campus elsewhere in Bangalore that would focus on fields such as solar power and sustainable development.

Ramaseshan Ramachandran
New Delhi

ation that showed the world that India can participate in giant, multicountry endeavours," says Vinod Chandra Sahni, director of the Raja Ramanna Center for Advanced Technology in Indore, which has co-ordinated India's role in the LHC.

In 2005 India also became the seventh full member of the International Thermonuclear Experimental Reactor (ITER) project currently being constructed in Cadarache, France, which is designed to see if fusion is feasible as a practical energy source. Expected to cost about $20bn, India will contribute more than $2bn over the next decade as part of its National Fusion Research Programme.

"On our own, we would have taken a long time to make an economically functional tokamak; but now, by just contributing 10% of the [development] work, India will have access to 100% of ITER's intellectual property," says Shishir Deshpande, chief of India operations for ITER.

India has also contributed $250m to the $1.5bn Facility for Antiproton and Ion Research (FAIR) at the GSI heavy-ion research lab in Darmstadt, Germany. Some Indian scientists will collaborate on the project, which once completed in 2014 will produce beams for research into nuclear physics, plasmas and nuclear astrophysics.

India's role in the Large Hadron Collider showed the world that it can participate in giant, multicountry endeavours

Nuclear concerns

One controversial scientific issue, which almost forced an early election in the middle of last year, centres on a nuclear deal between the US and India. The deal, which was only permittable after the International Atomic Energy Agency amended its rules last September, will lead to India signing contracts over the next few months worth tens of billions of dollars to import nuclear-reactor technology from France, Russia and the US to provide an extra 30 000 MW of energy. India had previously been barred from importing or exporting nuclear fuel or equipment after it tested a nuclear weapon in 1974.

Notwithstanding these imports, India's domestic atomic-energy programme continues with zeal. India has 17 working nuclear power plants and its futuristic commercial fast-breeder reactor is nearing completion at Kalpakkam on the coast of the Bay of Bengal. When complete in 2010–2011, the $900m reactor will be the world's first to use plutonium in high enough concentrations to produce electricity. "India's energy hopes ride on the success of this technology," says Baldev Raj, director of the Indira Gandhi Center for Atomic Research in Kalpakkam. Work is also likely to start in 2010 on building an advanced heavy-water reactor – a novel reactor design that generates most of its power using thorium (see *Physics World* August 2008 p10).

While Indian scientists try to tackle these hi-tech challenges, several issues relating to the everyday needs of the millions of ordinary Indians are not being forgotten. The India Meteorological Department in New Delhi is in the throes of a $125m modernization plan – an effort being personally piloted by science minister Sibal. He has promised that, if re-elected, he will ensure that India gets what he calls a "world-class weather-forecasting service". Part of the rationale is that two-thirds of the population of India still depend on agriculture for survival, and in order to improve crop yields the physics of the atmosphere needs to be better understood. That is a herculean task, but as Sibal points out, "Indian scientists need to think big and achieve big".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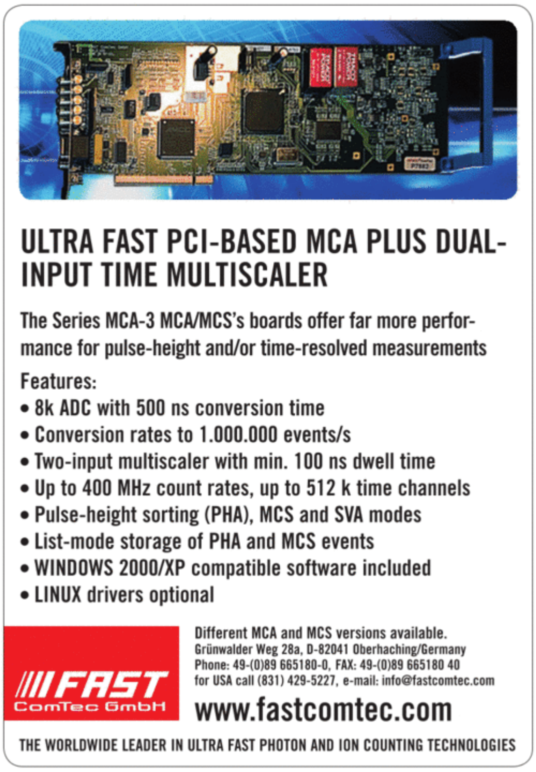
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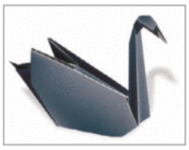
Backing black swans

Science must find new ways of encouraging revolutionary research

When one looks back over the history of physics, what stands out most are the big breakthroughs – the revolutionary discoveries and novel theoretical insights that changed the course of our subject forever. The humdrum stuff of "normal" science, in which established ideas are fleshed out, is all well and good. But it is the unpredictable, unforeseeable, paradigm-shifting findings that do most to shake up science.



So why then is science not set up to encourage more such revolutionary ideas and discoveries? What can we do to stimulate and nurture the "black swans" – the outliers that have a much more long-lasting impact than the mundane and expected "white swans"? The first question is easy to address, for the answer lies in our increasingly risk-averse scientific culture, where successful careers depend on pulling in big grants and publishing lots of papers, often of questionable significance.

How to nurture risk-taking maverick black swans is trickier to answer. One solution lies in research centres dedicated to innovative, high-risk and often interdisciplinary work, such as the privately funded Perimeter Institute for Theoretical Physics in Canada and the Santa Fe Institute (SFI) in New Mexico (pp22–26). Research at the SFI has, for example, led to the emergence of "econophysics", which seeks to use statistical physics to improve our understanding of the ups and downs of the financial markets. As the econophysicist Jean-Philippe Bouchaud explains (pp28–32), classical economics assumes that the financial markets act rationally and that fluctuations in stock-market prices follow a Gaussian distribution. But the theory is flawed, as it cannot predict the existence of extreme events, such as the current global financial crisis, and has unwisely encouraged politicians and banks to deregulate the markets on the assumption that any constraints will stop the market from reaching its supposedly perfect equilibrium state.

Econophysicists, in contrast, are well aware that market fluctuations have a power-law distribution with a long "tail" that can account for extreme events. Sure, econophysicists cannot predict such crashes either, but by constructing a more realistic theory of the markets, they can encourage regulators and politicians to find ways of reducing the chance of crashes happening and of mitigating against the effects of such events when they occur.

Changing tack to encourage revolutionary thinking of this sort throughout physics is not easy, with funding agencies almost certainly arguing that they already do support plenty of ground-breaking work. But the benefits of breakthrough science can be so big that ways of finding future black swans is essential.

Pure genius

The often underappreciated insights of Paul Dirac are celebrated in a new biography

Talking of revolutionary work, nothing fits the bill better than that of Paul Dirac. He predicted the existence of negative-energy states, which was confirmed with the discovery of the positron in 1932. As a new biography makes clear (pp38–39), Dirac's purely theoretical work ultimately led to the development of positron-emission tomography, which is now a vital tool in medical physics. What better example of the power of black swans?

German for physicists

Bremsstrahlung? Gedankenexperiment? Zitterbewegung? In an age when English is the lingua franca of the scientific world, **Ben Stein** looks at why physicists still employ German expressions and argues that we should treasure their use

Mathew Ward

"German is the language of science" I remember my father telling me as a boy growing up in the Bronx in New York during the 1970s. As I watched astronomy programmes on TV with my father and older brothers, I imagined having to speak ceaselessly in fluent German if I was ever to become a scientist as a grown-up. But when I started my studies at university in New York in the 1980s, I realized my father's advice – sought from weekly trips to the neighbourhood public library – was way out of date. Not only did my physics professors present their research in English at conferences all around the world, but they also published in English-language journals – thus seemingly not needing a single word of German.

So I left college relieved but a little disappointed that I did not have to learn German to study physics. Only recently, however, has it dawned on me that I have, all along, been learning little bits of German – or more precisely, important little bits of physics expressed in German.

About a year ago, the National Institute of Standards and Technology (NIST), where I now work as director of media relations, issued a press release on a paper concerning a phenomenon known as zitterbewegung (roughly pronounced Tsitt-ur-buh-VE-gung). The term describes a subtle "trembling motion" in electrons as they move at almost the speed of light in free space.

In 1930 Erwin Schrödinger predicted this hard-to-detect phenomenon, which remains unobserved to this day, when he analysed solutions to Paul Dirac's equations for relativistic electrons. But until working on the press release, I had never before encountered this intriguing term. So why did this early quantum-physics expression pop up in recent physics literature? The NIST paper proposed a new idea for detecting this elusive trembling motion by looking for the effect in slower, heavier ultracold atoms, which would wiggle in a more pronounced fashion than electrons. The authors suggested calling it a "jitterbug" motion, which we used in our press release, but we were also compelled to use the word zitterbewegung in the press release as well.

Just a few months ago, I received an e-mail from Undine Baier-Blott, who works as a translator at the National Metrology Institute of Germany (PTB) in Braunschweig, asking why we had used that particular word, rather than relying exclusively on English? After all, there are perfectly fine ways to translate the concept into English. And why, she asked more generally, are technical terms of German origin – such as ansatz, gedankenexperiment and bremsstrahlung (see box) that are hard for us Anglophones to pronounce – still being widely used in the English language of physics?

In the beginning

To start answering this question, let us go back a few hundred years, with the help of Germany's Goethe-Institut, which promotes German culture and language around the world. As the institute explains in an article entitled "German – the language of science", until the 18th century Latin was the language of scientific discourse in Europe; think Isaac Newton and the *Principia Mathematica*. But starting in the 17th century, British and French scientific institutions started encouraging their members to communicate about science in their native tongues, possibly in order to help communicate research findings to non-scientists.

Germany got off to a shakier start, not only in science but in all of academia. A 1687 public lecture at Leipzig by the philosopher Christian Thomasius sparked an outcry – and an order for his arrest – when he delivered a lecture in the German language. In the 18th century, three major German scientific academies in Göttingen, Berlin and Munich adopted different official languages – Latin, French and German, respectively, at various times throughout the century – with only the Bavarian Academy of Sciences in Munich selecting German at the outset.

But things changed in the 19th century. The rise of German classicism, most closely associated with the writer Goethe himself, brought international prominence to the German language. Add to this the success of science in Germany, and the use of German in scientific discourse began to thrive. This continued into the early 20th century, with many of the pioneers of modern physics, such as Albert Einstein, Werner Heisenberg, Max Planck and Schrödinger himself, all being based in Germany. They expressed their ideas in German journals such as *Annalen der Physik*, which is where Einstein published his seminal 1905 papers on special relativity, the photoelectric effect and Brownian motion.

Only with the exodus of Einstein and other intellectuals from Germany prior to the Second World War – and the associated rise of American English – did the German language begin to lose its hold. Today, the most prominent physics journals are in the English language – with Germans, Brazilians and Chinese alike all competing to express their most significant findings in

English. Even *Annalen der Physik* is now published entirely in English. So why do we in the physics world still use some German terms? Why do all English-speaking undergraduates learn that decelerating electrons can give off bremsstrahlung, instead of "braking radiation"?

One answer is that these German terms are historically important, and they connect us to the history of physics. With Heisenberg and Schrödinger under the supervision of Prussian-born theorist Arnold Sommerfeld, and in communication with Wolfgang Pauli, Einstein and Niels Bohr, these physicists started to figure out the new field of quantum mechanics. This was put quite eloquently to me by Ludwig Mathey, a German–American physicist at the Joint Quantum Institute (JQI) at NIST and the University of Maryland. "In the process, they came up with all these wonderful new names for physics phenomena," Mathey says, "which they then continued to use and the terms caught on."

New meanings

But I would go even further. I believe learning these original German terms, and decoding their meanings, helps us gain a deeper understanding of the concepts of modern physics. By learning the terms that the founders chose, we ponder the meanings and images that their words evoke as they grappled with new physics phenomena for the first time. Knowing the original words connects us with the freshest thinking of the great minds in modern physics.

Charles Clark, another physicist at JQI, argues that words such as zitterbewegung and bremsstrahlung are actually no longer German words, but have instead become English words of German origin. Performing a *Google* search on zitterbewegung from here in the US, with the top 100 results displayed, Clark found 99 pages in the English language and just one in German. The same search on the German *Google* site yielded 11 pages in German, one in Russian and the remaining 88 in English.

As Clark points out, this situation is even clearer for one of the central terms in physics: eigenvalue. "It's undoubtedly a uniquely English word, derived from the German *Eigenwert*, meaning "proper value" in English," he says. "But it has lost its initial capital and 'wert' has been replaced with a common English word." Eigenvalue, this strange Anglo-German hybrid, is in daily use in physics English, as are eigenfunction and eigenvector, which are much closer to their German originals of *Eigenfunktion* and *Eigenvektor*.

But these can all be argued to be English words. "There are English equivalents to these words, like 'characteristic value', which has been used in papers," Clark observes, "but these have faded into disuse, at least in physics." For whatever reason, these German-based terms have stuck, and there is no sign of them fading away.

Selected terms of German origin

Ansatz: mathematical equation that represents a best guess at describing a physical phenomenon
Bremsstrahlung: photon deceleration that results in the emission of photons; "braking radiation"
Festschrift: commonly used as a celebration of an individual's scientific contribution
Gedankenexperiment: thought experiment
Gerade/ungerade: even and odd, used in the context of the physics phenomenon known as parity
Heiligenschein: "halo"; an optical effect that appears near a strong light source; "Saint's shine"
Reststrahlen: "remnant radiation"; light reflected from a transparent object the constituent atoms, ions or molecules of which vibrate at a frequency close to that of the light
Schlieren optics: technique that measures the visible "streaks" produced by an inhomogenous transparent medium, such as hot air wafting over a candle
Stosszahlansatz: "molecular chaos" in a dilute gas – proposed by Boltzmann
Verschränkung: Schrödinger's term for entanglement
Zitterbewegung: a subtle "trembling motion" proposed to occur in electrons
Zwitterion: a molecule with regions of positive and negative charge; "hybrid ion"

Of course, English does not only assimilate German terms: other examples are tokamak from Russian, and kagome lattice from Japanese. But German's ability to form compound nouns gives it a conciseness that, I would argue, is especially appealing to us physicists. Words cannot express physics concepts the way that mathematical equations can, but German-based words seem to come closest in encapsulating the essence of physical ideas in an efficient manner. And as Ludwig suggests, they even present riddles that are fun to break down. (In zitterbewegung, for example, "zitter" expresses the concept of "jitter", while "bewegung" contains the core "weg", which means "way" – referring in this context to "motion".)

But beyond this playfulness, I believe there is something serious going on in the continuing use of these words. As we attempt to solve new problems, it is important to stay connected to our past and remember how we reached our present insights into the universe. Understanding the past, and learning the language our pioneers used as they tackled phenomena that were strange and new to them, seems very important for developing the insight and wisdom for making the next conceptual breakthrough. That is why I say, *Es lebe die Zitterbewegung* (long live the jitterbug)!

Ben Stein is director of media relations at the National Institute of Standards and Technology, US, e-mail bstein@nist.gov

Critical Point Making physics popular

Writing about physics for the public involves more than just translating complex scientific ideas into simple language, says **Robert P Crease**

I once interviewed the Northern Irish physicist John Bell, who told me a curious tale about the wife of the then-American ambassador to Switzerland. Bell recalled how she rolled up at his office at CERN bearing a dog-eared copy of *The Dancing Wu Li Masters*, a book by the author and "soul-healer" Gary Zukav, seeking answers to her questions about the connections between quantum physics and Eastern mysticism.

I expected the seasoned, hard-nosed physicist to take a dim view of both book and woman, and was startled when he did not. Bell said he felt that there was little harm and some good in Zukav's book. Quantum physics was marvellous, but so inaccessible that anything that allowed outsiders to start conversations with physicists was fine with him.

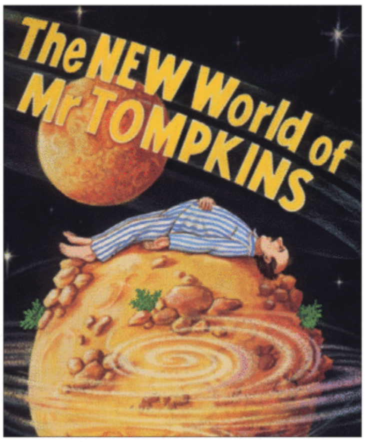
Although we classify such books as "popular science", it is a category that embraces quite a bit. Popular science can refer to science that is popular with the public – dinosaurs, superbugs, cosmology and the like. It can refer to science that appears in literature, such as plays by Tom Stoppard. Or it can refer to "expository" works that set out to explain scientific ideas to non-scientists, be they written by scientists such as Richard Feynman or non-scientists like Zukav.

Elizabeth Leane, a lecturer at the University of Tasmania in Australia, has recently looked at such expository works in a new book called *Reading Popular Physics*. In it, she notes that such material plays a strong role in shaping the interface between science and culture, as it is almost always what novelists and playwrights consult when learning about science. Stoppard's play *Hapgood*, for instance, begins with a quote from a Feynman popularization about how the double-slit experiment contains "the *only* mystery".

Strategies of popularization

It is tempting to view popularizations in what I call the "Moses and Aaron" framework. Just as Moses, the prophet, wrests knowledge from the beyond that his brother and spokesman Aaron transmits to the masses, so scientists discover truths about nature that popularizers translate into everyday language. The Moses and Aaron model treats popularization as a single skill directed at a single community.

But Leane points out that popular exposition is far more complex. There is a variety of literary tools – or "textual strategies" as she calls them – for starting conversations, and different branches of science lend themselves better or worse to each. Using Paul Davies' triage of the physics frontiers into "the very small, the very large and the very complex", Leane describes the characteristic strategies used to popularize cosmology, quantum physics and chaos/complexity.



Story time "Popular science" has great power.

Explaining quantum theory, for instance, seems both to require and to shipwreck metaphors – for what is "down there" just does not behave like what is "up here". A common tool is to anthropomorphize, personifying elements of the quantum world. Certain books, such as George Gamow's *Mr Tompkins Explores the Atom*, use such anthropomorphic metaphors guilelessly, trusting the reader to recognize the difference between what is literal and what is not. Others, especially the "new-age" accounts, tend to deliberately blur that difference for their own ends. These include Zukav, who moves from a claim about the role of observation on atomic systems to the claim that "physics has become a branch of psychology".

Expositions of cosmology tend to appropriate the narrative conventions of the novel. These are "mythic" to the extent that they depict the course of science as having a smooth linear structure and as heading towards an ultimate, yet-to-be-achieved goal, when in reality science follows blind alleys, false starts and dead ends. Leane shows that while a book like Steven Weinberg's *The First Three Minutes* denounces the blurring of myth and science, it also deploys "mythic narrative structures" in depicting unification theories as the ultimate goal of the universe.

Finally, Leane examines James Gleick's *Chaos* and other books that emphasize details of person, place and time. Expositions of this kind, she says, often borrow from established literary character types in their portrayals of scientists and scientific advance; Gleick favours the hard-nosed detective "mixing it up" with the world. But these character types carry additional baggage – they tend to be loner males with dysfunctional families – which can distort the underlying story.

Many strategies discussed by Leane appear in "the top 10 books from the last 20 years" that were picked by the *Physics World* editorial team last October (p33). For example, Stephen Hawking's *A Brief History of Time* (which topped the list) presents a linear progression of the universe in a cosmic evolutionary narrative that starts with the Big Bang and culminates not with the end of the universe, but with the end of physics – the search for a "theory of everything". Dava Sobel's *Longitude* (in fourth place) is more historical and character-based, focusing on an artefact and its creator. Feynman's *What do You Care…?* (ninth) is a classic example of the cultivation of a popular stereotype of the scientist.

The critical point

All too often, Leane writes, the public and even non-science scholars treat popular expositions of science naively as "information sources" rather than as "textual reconstructions". This can create profound misunderstanding, and Leane traces much of the hostility between the sciences and the humanities to distorted images of the other side gained from the innocent use of popularizations. Leane's work shows that the literary character of popularizations should not be ignored just because they are about science, but should be as much the subject of literary analysis as any other form of writing.

Starting conversations – as Bell told me that Zukav's book does – is one thing, but maintaining and strengthening such conversations is another. Encouraging good conversation requires understanding conversational strategies – both their use and misuse – and for this purpose Leane's book provides a fruitful beginning. For while the long-term strength of science depends on many things – funding, reliable careers and good teaching, among others – it also depends on healthy, long-term conversations between scientists and non-scientists.

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Nuclear politics

The sentiments expressed by Sidney Drell in his forum article "The nuclear threat: a new start" (February pp16–17) are laudable, but it was disappointing to find this almost entirely political story in isolation. The article, which outlined the prospects for reducing weapons stockpiles under the new US administration, would have been more pertinent as an introduction to a series describing the technology used in detecting nuclear-testing activity. It would have been interesting to discuss the specific equipment and methods used, together with the analysis and correlation techniques – along with an indication of how sensitive and reliable they are (if the information is not classified). It is far easier to detect an explosive event than it is to detect and quantify weapons stores, which is a key factor for any negotiated solution. Apart from deductions based on actual inspection and satellite surveillance, are there other techniques that can be applied to this issue?

The physics problems are perhaps easier to solve than the human ones, and a psychologist's viewpoint on the latter would be complementary. For example, given the low esteem in which politicians are held throughout the world, would you trust them not to hide a few bombs in a deep bunker, in violation of any agreement to scrap them? Would it be in their national interest to do this? Public perceptions can be changed, as demonstrated by attitudes to nuclear power, but it is usually a slow process and needs dedicated promotion and good justification. The key to progress is recognizing that any solution must be considered from the perspective of those making the decisions. For politicians, the idealized reasons will be coloured by considerations of what is in it for them, their political party and their country, along with the short-term benefits – particularly before the next election.

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The ratings game

How sad to read a supposedly serious debate among distinguished physicists (February p19) about which combinations of the latest Research Assessment Exercise (RAE) ratings represent a university physics department's true strengths. Your comment that "clearly no ranking system is perfect" was accurate and to the point. We live in difficult times, and while there may occasionally be little choice for scientists but to play the bureaucrats' games, we should not accord them any real meaning. What is the difference between a department ranked as "world leading" and one judged "internationally excellent"? Which rating should one prefer? To lead, one must have competitors, but into which category would the bureaucrats have placed, say, Albert Einstein's work of 1905? The late Geoffrey Wilkinson, once of Imperial College London and a Nobel laureate in chemistry, described exercises like these as "the usual fashionable claptrap". We need his penetrating wisdom today.

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Art meets science

I read with great interest Calla Cofield's feature article "Underneath the surface" (February pp32–35) on art and science. I was one of the researchers who examined the paintings that were attributed to Jackson Pollock, and I believe that she is not entirely correct in her assumption that scientists have yet to learn how to work and communicate with art historians.

My colleagues and I have enjoyed long careers in art galleries and museums. For example, the Straus Center for Conservation and Technical Studies is part of the Harvard Art Museum, where our extensive publications rely on collaborations between scientists, art historians and conservators. We also provide undergraduate- and graduate-level classes to students in the Department of History of Art and Architecture at Harvard University. As we are scientists in a non-science environment, communication is crucial in our day-to-day activities. I do not believe that communication issues lay at the centre of the debate over whether Pollock created the paintings in question.

On a more trivial note, the article contained two factual errors that I would like to correct. The substance we detected on the paintings in question was Pigment Red 254, not 245 as stated in the article, and it was commercially available after 1986 rather than the 1990s.

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Comments from *physicsworld.com*

Space scientists and environmentalists alike were aghast when NASA's $270m Orbiting Carbon Observatory crashed into the Pacific Ocean after part of its launch vehicle (known as a fairing) failed to jettison properly. This month's news section includes more details of the loss (see p6), while a *physicsworld.com* article posted on the day of the crash ("NASA's carbon-dioxide mission fails" 24 February) provoked both dismay and cynicism.

Conspiracy theorists will go nuts on this. [The satellite] was never meant to work, as it would have uncovered the truth – the truth that we're all being taxed to the hilt for nothing we have control over. Or is it just an unfortunate fate for a potentially scientifically important experiment?
rlockyer, UK

It's really tempting to think about conspiracy. However, why would NASA design a mission targeted to fail? It would be cheaper to simply not do the mission. Besides, NASA is not alone in the world of space research. Other countries like Japan, or the European Space Agency in Europe, could perform similar experiments.
cmhintl, Spain

Why was no fail-safe system installed? It is obvious that if the fairing failed to release, then the mission would be lost, yet there is no mention of any second system in place. Even a simple clock timed to trigger a second, parallel deployment system would have saved the day. I believe the failure to deploy any fail-safe system was as irresponsible as it gets.
Chris Coles, US

I guess that part of the problem here is budget restraints. Maybe it would be ideal to have a Mercedes-Benz, but you can only afford a Chevy, so what can you do? This is just a reminder that rocketry is still subject to uncertainty and shouldn't be taken for granted. Each successful launch is a feat of engineering.
jjeherrera, Mexico

Failure analysis: sounds like that gravity thingy.
baddream, US

physicsworld.com

Read these comments in full and add your own at physicsworld.com

Canoe do physics?

How disappointing that Olympic canoeist David Florence, who has a degree in physics, sees no direct applications of physics in his sport (March p65). How can he be unaware of the considerable scientific and engineering effort supporting UK sport? Physics underpins materials science, fracture mechanics, aerodynamics, hydrodynamics, performance evaluation, etc. Without these things, he would be an unlikely medallist.

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Students and the LHC

Your news article "CERN hold-up hurts graduate students" (March p14) rightly highlights the plight of researchers craving data from the Large Hadron Collider to complete their theses. A similarly painful problem occurred in the early 1990s when the mirror of the Hubble Space Telescope proved defective. It is to be hoped that CERN will not deal with the problem by ransacking the budget and making short-sighted cuts – as the Particle Physics and Astronomy Research Council (the forerunner of the UK's Science and Technology Facilities Council) did when the rocket carrying the original Cluster satellites blew up in 1996. It seemed to some who worked at the council at the time that the only thing that mattered was space-based solar astronomy.

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Unitary disagreements

I agree with Michael Albrow (March p18) that "you always need a numerator" to accompany units such as "m^{-2}" or "s^{-1}", and would like to reassure him that this need is not just a limitation of his conceptual abilities. The problem of the missing numerator arises from some people insisting that everything must be expressed in terms of mass, length and time (and, if they are feeling generous, electric charge). Take angles. They clearly have both units and dimensions, but because these cannot be expressed in such terms, angles are often regarded as dimensionless – in other words, pure numbers. Try telling that to a navigator!

No physical quantity can be expressed as a pure number. Anyone who doubts this might like to try turning to the person next to them on the train and offering to give them "100" for their briefcase without specifying whether it is 100 pounds or 100 pennies and seeing what reaction they get. In the case of the density of cars in a car park, the unit is "car m^{-2}", not simply "m^{-2}" as Clifford Jones claims.

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The confusion over "unimaginable" inverse units clearly stems from the all-too-common failure to use the SI nomenclature correctly. The SI unit of population density is neither "m^{-2}" nor "persons m^{-2}", but "mol m^{-2}". However, this failure is understandable, since we must recognize that the SI system is biased in favour of chemical over mesoscopic applications. I speak, of course, merely as one of the 11.2 femtomol of human beings currently dwelling on this planet, who parks 1.66 yoctomol of vehicle in my car park.

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Next month in Physics World

Physics 2.0
Physicists were the pioneers of the Web, but they have been puzzlingly slow in adopting new social tools like blogging and wikis. How can we start a better online collaboration?

Searching for Schön
The physicist Jan Hendrik Schön was fired from Bell Labs in 2002 after faking data and publishing fraudulent papers in *Nature* and *Science*. But what motivated one of the biggest scientific scandals of all time?

Cardano's world
The two main ingredients of quantum theory – probability and complex numbers – can be traced back to one of the most colourful characters of the Italian Renaissance, Girolamo Cardano

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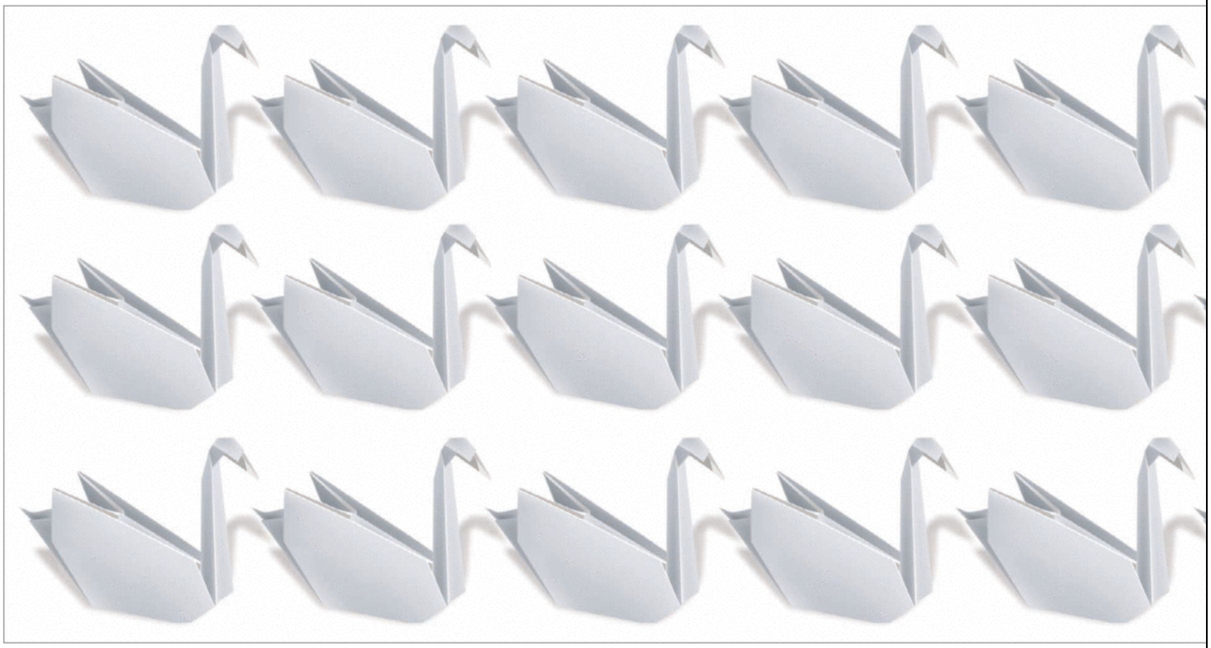

In search of the black swans

The publish-or-perish ethic too often favours a narrow and conservative approach to scientific innovation. **Mark Buchanan** asks whether we are pushing revolutionary ideas to the margins

In 1890 an electricity company enticed the German physicist Max Planck to help it in its efforts to make more efficient light bulbs. Planck, as a theorist, naturally started with the fundamentals and soon became enmeshed in the thorny problem of explaining the spectrum of black-body radiation, which he eventually did by introducing the idea – a "purely formal" assumption, as he then considered it – that electromagnetic energy can only be emitted or absorbed in discrete quanta. The rest is history. Electric light bulbs and mathematical necessity led Planck to discover quantum theory and to kick start the most significant scientific revolution of the 20th century.

Around the same time, Planck's colleague Wilhelm Röntgen was experimenting with cathode rays when he noticed an odd glow coming from a fluorescent screen some distance away that was not part of the intended experiment; in so doing he discovered X-rays, and helped propel medicine into the modern era. Of course, it is not just German scientists who make world-changing discoveries by unexpected paths. In 1964 US physicists Arno Penzias and Robert Wilson famously detected the cosmic microwave background radiation in annoying noise that they could not eliminate from their cryogenic microwave receiver at Bell Labs.

This is how discovery works: returns on research investment do not arrive steadily and predictably, but erratically and unpredictably, in a manner akin to intellectual earthquakes. Indeed, this idea seems to be more than merely qualitative. Data on human innovation, whether in basic science or technology or business, show that developments emerge from an erratic process with wild unpredictability. For example, as physicist Didier Sornette of the ETH in Zurich and colleagues showed a few years ago, the statistics describing the gross revenues of Hollywood movies over the past 20 years does not follow normal statistics but a power-law curve – closely resembling the famous Gutenberg–Richter law for earthquakes – with a long tail for high-revenue films. A similar pattern describes the financial returns on new drugs produced by the bio-tech industry, on royalties on patents granted to universities, or stock-market returns from hi-tech start-ups.

What we know of processes with power-law dynamics is that the largest events are hugely disproportionate in their consequences. In the metaphor of Nassim Nicholas Taleb's 2007 best seller *The Black Swan*, it is not the normal events, the mundane and expected "white swans" that matter the most, but the outliers, the completely unexpected "black swans". In the context of history, think 11 September 2001 or the invention of the Web. Similarly, scientific history seems to pivot on the rare seismic shifts that no-one predicts or even has a chance of predicting, and on those utterly

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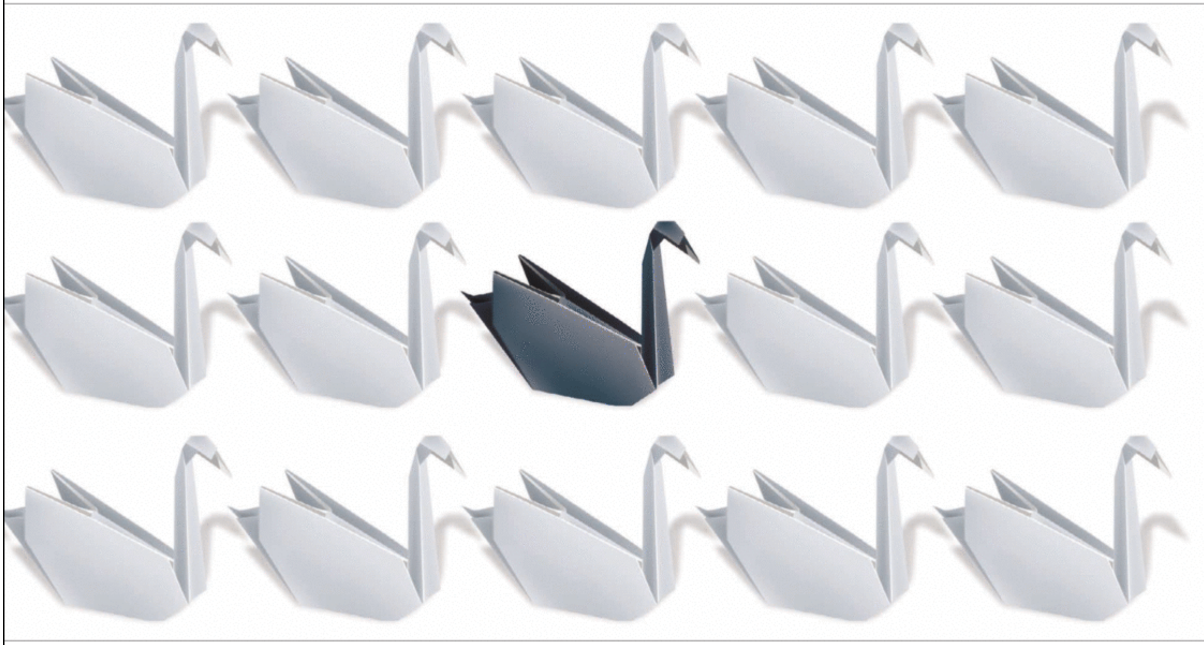


profound discoveries that transform worlds. They do not flow out of what the philosopher of science Thomas Kuhn called "normal science" – the paradigm-supporting and largely mechanical working out of established ideas – but from "revolutionary", disruptive and risky science.

Squeezing life out of innovation

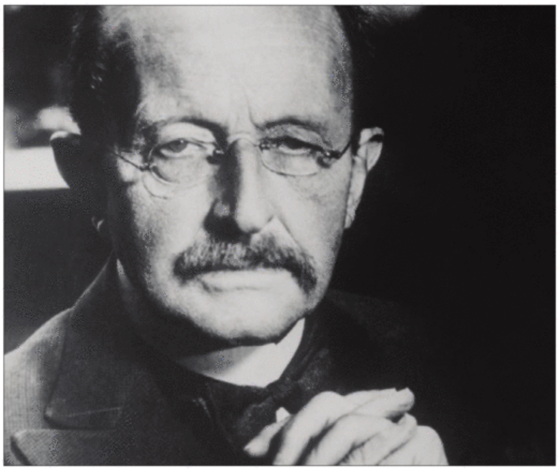
All of which, as Sornette has been arguing for several years, has important implications for how we think about and judge research investments. If the path to discovery is full of surprises, and if most of the gains come in just a handful of rare but exceptional events, then even judging whether a research programme is well conceived is deeply problematic. "Almost any attempt to assess research impact over a finite time", says Sornette, "will include only a few major discoveries and hence be highly unreliable, even if there is a true long-term positive trend."

This raises an important question: does today's scientific culture respect this reality? Are we doing our best to let the most important and most disruptive discoveries emerge? Or are we becoming too conservative and constrained by social pressure and the demands of rapid and easily measured returns? The latter possibility, it seems, is of growing concern to many scientists, who suggest that modern science is in danger of losing its creativity unless we can find a systematic way to build a more risk-embracing culture.

The voices making this argument vary widely. For example, the physicist Geoffrey West, who is currently president of the Santa Fe Institute (SFI) in New Mexico, US, points out that in the years following the Second World War, US industry created a steady stream of paradigm-changing innovations, including the transistor and the laser, and it happened because places such as Bell Labs fostered a culture of enormously free innovation. "They brought together serious scientists – physicists, engineers and mathematicians – from across disciplines", says West, "and created a culture of free thinking without which it's hard to imagine how these ideas could have come about."

Unfortunately, today's academic and corporate cultures seem to be moving in the opposite direction, with practices that stifle risk-taking mavericks who have a broad view of science. At universities and funding agencies, for example, tenure and grant committees take decisions based on narrow criteria (focusing on publication lists, citations and impact factors) or on specific plans for near-term results, all of which inherently favour those working in established fields with well-accepted paradigms. In recent years, tightening business practices and efforts to improve efficiency have also driven corporations in a similar direction. "That may be fine in the accounting department," says West, "but it's squeezing the life out of innovation."

Are we doing our best to let the most important and most disruptive discoveries emerge? Or are we becoming too conservative and constrained by social pressure and the demands of rapid and easily measured returns?



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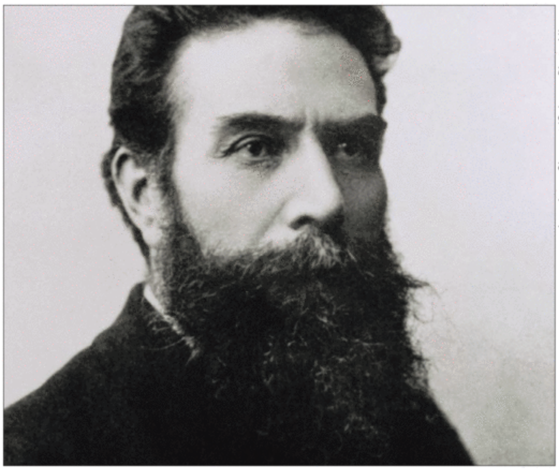

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Serendipity Max Planck (above left) and Wilhelm Röntgen (above right) both made important discoveries in unexpected ways. The transistor (opposite left) and the laser (opposite right) are also products of serendipity.

The black swans of science

A key problem, suggests mathematical physicist Eric Weinstein of the Natron Group, a hedge fund in New York, is that it is too easy for scientists in the "establishment" of any field to cut down new ideas, and to do so without really putting anything at risk, thereby leading to a culture that is systematically biased toward caution. "High-risk science is much more associated with figures from the past," he says.

The result, he suggests, is that science is becoming less a "bottom-up" enterprise of free-wheeling exploration – energized by the kind of thinking that led Einstein to relativity – and more a "top-down" process strongly constrained by social conformity, with scientific funding following along fashionable lines. The publish-or-perish ethic, in particular, strongly rewards those scientists doing more or less routine technical work in established fields, and punishes more risky work exploring unproven ideas that may take a considerable period of time to reach maturity.

This is especially damaging given the disproportionate benefits that come from the most important discoveries, which seem to be inherently unpredictable in both timing and nature. As Taleb argues persuasively in *The Black Swan*, any sensible long-term strategy in a world dominated by extreme and unpredictable events has to accept, and even embrace, that unpredictability. He illustrates the idea in the financial context. People investing in venture-capital start-ups, for example, have to expect continual losses in the short term, and bank on the fact that they will ultimately make up for those losses by hitting on a few really big winners in the long run.

More generally, Taleb's basic investing strategy – which could easily be translated into research terms – is to put a fair fraction of funds into very conservative processes that will not lose their value, even if they have little chance of producing big gains; and to put a small but reasonable fraction into high-risk, high-reward settings, thereby gaining exposure to the potentially enormous gains from these investments. These may be unpredictable in detail, but the statistics makes the expected long-term pay-off very high.

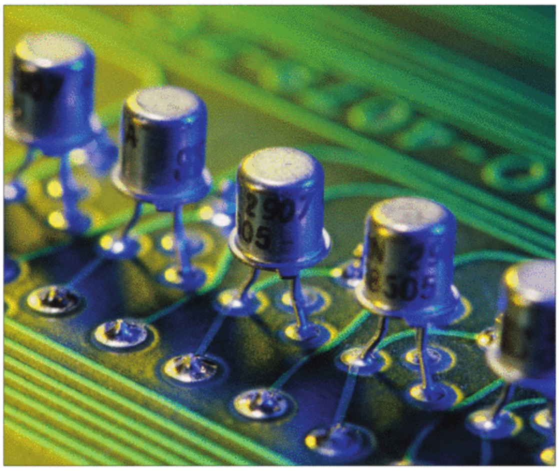
Even so, it takes discipline and fortitude to stick with this strategy. As Taleb points out, if everyone around you believes in the dominance of normal statistics, then they will think that you are foolish, and the short-term evidence will probably back them up. You will be losing money in the short run, seeing no returns, and this may go on for a considerable time. The same goes for high-risk science relative to research pursuing more short-term goals. In the short run, what the mavericks do will almost always seem less successful, perhaps even like wasting their time, and it is easy to think that this is the kind of research we should not pursue, even if this is actually very much mistaken.

This is a trap, West suggests, into which modern science planning has fallen. "My fear", he says, "is that by eliminating the mavericks we end up hobbling our ability to discover the big, new ideas – the next transistor. That's a serious and tragic error."

Hill climbers and valley crossers

What is to be done? Some funding agencies, of course, have long recognized the need to fund "blue sky" research – work that may be high risk but may also be high reward. In the US, for example, the National Science Foundation has high-risk programmes in areas ranging from basic physics through to anthropology. Similarly, the European Commission, even in the decidedly practical area of information and communications technology, has a programme in future and emerging technologies that only funds research identified as having the potential to overturn existing paradigms. Perhaps the most famous centre that supports high-risk science demanding long-term commitment and transdisciplinary involvement is the SFI, which is privately funded. In the past few years, the SFI has been joined by a host of new centres, such as the Perimeter Institute for Theoretical Physics in Waterloo, Canada, a public–private initiative strongly aided by the Canadian government and founded in 1999 by Mike Lazaridis, chief executive of Research in Motion, which created the BlackBerry.

But physicist Lee Smolin, currently at the Perimeter Institute, suggests that science overall requires a much broader and more coherent approach to risky science. To see the kinds of policies needed, he suggests, it is



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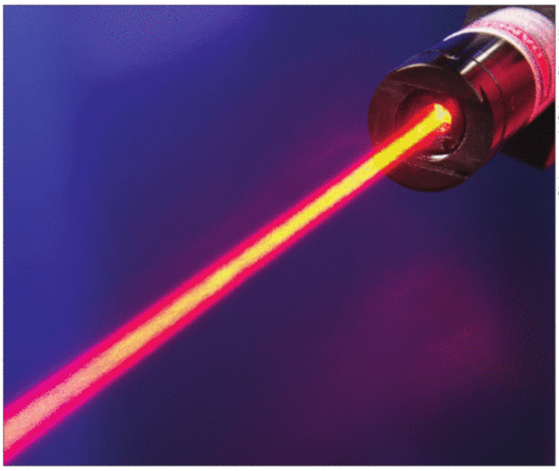

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useful to note that scientists, at least in some rough approximation, follow working styles of two very different kinds, which mirror Kuhn's distinction between normal and revolutionary science.

Some scientists, he suggests, are what we might call "hill climbers". They tend to be highly skilled in technical terms and their work mostly takes established lines of insight that pushes them further; they climb upward into the hills in some abstract space of scientific fitness, always taking small steps to improve the agreement of theory and observation. These scientists do "normal" science. In contrast, other scientists are more radical and adventurous in spirit, and they can be seen as "valley crossers". They may be less skilled technically, but they tend to have strong scientific intuition – the ability to spot hidden assumptions and to look at familiar topics in totally new ways.

To be most effective, Smolin argues, science needs a mix of hill climbers and valley crossers. Too many hill climbers doing normal science, and you end up sooner or later with lots of them stuck on the tops of local hills, each defending their own territory. Science then suffers from a lack of enough valley crossers able to strike out from those intellectually tidy positions to explore further away and find higher peaks.

"This is the situation I believe we are in," says Smolin, "and we are in it because science has become professionalized in a way that takes the characteristics of a good hill climber as representative of what is a good, or promising, scientist. The valley crossers we need have been excluded or pushed to the margins."

Smolin suggests that we need to shift the balance to include more valley crossers, and that this should not really be too hard to do if we take a determined approach. What we need, in general, is to put policies in place that will judge young scientists not on whether they are linked into programmes established decades ago by now-senior scientists, but solely on the basis of their individual ability, creativity and independence. Some specific steps that might be taken, he suggests, include ensuring that departments strong in any established field also include scientists with diverging views. Similarly, conferences focusing on one research programme should be encouraged to include participants from competing rival programmes.

In addition, funding agencies should develop a means of penalizing scientists for ignoring the really "hard" problems, and of rewarding those who attack long-standing open issues. Perhaps, Smolin suggests, an agency or foundation could create some really long-term fellowships to fund young researchers for, say, 10 years, thus allowing them the space to pursue ideas deeply without the pressure for rapid results.

The wisdom of crowds

Weinstein suggests another idea – that we should borrow some ideas from financial engineering and make scientists back up their criticisms by taking real financial risks. You think that some new theory is utterly worthless and deserving of ridicule? In the world Weinstein envisions, you could not trash the research in an anonymous review, but would buy some sort of option giving you a financial stake in its scientific future, an instrument that would pay off if, as you expect, the work slides noiselessly into obscurity. The money would come from the theory's proponents, who would similarly benefit if it pans out into the next big thing.

Weinstein's point is that markets, in theory at least, work efficiently and – putting the current financial meltdown to one side – lead to the accurate valuation of products. They exploit the "wisdom of crowds", as a popular book of the same title recently put it. Take the famous electronic prediction markets at the University of Iowa, which pool the views of thousands of diverse individuals and consistently seem to give better predictions than any expert. For example, they predicted last year's US presidential election correctly to within half a percentage point.

Could the same not be done for weighing up the likely value of scientific ideas? Those ideas, Weinstein argues, do not get weighed fairly today. As he points out, mavericks get their papers routinely rejected for what they feel are unfair reasons, and they often feel suppressed by the mainstream community, while mainstream scientists think it is perfectly obvious that the ideas in question are ludicrous and should not waste the community's time. Current research practice lacks any mechanism that would arrange a fruitful meeting

Current research practice lacks any mechanism for a fruitful meeting between mavericks and the mainstream community

Santa Fe Institute

Perimeter Institute

Back to basics
The Santa Fe Institute (left) and the Perimeter Institute (right) promote an independent, curiosity-driven approach to physics.

between the two – letting the maverick's ideas gain free expression while at the same time letting the critics take a real stake based on their own knowledge.

"What do you do when you're confronted with some maverick with a crazy idea?" he asks. "You've tried it, your students have tried it, and you know it's almost certain to fail. Why can't you use this knowledge to your own advantage? At the moment, you just can't express your view in the market efficiently."

The situation is directly akin to a trader on the stock market who has sound knowledge, for example, that a certain asset is currently undervalued, but, for whatever reason, cannot buy it and so benefit from that knowledge. In financial theory, a market of this kind of called "incomplete", and its incompleteness leads to inefficiency, because all relevant knowledge does not get expressed in the market.

To counter the analogous inefficiency in the case of science, Weinstein suggests, it should be possible for the critic to take a position on the idea. "It would be more efficient," he says, "if the maverick could demand of the critic, if my theory is so obviously wrong, why don't you quantify that by writing me an options contract based on future citations in the top 20 leading journals secured by your home, furniture, holiday home and pension?"

That may be going a little over the top, but it makes the point. Bringing such possibilities into play, Weinstein suggests, would move research practice closer to the "efficient frontier" – the place where ideas get judged fairly based on all available knowledge, and risk takers, rather than being suppressed by social conformity, get encouraged by those taking a financial stake in the potentially enormous consequences of their success. Such mechanisms, Weinstein argues, would help avoid the effective censorship that often afflicts peer review, and that currently keeps research on the cautious side of the efficient frontier.

As one specific idea, Weinstein envisions something he calls synthetic tenure, which resonates with Smolin's call for long-term fellowships. Today, he suggests, young researchers can easily be deterred from tackling really hard problems because they fear for their careers if they work on an issue for a decade and do not make significant progress. To give exceptional researchers the confidence to tackle hard problems, he suggests that an agency or foundation might make an agreement by which they would guarantee that person a good position in the future in some stimulating field, if their project does not work out.

The new Einsteins

It is precisely this kind of thing, Smolin argues, that could be helpful. If more scientists started pushing for a return to independent, curiosity-driven science, then this might also encourage the big funding agencies and the other new sources of private funds such as the Perimeter Institute or the Howard Hughes and Gates Foundations. Indeed, Weinstein suggests, these new structures may have similarities with recent developments in financial engineering with the new structures emerging as "intellectual hedge funds" in response to perceived inefficiencies of more traditional agents, which play the role of more risk-averse mutual funds.

The price to pay for not moving to re-establish such independence will lie in a failure to realize the huge and unpredictable discoveries that move science forward most in the long term – discoveries made possible only when individuals leap out of what is comfortable and accepted, and wander out into spaces unknown. It is the true enormity of the potential gains that makes this goal of reaching the "efficient frontier" so important. If today we seem to have a dearth of new Einsteins, Smolin suggests, this may just reflect that we have become a little too risk averse.

New Einsteins, he points out, will not be working in areas that have been well established for decades. They may not even work in an area linked to the name of any established, senior scientist. New Einsteins may be slipping out of view and out of science altogether just because our scientific culture currently simply has no way of encouraging them. ■

The (unfortunate) complexity of the economy

Jean-Philippe Bouchaud explains how physicists are bringing new ideas and methodologies to the science of economics

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The current financial crisis puts the science of economics under huge pressure. Classical economics, which was formalized in the 1950s and the 1960s, is the theory that still shapes much of economic thinking today. Its foundations are the assumptions of economic equilibrium and rational expectations. In theory, deregulated markets should be efficient: prices faithfully reflect the underlying fundamental values, while markets ensure optimal allocation of resources. Any mispricing or forecasting error should be quickly corrected by economic agents, who act with perfect rationality and absolute knowledge about all future states of the world and their probabilities. These equilibrated markets should therefore be stable: crises can only be triggered by exogenous events – such as natural catastrophes, terrorist attacks or political disruptions – and never by the dynamics of the market itself, such as speculation or complex financial engineering. This, however, stands in contrast to most financial crashes, including the latest one, which all seem to be caused by irrational market bubbles.

Classical economics has deeply influenced scores of decision-makers high up in government agencies and financial institutions. The last 20 years of deregulation have been prompted by the argument that constraints of any kind prevent the markets from reaching their supposedly perfect efficient equilibrium state. Some of those decision-makers are now "in a state of shocked disbelief", as Alan Greenspan, the American economist and former chairman of the US Federal Reserve, declared recently. He has now admitted that he had put too much faith in the self-correcting power of free markets and had failed to anticipate the self-destructive power of wanton mortgage lending. However, a large fraction of economists still abide by the notions of economic equilibrium and rational expectations. These concepts have not only dominated economics, but also permeated international politics, sociology and law.

Unfortunately, nothing is more dangerous than dogmas donned with scientific feathers. The current crisis might offer an excellent occasion for a paradigm change, previously called for by prominent economists like John Maynard Keynes, Alan Kirman and Steve Keen. They have forcefully highlighted the shortcomings and contradictions of the classical economic theory, but progress has been slow. The task looks so formidable that some economists argue that it is better to stick with the implausible but well-corseted theory of perfectly rational agents than to venture into modelling the infinite number of ways agents can be irrational.

Physicists, however, feel uncomfortable with theories not borne out by (or even blatantly incompatible with) empirical data. But could the methodology of physics really contribute to the much-awaited paradigm shift in economics? Such an approach is called econophysics (a term coined in 1995 by Boston University physicist Gene Stanley), a field that effectively emerged from a famous 1987 conference between physicists and economists held at the Santa Fe Institute in New Mexico. After 20 years or so of "econophysics", and about 1000 papers published on the *arXiv* preprint server (a new section "Quantitative Finance" was created in December 2008), it is perhaps useful to give a personal bird's eye view of what has been achieved so far and what might be taught, in the long run, in order to foster a better grasp of the complexity of economic systems.

At a Glance: Econophysics

- The present financial meltdown reflects the underlying flaws in the current economics paradigm, which is based on the assumptions of economic equilibrium and rational expectations
- Econophysics is the application of the methods of statistical physics to economics problems and is a more empirical and intuitive approach than that taken by economists. Also, it focuses more on mechanisms and analogies, rather than on axioms and theorem proving, which is standard practice in economics
- Physicists have (re)discovered that the distribution of price changes, of company sizes, and of individual wealth, among other things, can be described by power laws. This is intriguing because many complex physical systems share the same dynamics
- Physicists have also tried to model the economy by using "toy" models inspired by physical systems, such as the random field Ising model and an approach called minority games. Although simplified, these toy models offer a more realistic perspective of the economy than traditional mainstream models

The intuition of physicists

Econophysics is in fact a misnomer, since most of its scope concerns financial markets. To some economists, finance is a relatively minor subfield and any contribution, even the most significant, can only have a limited impact on economics science at large. I personally strongly disagree with this viewpoint: recent events confirm that hiccups in the financial markets can cripple the entire economy.

From a more conceptual point of view, financial markets are an ideal laboratory for testing several fundamental concepts of economics. Are prices really such that supply matches demand? Are price moves primarily due to news? (The answer to both these questions seem to be clear "no", as I have argued elsewhere, see arXiv:0803.1769 and arXiv:0809.0822, respectively) The terabytes of data spat out everyday by financial markets allow one (in fact compel one) to compare in detail theories with observations. This proliferation of data should soon concern other spheres of economics and social science: credit cards and e-commerce

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Panic on the market A trader on the stock exchange watches the market collapse.

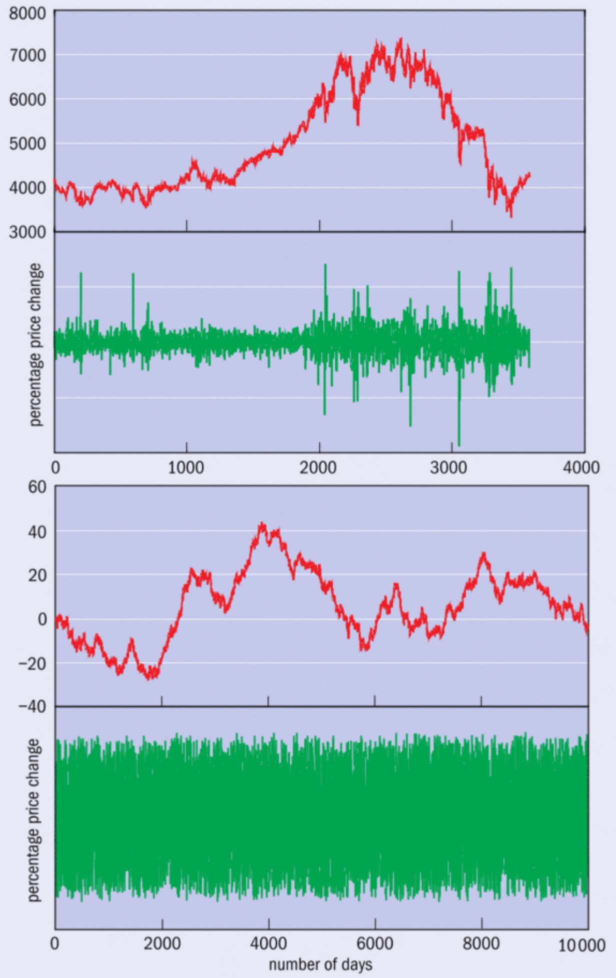
will allow one to monitor consumption in real time and to test theories of consumer behaviour in great detail (see D Sornette *et al.* 2004 *Phys. Rev. Lett.* **93** 228701). So we must get prepared to deal with huge amounts of data, and to learn to scrutinize them with as little prejudice as possible, while still asking relevant questions. These will start from the most obvious ones – those that need nearly no statistical test at all because the answers are obvious, as figure 1 exemplifies – and only then delve into more sophisticated problems. As I will try to illustrate, the very choice of the relevant questions, which ultimately leads to a deeper understanding of the data, is often sheer serendipity: more of an art than a science. That intuition, it seems to me, is well nurtured by an education in the natural sciences, where the emphasis is on mechanisms and analogies, rather than on axioms and theorem proving.

Faced with a mess of facts to explain, Richard Feynman advocated that we should choose one of them and try our best to understand it in depth, with the hope that the emerging theory will be powerful enough to explain many more observations. In the case of financial markets, physicists have been immediately intrigued by a number of phenomena described by power laws. For example, the distribution of price changes, of company sizes and of individual wealth all have a power-law tail, which is to a large extent universal. The power-law distribution of price changes goes against the popular Black–Scholes model – the financial model used to evaluate the price of equity options – that assumes fluctuations to be Gaussian. Unlike the Gaussian distribution, power laws have a long tail that accounts for rare extreme events, such as market crashes. Furthermore, the activity and volatility of markets have a power-law correlation in time, reflecting their *intermittent* nature: quiescent periods are intertwined with bursts of activity, on all timescales. Again, as figure 1 testifies, this is obvious to the naked eye.

Power laws leave most economists unruffled (aren't they, after all, just another fitting function?), but they immediately send physicists' imagination churning. The reason is that many "complex" physical systems display very similar intermittent dynamics: velocity

> The activity and volatility of markets have a power-law correlation in time, but while such laws leave most economists unruffled, they immediately send physicists' imaginations churning

1 Markets: the FTSE versus a Gaussian simulation



Shown here are two representations of the time evolution of a typical market. In the FTSE index (top), the upper curve shows the price time series and the lower curve represents the daily price changes. The corresponding charts for synthetic price changes (bottom) assume the standard Black–Scholes (Gaussian) model. The difference is obvious to the naked eye, and the salient statistical features of real price changes stand out immediately by comparing the bottom graphs: large spikes correspond to large up or down market moves. The intermittent nature of the dynamics is also apparent: large moves are clustered together, suggesting analogies with intermittent dynamics observed in other complex systems, such as turbulent flow (see figure 2), Barkhausen noise (see figure 3) and crack or earthquake dynamics.

fluctuations in turbulent flows (figure 2), avalanche dynamics in random magnets under a slowly varying external field (figure 3), teetering progression of cracks in a slowly strained disordered material, and so on. The interesting point about these examples is that while the *exogenous* driving force is regular and steady, the resulting *endogenous* dynamics is complex and jittery. In these cases, the non-trivial (or as physicists say "critical") nature of the dynamics comes from collective effects: individual components have a relatively simple behaviour, but their interactions lead to new, emergent phenomena. The whole is fundamentally different from any of its elementary subparts. Since this intermittent behaviour appears to be generic for physical systems with both heterogeneities and interaction, it is tempting to think that the dynamics of financial markets, and more generally of economic systems, does reflect the same underlying mechanisms.

Modelling the economy

An example of the application of a physics toy model to economics is the random field Ising model (RFIM), a statistical-physics model that accounts for how spins order within a disordered magnet; in economics, it attempts to describe situations where there is a conflict between personal opinions, public information and social pressure (see J P Sethna *et al.* 2001 *Nature* **410** 242).

Imagine a collection of traders all having different *a priori* opinions, say optimistic (buy) or pessimistic (sell). Traders are influenced by some slowly varying global factors, such as interest rates, inflation, earnings and dividend forecasts. One assumes no shocks whatsoever in the dynamics of these exogenous factors, but posits that each trader is also influenced by the opinion of the majority. They conform to it if the strength of their *a priori* opinion is weaker than their herding tendency. So if all the agents made up their mind in isolation (zero herding tendency), then the aggregate opinion would faithfully track the external influences and, by assumption, evolve smoothly. But surprisingly, if the herding tendency exceeds some finite threshold, then the evolution of the aggregate opinion jumps discontinuously from optimistic to pessimistic as global factors deteriorate only slowly and smoothly. Furthermore, some *hysteresis* appears. Much as supersaturated vapour refuses to turn into a liquid, optimism is self-consistently maintained. In order to trigger a crash, global factors have to degrade far beyond the point where pessimism should prevail. These factors must then improve much beyond the crash tipping point before global optimism is reinstalled, again somewhat abruptly.

Although the model is highly simplified, it is hard not to see some resemblance with all bubbles in financial history. The consecutive reports about the level of leverage used by banks to pile up bad debt should have led to a self-correcting, soft landing of the global markets – or so the efficient market theory would predict. Instead, collective euphoria screened out all the bad omens until it became unsustainable. Any small, anecdotal event or insignificant news item is then enough to spark a meltdown. This exemplifies in a vivid way the breakdown of one of the cornerstones of classical economics, namely that an ensemble of heterogeneous and interacting agents can be replaced by a single "representative" one (criticized in Kirman's 1992 essay "Whom or what does the representative individual represent?", *J. Economic Perspectives* **6** 117).

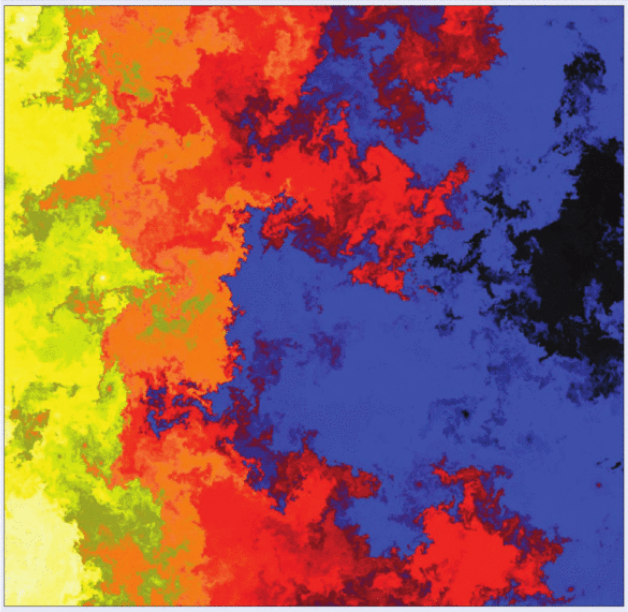
In the RFIM, this scenario is impossible: the behaviour of the crowd is fundamentally different from that of any single individual. Much as in statistical physics or materials science, the link between the micro and the macro remains one of the main theoretical challenges in economics: how, in other worlds, does one infer the aggregate behaviour (for example the aggregate demand) from the behaviour of individual elements?

Another, richer, family of models used in econophysics is called minority games, a framework in which agents learn to compete for scarce resources. A crucial aspect here is that the decisions of these agents *impact* on the market: prices move as a result of these decisions. A remarkable result is the observation, within this framework, of a genuine phase transition as the number of speculators increases. So we go from a predictable market where agents can eke out some profit from their strategies (phase 1) to an overcrowded market where these profits vanish or become too risky (phase 2). Around the critical point where predictability disappears and efficiency sets in, intermittent power-law phenomena emerge, akin to those observed on real stock markets. The cute point of this analysis is that there is a well-grounded mechanism (called "self-organized criticality" by the late Danish physicist Per Bak) that keeps the market in the vicinity of the critical point: fewer agents means more opportunities for profit, which attracts more agents; more agents means no profit opportunities, so that frustrated agents leave the market.

There are other examples, in physics and computer science, where competition and heterogeneities lead to interesting phenomena that could be metaphors for the complexity of economic systems. These include spin-glasses, the spins within which interact randomly with one another – its application to economics having been first suggested by physics Nobel laureate Philip Anderson at the 1987 Santa Fe meeting. Molecular glasses, protein folding and Boolean satisfiability problems are other examples. In all these cases, the energy of the system is an incredibly complicated function of the various degrees of freedoms (the spins, the position of the atoms of the protein, the Boolean variables). Generically, this function is found to display an exponential number (dependent on the number of degrees of freedom) of local minima, i.e. points of equilibria. The absolute best one is (a) extremely hard to find; (b) only marginally better than the next best one; and (c) extremely fragile to any change in the parameters of the problem – the best one can easily swap over to become the second best, or even cease abruptly to be a minimum. Physical systems with these "rugged" energy landscapes display characteristic phenomena that have been studied extensively in the last 20 years, both experimentally and theoretically. The dynamics is extremely slow as the system is lost amidst all these local minima; equilibrium is never reached in practice; and there is intermittent sensitivity to small changes of the environment. There is no reason to believe that the dynamics of economic systems, also governed by competition and heterogeneities, should behave very differently – at least beyond a certain level of complexity and interdependency.

If true, this would entail a major change of paradigm. First, even if an equilibrium state exists in theory, it may be totally irrelevant in practice, because the time to reach it is far too long. As Keynes noted, "in the long run we are all dead". The convergence to the "Garden of Eden" of economic systems might not be hobbled by regulations but by their tug-induced complexity. One can in fact imagine situations where regulation could nudge free, competitive markets closer to an efficient state that they would never otherwise reach. Second, complex economic systems should be inherently fragile to small perturbations, and generically evolve in an intermittent way, with a succession of rather stable epochs punctuated by rapid, unpredictable changes – again, even when the exogenous drive is smooth and steady. No big news is needed to make markets lurch wildly, in agreement with recent empirical observations (see A Joulin *et al.* 2008 arXiv:0803.1769). Within this metaphor of markets, competition and complexity could be the essential cause of their endogenous instability (on this point, see M Marsili ssrn.com/abstract=1305174).

2 Turbulence



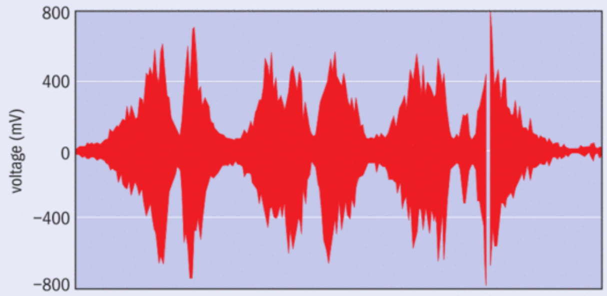
A colourful representation of a turbulent flow, showing a complex intertwining of highly active and quiescent regions (A Celani and M Vergassola 2001 *Phys. Rev. Lett.* **86** 424).

A different methodology

The above models tell interesting stories but are clearly highly stylized and aim to be inspiring rather than convincing. Still, they seem a bit more realistic than the traditional models of economics that assume rational agents with infinite foresight and infinite computing abilities. Such simplifying caricatures are often made for the sake of analytical tractability, but many of the above results can in fact be established analytically using statistical-mechanics tools developed in the last 30 years to deal with disordered systems.

One of the most remarkable breakthroughs is the correct formulation of a mean-field approximation to deal with interactions in heterogeneous systems. Whereas the simple Curie–Weiss mean-field approximation for homogenous systems is well known and accounts for interesting collective effects (see W Brock

3 Barkhausen noise



A time trace of intermittent Barkhausen noise produced by domain walls in random magnets as they unpin from impurities and repin some (random) time later. The dynamics is made up of a succession of "avalanches" of all sizes, which correspond to the domain walls sweeping areas of all size as they unlock (J P Sethna *et al.* 2001 *Nature* **410** 242).

and S Durlauf 2001 *Rev. Economic Studies* **68** 235), its heterogeneous counterpart is far subtler and has only been worked out in detail in the last few years. It is a safe bet to predict that this powerful analytical tool will find many natural application in economics and social sciences in the years to come.

As models become more realistic and hone in on details, analytics often has to give way to numerical simulations. The situation is now well accepted in physics, where numerical experimentation has gained a respectable status, which, in the words of science writer Mark Buchanan, bestows us with a "telescope of the mind, multiplying human powers of analysis and insight just as a telescope does our powers of vision".

Sadly, many economists are still reluctant to recognize that, although very far from theorem proving, numerical investigation of a model is a valid way to do science. Yet, it is a useful compass with which to venture into the wilderness of irrational-agent models: try this behavioural rule and see what comes out, explore another assumption, iterate, explore. It is actually surprising how easily these numerical experiments allow one to qualify an agent-based model as potentially realistic (on which one should dwell further) or completely off the mark.

What makes this expeditious diagnosis possible is the fact that for large systems, details do not matter much – only a few microscopic features end up surviving at the macro scale. This is a well-known story in physics: the structure of the Navier–Stokes equation for macroscopic fluid flow, for example, is independent of all molecular details. What researchers should focus on now is therefore identifying the features that explain financial markets and economic systems as we know them. This is of course still very much an open problem, and simulations will play a central role. The main drive of econophysics is that competition and heterogeneity, as described above, should be the key ingredients of a better new theory of economics.

> The most valuable contribution of physics to economics will end up being of a methodological nature, as physics constructs models of reality based on a subtle mixture of intuition, physical analogies and mathematical treatment

A slew of other empirical results, useful analytical methods and numerical tricks have been established in econophysics, which I have no space to review here. But in my opinion, the most valuable contribution of physics to economics will end up being of a methodological nature. Physics has its own way of constructing models of reality based on a subtle mixture of intuition, physical analogies and mathematical treatment, where the ill-defined concept of *plausibility* can be more relevant than the accuracy of the prediction. Kepler's ellipses and Newton's gravitation were more plausible than Ptolemy's epicycles, even when the latter theory, after centuries of fixes and stitches, was initially a more accurate way to describe observations.

When Anderson first heard about the theory of rational expectations in the 1987 Santa Fe meeting, his befuddled reaction was "You guys *really* believe that?". He would probably have fallen off his chair had he heard US economist and Nobel laureate Milton Friedman's complacent viewpoint on theoretical economics: "In general, the more significant the theory, the more unrealistic the assumptions." Physicists definitely want to know what an equation means in intuitive terms, and believe that assumptions ought to be both plausible and compatible with observations. This is probably the most urgently needed paradigm shift in economics. ■

More about: Econophysics

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Planets under pressure

The pressures inside planets can be high enough to collapse diamonds and turn noble gases into metals. **Raymond Jeanloz** describes how we can study such extreme conditions without leaving the laboratory, and what the results might tell us about life elsewhere in the universe

Raymond Jeanloz is a professor of astronomy and Earth and planetary science at the University of Berkeley, California, US, e-mail jeanloz@berkeley.edu

Deep inside the planet Jupiter, diamonds hail down from hydrocarbon clouds as intense atmospheric pressures break methane into its atomic components. Further in – but still only 15% of the way to the planet's centre – the pressure reaches a million times that of the Earth's atmosphere. This is enough to transform hydrogen from the transparent, insulating gas we know at our planet's surface into a metallic fluid that sustains Jupiter's huge magnetic field. Even diamond is not forever: at pressures of 8–10 million atmospheres it is transformed into an opaque, metallic form of carbon, rather than the familiar transparent crystal.

No human could ever set foot on Jupiter, and not even the toughest robotic instrument could survive the extreme pressures of its interior for long. Instead, physicists rely on laboratory experiments and theoretical models to mimic and predict the behaviour of matter inside both gas-giant planets like Jupiter and rocky ones like the Earth and Mars. What we have learned in the past few years about matter at high pressures – and what we expect to learn with new tools currently being developed – will allow us to address fundamental questions about how such planets form and evolve over geological or astrophysical timescales.

Such questions have become even more intriguing in recent years, as over the past decade more than 330 planets have been discovered that orbit stars other than our own. These observations are dramatically altering our understanding of planetary systems. Many of these systems have been found to contain "supergiant" planets with masses several times that of Jupiter; in some cases, these planets are orbiting their parent stars at distances closer than Mercury is to our Sun. There is also evidence of "super-Earths" – rocky planets much larger than our own. Indeed, we now know that our own solar system is relatively atypical compared with most of the planetary systems observed to date, which has raised additional questions. For example, how large (or small) does a planet have to be to nurture life? And what is the nature of celestial bodies that are almost big enough to be stars? Answering these questions will depend on understanding the materials making up planets as well as on improved astronomical observations.

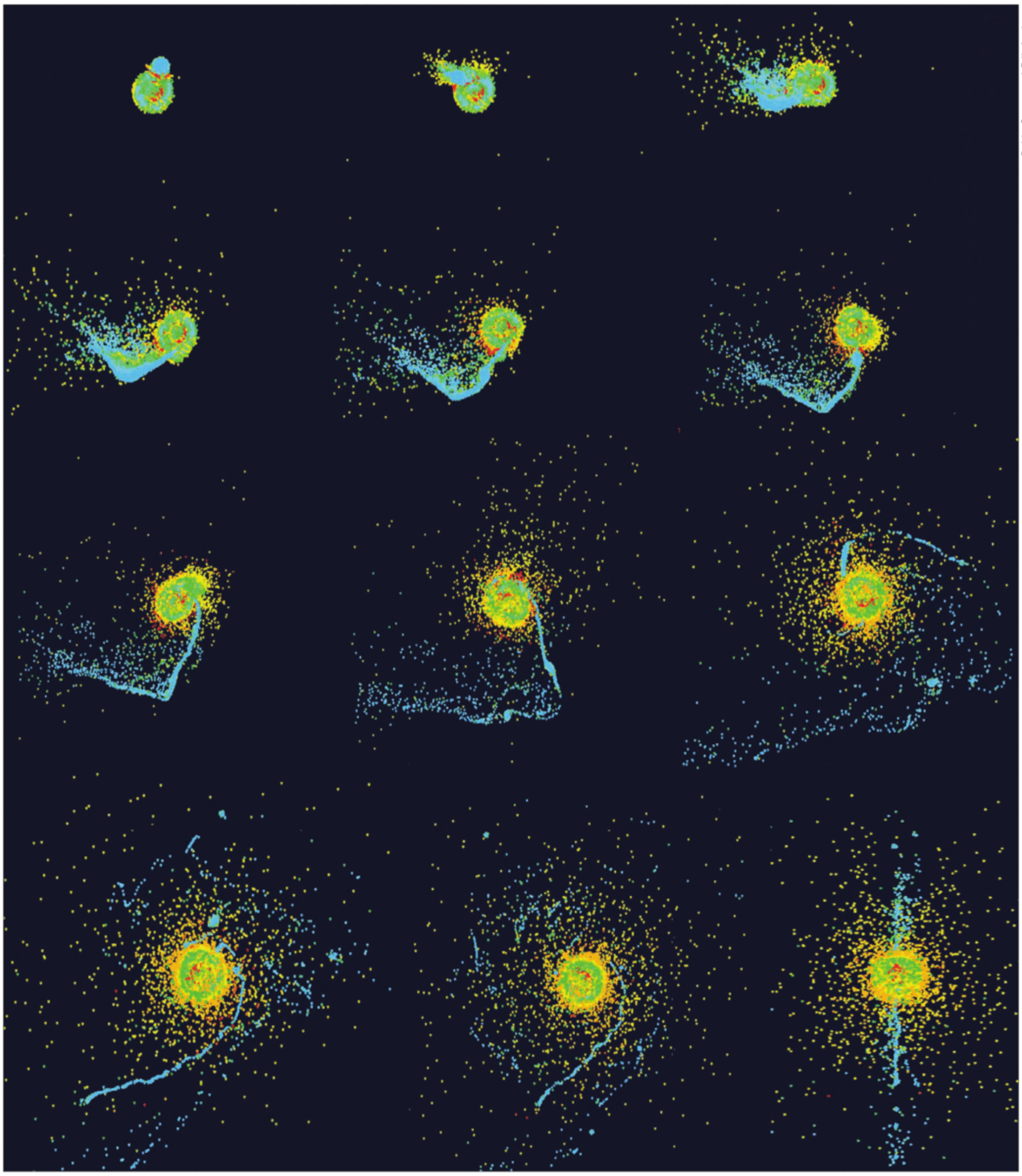
What we have learned about matter at high pressures – and what we expect to learn with new tools being developed – will allow us to address questions about how planets form and evolve over time

Changing under pressure

Thanks to pioneering experiments by William and Lawrence Bragg using X-ray diffraction and by Percy Williams Bridgman on high-pressure materials, scientists have known for almost 100 years that the packing of atoms can change, and the properties of materials be correspondingly altered, under the pressures that exist deep inside planets. For example, at pressures above 50 000 atmospheres, or five gigapascals (GPa), graphite transforms into diamond as carbon atoms rearrange from a hexagonal to a cubic stacking pattern. Under such conditions, which can be found 200–600 km inside the Earth and Mars, methane breaks down into carbon and hydrogen. Indeed, in 1998 a group led by Erio Tosatti of the International Center for Theoretical Physics in Trieste, Italy, used quantum-mechanical calculations to predict that the "weather" inside giant planets with methane atmospheres is cloudy with a chance of diamond hailstorms.

Just under halfway to the centre of Earth, the pressure reaches a million atmospheres – enough to spread atoms' outer-electron orbitals so that they overlap and intermix more extensively. These changes affect the behaviour of the atoms' chemical bonding. For example, xenon – normally a "non-bonding" noble gas – becomes metallic at these pressures, as does liquid hydrogen. Oxygen also becomes metallic, allowing rock (which consists of oxygen chemically bound by metal ions) to alloy with liquid iron. At low pressures, in contrast, oxide "slag" does not bind with liquid iron but instead separates and floats on top of it. Hence, this pressure-related chemical transition blurs the boundary between the Earth's rocky mantle and the liquid-iron alloy of the outer core.

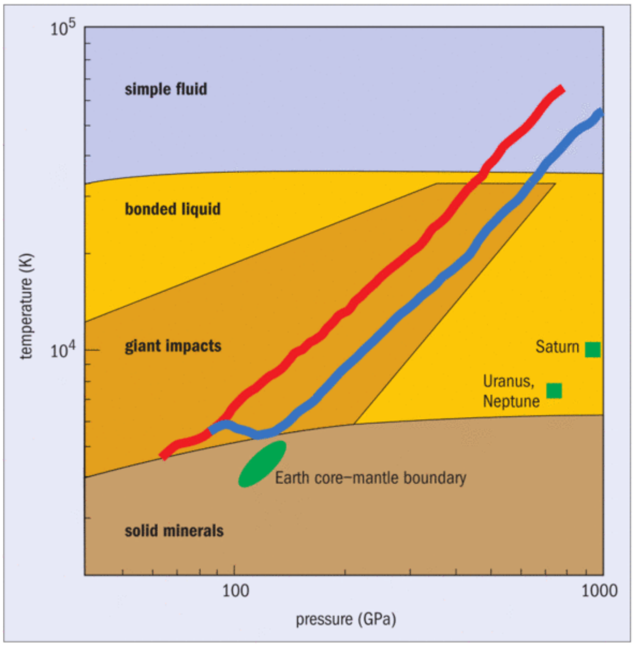
In fact, even in the mantle the pressures are high enough to collapse iron ions within minerals to nearly half their normal volume. To understand this, consider an iron ion bonded to six oxygen atoms. At low pressures, the electrons that make up the bonds will be in orbitals pointing towards the oxygen atoms – the lowest energy configuration. Under higher pressures, electrons from the oxygen atoms will overlap with these orbitals, thus pushing the iron atom's electrons into other, higher-energy orbitals, which occupy less volume. Seismic waves passing through this denser material will undergo a change in velocity, and the transition from low-spin to high-spin electron configurations also



changes the optical properties and heat conductivity of the matter deep within our planet. This is important because the sound waves emanated by earthquakes travel throughout the interior and cause the entire planet to oscillate. Measuring these oscillations has provided us with detailed information about the Earth's internal structure, and there is hope that in the future we will also be able to observe oscillation modes in other planets.

A number of groups are now documenting even more extensive changes within gas-giant planets like Jupiter and Saturn, where core pressures approach 40–70 million atmospheres (4–7 TPa). In 2008 Jon Eggert and colleagues at the Lawrence Livermore National Laboratory (LLNL) in the US showed that helium becomes metallic at pressures and temperatures above 20 million atmospheres and 20 000 K. In other words, the hydrogen–helium mixture comprising

New Moon Simulations show how the Moon could have formed from debris splashed out in a collision between the Earth and a Mars-sized object. Red represents regions of high internal energy.



Under pressure A phase diagram for silica – the raw material for glass – shows the temperatures and pressures required to transform it into more exotic substances like a "bonded liquid", in which the local molecular structure is being torn apart by extreme conditions, and a "simple fluid", where the material behaves like a metal. The red and blue lines represent experimental shock data obtained from samples of fused silica and quartz, respectively. Giant planetary impacts can produce temperatures and pressures found in the centre-left region of the diagram; additional data points show conditions inside the Earth and gas-giant planets.

"gaseous" planets is likely to be a liquid-metal alloy throughout much of their interiors. At pressures of about 1–5 million atmospheres, however, hydrogen is a liquid metal, whereas helium is not. In such regions, the two light elements tend to segregate like oil and water. This same segregation process works for rocky planets as well. On Earth, for example, it has produced regions of different bulk composition: the gaseous atmosphere; rock mantle; and iron-alloy core. Similarly, the giant planets are thought to have several Earth masses' worth of rock and iron as cores deep inside their hydrogen- and helium-rich fluid envelopes.

Sinking of the heavier components relative to the lighter ones can be an important source of energy. For example, the gravitational energy released by this process of "differentiation" inside the Earth has heated our planet's interior by about 2000 K. It is thought that roughly half the heat now coming out of our planet, including that from volcanic eruptions and the movement of tectonic plates, is such "primordial" heat left over from Earth's formation and differentiation more than 4.5 billion years ago.

The centre of a five-Jupiter-mass planet experiences pressures of over a billion atmospheres

But what happens at pressures above a few tens of millions of atmospheres? As with oceans, the pressure inside a planet increases with depth due to the weight of the overlying layers. The core pressure is roughly proportional to M^2/r^4, where r is the planet's radius and M is its mass. Giant and supergiant planets tend to be about the same size because the extra gravitational compression compensates for the added mass. The centre of a five-Jupiter-mass planet is therefore expected to experience pressures of over a billion atmospheres, which is enough to change the inner electron orbitals of the atoms at the planet's core. A planet that is about 15 times the mass of Jupiter undergoes an even more significant transition: the internal pressures and temperatures are sufficient to ignite thermonuclear fusion, and thus the planet becomes a small "brown dwarf" star.

High-pressure experiments

Scientists' first attempts to study the billion-atmosphere regime came as by-products of underground nuclear tests carried out during the Cold War – "experiments" that are now constrained by international agreements, and that few would wish to replicate. Because such methods are not likely to be pursued in the future, experimental studies of ultra-high pressures have shifted to laboratory techniques using diamond-anvil cells and powerful lasers.

Diamond-anvil cells work by squeezing small samples – typically less than 0.1 mm across by 0.01 mm thick – between the points of two gem-quality diamonds. As well as compressing the specimen, the two gems serve as windows through which researchers can use spectroscopy and diffraction techniques to study the sample under pressures of several million atmospheres. Shock-wave methods, in which a sample is hit by a projectile travelling at a speed of about 1–5 km s^{-1} and studied during the brief transit time ($<1\,\mu s$) of the resulting pressure wave, have proved equally important in characterizing materials at planetary-interior conditions. For example, in 1996 researchers at LLNL used shock waves to convert fluid hydrogen into its metallic form for the first time.

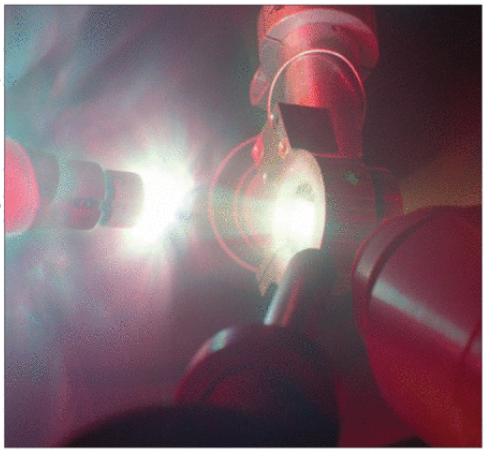
More recently, it has become possible to use the impact of an intense pulse of light generated by a laser, rather than a projectile causing a mechanical impact, to make high-quality shock-wave measurements up to pressures of tens of millions of atmospheres. This has let researchers document the dramatic changes in chemical bonding that occur when liquid silica – the stuff of which glass is normally made – transforms into a metallic state at very high pressures and temperatures.

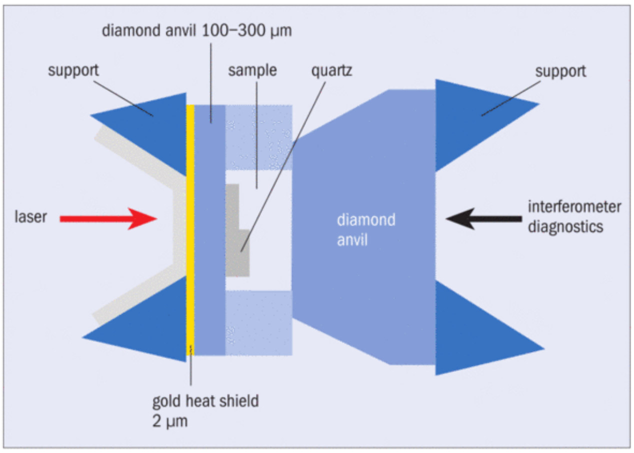
Another trick is to combine the techniques by applying laser-driven shocks to samples already at high pressure inside a diamond-anvil cell. By changing the initial density of the sample, it is possible to achieve much higher densities and lower temperatures in the shock-compressed state than it would be through shock-compression alone. Thus, the effects of temperature and density (or pressure) can be separated when determining the conditions required for, say, hydrogen, helium or silica to become metallic.

How planets are born

These measurements have already led to a number of discoveries with implications for planetary formation and evolution. For example, the conditions required to transform silicon dioxide into a liquid metal – pressures and temperatures above 10^6 atmospheres and 10 000 K – may seem extreme but they are in fact typical of conditions during the giant impacts that characterize the

Eugene Kowaluk, University of Rochester





What a blast! A photograph of a diamond-anvil cell at the Omega laser facility in the US (left) shows the sample inside the cell being blasted with a pulse of intense laser light. Such experiments allow researchers to study how materials behave at temperatures and pressures not normally seen outside the interiors of planets. Besides compressing the samples, the diamonds in the cell also serve as windows for diagnostic measurements (right).

later stages of planetary growth.

We already know that as matter accretes in a disc around a young star, developing protoplanets are impacted by external objects, or bolides. This process of aggregation by mutual gravitational attraction is how planets grow, but computer simulations of this process show that the accretion is surprisingly clumpy. In other words, at each stage the growing planet is impacted by objects that have themselves grown to comparable sizes. Hence, as planets reach their final size, simulations have shown that they will be hit by other full-grown planets.

In fact, our own Moon is thought to have been splashed out of the Earth by a late-stage glancing blow from a Mars-sized object. This is the only hypothesis that explains the known properties of the Earth–Moon system. For example, chemical analyses of lunar rocks are best explained by inferring that the entire Moon was molten 4.5 billion years ago, and a giant impact is one of the only plausible sources of the energy (heat) that would have been required to melt it. A glancing impact is also one of the only means of creating such a massive object as the Moon at the appropriate distance from our planet yet keeping it in the Earth's orbit.

Theoretical estimates by Damian Hicks of LLNL (among others) indicate that peak pressures during such collisions are high enough that SiO_2-based materials in the rocky mantle of the early Earth would have been transformed into liquid metal. Because the thermal conductivity of a metal is an order of magnitude higher than it is for most non-metals, this liquid-metal phase implies that the superhot "magma ocean" created in the impact was highly conductive and could also have affected chemical interactions between the Earth's early mantle and core.

As for extrasolar planets, theorists such as Renata Wentzcovitch of the University of Minnesota in the US and Lars Stixrude at University College London in the UK are already making predictions about the atomic-packing configurations and physical properties of oxide minerals, iron alloys and hydrogen fluids at conditions that may exist in giant and super-giant planets. The recently observed "super-Earths" are of particular interest. While large planets have enough gravitational pull to retain thick envelopes of hydrogen and helium, and are thus not considered hospitable to life, it may be that rocky planets of several Earth masses can exist with atmospheres thin enough to allow life.

Stars in the laboratory

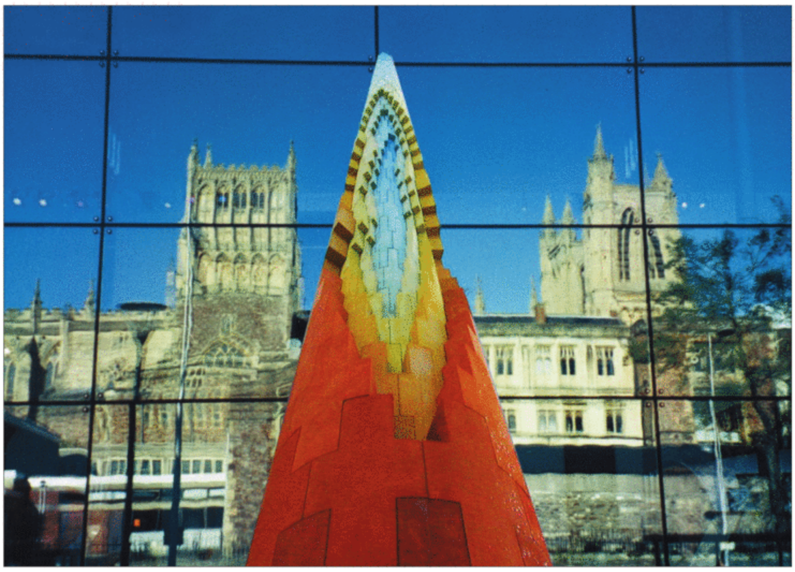
At the moment, some tests of these predictions are restricted by the inherent limitations of diamond-anvil experiments: above 10 million atmospheres, diamond undergoes a transition to metallic carbon, thus making the anvils no longer usable. However, a new generation of lasers currently being constructed should allow us to probe the billion-atmosphere regime under controlled conditions. These giant multi-kilojoule to megajoule lasers at facilities like Gekko in Japan, Laser Mégajoule in France, Orion in the UK, and Omega and the National Ignition Facility in the US create intense pulses of light that drive an enormous shock wave through the sample upon impacting a material. When the outer layers of the sample absorb this light, they evaporate and rapidly expand back toward the laser; as with a rocket, conservation of linear momentum produces a pressure wave that ploughs through the sample. Using these facilities, we expect to take samples initially at million-atmosphere pressures and shock-compress them to over a billion atmospheres, thereby reaching densities up to hundreds of times greater than the original sample.

Ultimately, these experiments will probe not only the high-density states of planetary interiors, but also the high temperatures (more than a million Kelvin) at which nuclear fusion ignites. Under these conditions, it is not just the electron orbitals that are transformed – as in the interiors of gas-giant and supergiant planets – but the nucleus itself. It will then be possible to characterize the physics and chemistry taking place inside brown-dwarf stars and other sub-stellar objects. The transition between planets and stars will, for the first time, become accessible to study in the laboratory. ■

Reviews

Sir John Enderby

Beautifully strange



Landmark science A sculpture in central Bristol commemorating Paul Dirac.

The Strangest Man: The Hidden Life of Paul Dirac, Quantum Genius
Graham Farmelo
2009 Faber and Faber £22.50hb 560pp

The list of famous Bristolians is an illustrious one. The Victorian engineer Isambard Kingdom Brunel, for example, is recognized everywhere in Bristol for his many iconic structures, even though he was not born, bred or even resident in the city. Another well-known son of the city is the Hollywood legend Cary Grant, born as Archie Leach in the suburb of Horfield and now commemorated with a striking bronze statue outside Bristol's hands-on science museum. The physicist Paul Dirac actually went to the same elementary school as Grant/Leach, and the abstract sculpture dedicated to him stands just a stone's throw away from Grant's bronze likeness. Dirac also has a building named after him: Dirac House, the headquarters of IOP Publishing (which publishes *Physics World*).

Yet in spite of these efforts to publicize Dirac's many contributions to science, his city of birth and (until recently) the school where he was educated seemed almost unaware that in Dirac, Bristol produced one of the great minds of the last century, and arguably the greatest British physicist since Isaac Newton. Part of this lack of knowledge among both Bristolians and the general public is Dirac's legendary reticence, literal-mindedness and almost total inability to communicate with anyone – except, possibly, his immediate family.

All of this makes Dirac a very difficult subject for the sort of sympathetic biography that Graham Farmelo has produced in *The Strangest Man: The Hidden Life of Paul Dirac, Quantum Genius*. The book represents years of careful research and conversations with family and friends who knew Dirac and his work. In it, Farmelo, a science communicator and senior research fellow at the London Science Museum, describes the life and work of this profoundly brilliant man, exploring the origins of his near-pathological reticence and in the last chapter proposing a possible explanation. I doubt whether a better biography will appear in most of our lifetimes.

> In Paul Dirac, Bristol produced arguably the greatest British physicist since Isaac Newton

Dirac's parents Charles and Florence were married in 1899 and lived for a time at 42 Cotham Road, probably in rented rooms, where Dirac's older brother Felix was born. Shortly afterwards, Charles bought a small terraced house in Monk Road and Paul Adrien Maurice Dirac, the second son, was born in 1902. His sister Betty was born in 1906, so Flo certainly had her hands full with a young family and the ever-increasing and apparently irrational demands of her husband.

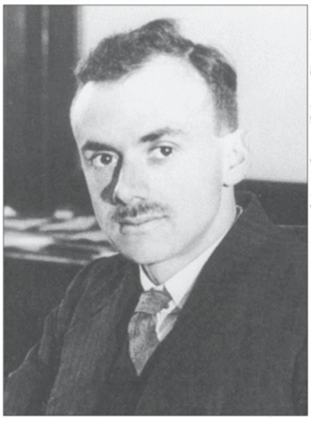
These demands included Charles' insistence that only French be spoken at the family dining table. As a result, Flo, Felix and Betty ate in the kitchen, while Paul – whose French was just passable – was allowed to sit with his Swiss-born father. In later life, Dirac acknowledged that his difficulty in communicating with others may have stemmed from this period, poignantly explaining to Kurt Hofer – an Austrian-born cell biologist who became a close friend – that "since I found that I couldn't express myself in French, it was better for me to stay silent than to talk in English".

Time and again, Farmelo returns to the difficult personal relations that plagued Dirac's family. Although in today's parlance the Diracs were upwardly mobile – they soon moved to a larger semi-detached house in Julius Road, a more salubrious part of Bristol – Charles was also a serial tax evader. His crimes only came to light after his death, however, leaving Flo with an unwelcome tax bill. At one stage in the relationship she appears to have sought separation from her husband due to suggestions that he was having an extramarital affair, and their oldest child Felix committed suicide when Dirac was 23. But despite all of these traumas, Dirac is said to have wept only once in his life: in 1955, when he heard of the death of his hero, Einstein.

Given this background, it is hardly surprising that in his later life it was only with some unhappiness and after pleading from his mother that Dirac could be persuaded to visit Bristol. Instead, St John's College, Cambridge, became the place he regarded as his true home. While there, Dirac made his most important breakthrough: he succeeded in welding together special relativity and quantum mechanics to produce what is often and rightly regarded as one of the great equations in physics. He became the Lucasian Professor of Mathematics there in 1932, and in 1933 his famous equation won him a Nobel prize (shared with Schrödinger) "for the discovery of new productive forms of atomic theory".

The conclusions of the Dirac equation were highly controversial when they were first described in 1928, but in a curious way, the criticisms appeared to simply bounce off Dirac – a consequence, perhaps, of his deeply private personality. The idea of negative energy states and the consequent hole theory was finally resolved by the discovery of the positron in 1932. The equation also showed that spin was a natural consequence of relativity and quantum mechanics, and not simply an add-on to explain atomic spectra. Recognizing this, it is only just and fair that the unique characteristics of electrons that make such devices as transistors, mobile phones and solid-state lasers possible are known as Fermi–Dirac statistics.

Farmelo takes the reader through difficult physics in a masterly manner – a consequence, no doubt, of his vast experience in science communication. The author also describes some aspects of Dirac's work of which even professional physicists may not be aware. For example, in 1933 Dirac started an experimental study with Peter Kapitza on the possibility of bending a beam of electrons with light. He also developed an experiment to separate isotopes – much to the approval of Ernest Rutherford, who thought that it "augurs well for theoretical physics that the Lucasian Professor is soiling his hands in the laboratory". As a result, Dirac became peripherally involved in the Manhattan Project, performing theoretical investigations of the "separation power" of uranium-enriching devices, although he declined a full-time position.



Science Source/Science Photo Library

Master of the equation Paul Dirac.

Dirac's life changed dramatically during a sabbatical at Princeton University in 1934 when he met Margit Wigner, a Hungarian divorcee and mother of two children, Gabriel and Judy. Margit, the sister of nuclear physicist Eugene Wigner, was known to friends and family as Manci. She was the opposite in nearly every sense to Dirac, but their affection turned to love and they were married in January 1937. Manci had to spend some time in Budapest after the honeymoon and as a result, Dirac penned "the first love letter I have ever written". Until then, Dirac had replied to questions from Manci in tabular form!

The marriage did experience some strains (often arising from Manci's dislike of Cambridge), but Dirac was a loving husband and stepfather to Manci's children and to the two daughters of the marriage, Mary and Monica. Within the family, Dirac appears to have been far more communicative than he was with outsiders. At the opening of Dirac House in 1997, I remember Monica describing how his scientific approach to vegetable gardening caused much amusement in the family, which Dirac took in good humour.

One feels a sense of anticlimax as the book nears its end. Dirac fell out with the Cambridge hierarchy over what seems a rather trivial dispute about car parking, and by the mid-1960s he spent most of the week working at home. Meanwhile, Manci had set her heart on escaping from Cambridge, and in 1971, having seen their children well settled (except for Dirac's stepdaughter Judy, who had disappeared in 1968 and was by then presumed to be dead), the couple finally emigrated from the UK to Florida, where Dirac died in 1984.

Physicists remain divided over the legacy of Dirac's later years. Was his opposition to the success of quantum electrodynamics justified on the grounds that the theory lacked beauty? Do monopoles really exist? Can his large-number hypothesis – which suggests that fundamental constants change with time – ever be reconciled with general relativity? But all physicists agree that the towering achievement of the Dirac equation will, as Farmelo makes clear, set Dirac apart and place him in a league with Newton and Einstein.

Perhaps the most controversial part of the book is its last chapter, in which Farmelo explores the possibility that Dirac's pathological reticence was in fact undiagnosed autism or Asperger's syndrome. Autism covers a wide spectrum of behaviour, and as the writer and doctor Milo Keynes points out in *The Notes and Records of the Royal Society* (2008 **62** 289), it has become something of a catch-all phrase for behaviour that departs significantly from the norm: "In the past 10 years it has been firmly claimed that Newton must have shown the development disorder of Asperger's syndrome, a disorder that has been posthumously assigned to Michelangelo, Henry Cavendish, Albert Einstein, Marie Curie, Ludwig Wittgenstein and Paul Dirac." Clearly, Dirac joins a long and distinguished list of retrospectively diagnosed luminaries.

For what it is worth, my guess is that Dirac was by nature a shy individual and that this shyness was reinforced by a difficult early home environment. Farmelo is correctly very cautious in what he has written, and regardless of the conclusions he draws about Dirac's personality, it is clear that writing about him has been a labour of love. I most warmly recommend this book both to professional physicists and to laypersons interested in fundamental physics, as well as to anyone who finds the interaction between personality and intellectual endeavour fascinating.

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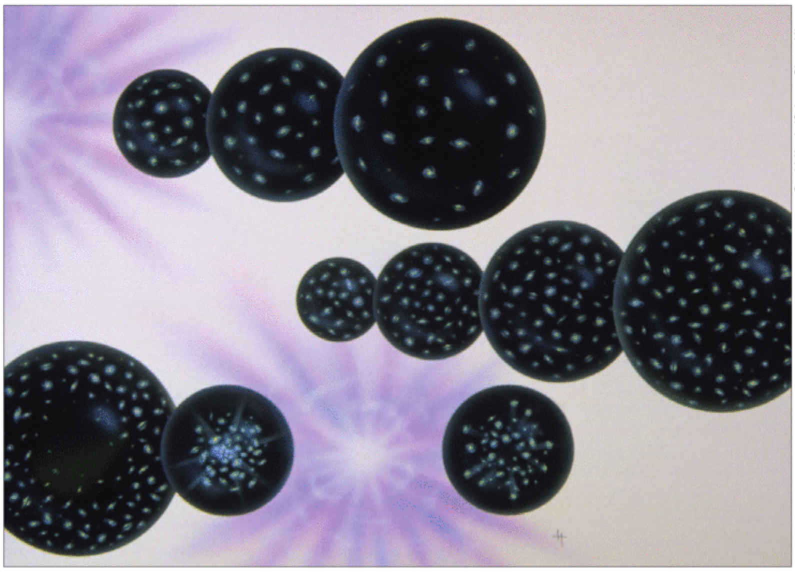
Ruth Gregory

Cosmic alternatives?



David Hardy/Science Photo Library

Our possible pasts
Some alternatives to the Big Bang theory may still be worthy of exploration.

Facts and Speculations in Cosmology
Jayant Narlikar and Geoffrey Burbidge
2008 Cambridge University Press
£30.00hb 296pp

"Cosmologists are often in error but never in doubt." This pithy characterization by the Soviet physicist Lev Landau sums up the *raison d'être* of *Facts and Speculations in Cosmology*. Authors Jayant Narlikar and Geoffrey Burbidge are proponents of a "steady state" theory of cosmology, and they argue that the cosmological community has become fixated on a "Big Bang" dogma, suppressing alternative viewpoints. This book very much does what it says on the tin: it sets out what is known in cosmology, and puts forward the authors' point of view on an alternative to the Big Bang.

How can we be in a situation where cosmologists have allegedly become like narrow-minded cardinals brooking no dissent – the very thing they wished to destroy? What makes early-universe cosmology such a fascinating (and infuriating) area of study is that it frequently flies in the face of what we understand to be science. Science is about building a case, discovering various aspects of nature, and trying to understand what makes it tick. We come up with a theory, and then good scientific practice demands that we test that theory first on what we know, then on what we have not yet discovered by making a prediction. If a theory makes a prediction that is not observed, then that theory is considered wrong. If, however, the theory succeeds, then it is tested again – and again and again.

Cosmology, however, is about the universe. How can we test the universe? We cannot be independent external observers, and we can hardly run the experiment again! Narlikar and Burbidge (both of whom are cosmologists themselves) argue that by its very nature, cosmology can never be as precise a science as particle physics or astronomy, the two basic pillars on which cosmological endeavour rests. How then do we make cosmology a science, and how do we test our cosmological theories?

Our picture of the universe has evolved throughout the ages, reflecting a growing sophistication in our understanding of nature and our confidence in pushing our theories beyond their level of testability. Initially, humankind's view of the universe was more of a narrative – a story designed to represent a picture beyond our comprehension – but gradually, as our ability to reach out to the stars developed, our idea of the heavens and our place in them became more systematic, concrete and well founded. We now find ourselves at the point where we have developed a very good scientific description of the universe around us. Now, the authors argue, we are once again pushing the boundaries of our understanding back into the "narrative": the region beyond our direct comprehension.

One of the interesting features they explore is how we do this – how we guide our steps and what principles we use when we begin to enter into the unknown. Typically, particle cosmologists (those studying the very early universe) use a principle of aesthetic simplicity as a guide. Given two alternative theories, each of which fits the facts as currently known, the particle cosmologist will prefer the simpler theory – the one requiring fewer inputs or less-contrived constructions. It is a good principle, and indeed one that has stood particle physics in very good stead, but should we be applying it to cosmology? Are we in fact no different from Aristotle, setting our planets on heavenly spheres because the circle is so perfect geometrically?

Worse still, the authors argue, we may be guilty of Ptolemy's error of introducing "fixes" to our theory to make it fit the data, rather than abandoning it in favour of something genuinely simpler. In particular, these authors contend that the Western Judeo–Christian tradition of creation has been a strong influence in our readiness to accept the Big Bang – in which our universe has a definite beginning a finite time ago – as our standard model. Finally, they put forward their alternative picture, which is that the universe has existed for an eternity, ever expanding, in a quasi-cyclic process.

Their idea is that the universe has a "negative energy" radiation-type field that drives expansion and also allows matter to be created – a prerequisite of any steady-state expansion. This radiation field causes periodic crunches, from which the universe re-expands in pseudo-Big Bang style. The model accounts for the cosmic microwave background (CMB), and indeed supernova dimming, by virtue of thin, metallic whiskers in the intergalactic medium that rescatter and thermalize photons (correspondingly dimming light from distant sources). Thus, they claim, all the usual tenets of the standard Big Bang model admit an alternative explanation.

The authors give a nice review of cosmology, focusing on the facts and presenting a concise and lucid account of the development of our view of the universe to the current time. Their book is aimed at the intelligent reader, but not necessarily one with a scientific background – anyone with an enquiring mind would be able to follow the clear logic and presentation that is employed.

There are however, several flaws. Not surprisingly, the authors do not address the criticisms of their model, and instead simply present it as an equally reasonable alternative theory. (Ned Wright, an astronomer at the University of California in Los Angeles, maintains a useful clearing-house of such criticisms on his website.) But perhaps the most annoying feature of the narrative is that the authors have misrepresented the cosmological community, and more importantly, misrepresented the Big Bang model. As they themselves state, the "Big Bang" is simply a time early on in the universe at which our laws of physics break down. If we are conservative, we might say that this is the energy we have explored at particle accelerators: the standard cosmological evolution from this point is well verified and fits all the data extremely well given a certain starting state.

Our picture of the universe has evolved, reflecting our confidence in pushing our theories beyond their level of testability

The real issue the authors have is with the paradigm of *inflation*, which describes a period of rapid expansion in the early universe. In a wide range of candidate models, inflation gives rise to precisely the fluctuations in density supported by the CMB data. However, Burbidge and Narlikar give the impression that the community does not question this model, and that there are no alternatives being explored. This is just plain wrong! There are a significant number of people in the community who do precisely that: theories like the pre-Big Bang scenario, heterotic M-cosmology and braneworld-modified gravity are but a few of the alternatives on the market. These models use ideas from superstring theory, in which the extra dimensions needed to incorporate gravity as a quantum theory can have fascinating implications for the early universe. In some cases, such ideas do produce cyclic models notionally similar to the quasi-steady state, but they are far better-founded in a consistent particle-physics theory.

That said, the scientific integrity of the authors does resonate, as does one of their laments: that in these days of assessment and review, we can no longer simply explore in an attitude of scientific curiosity. Instead, we must justify our needs by stating not just what we are going to look for, but what we are actually going to *find* – an attitude that time and again has been proven to frustrate, rather than foster, innovation and progress. However much one disagrees with their claims, one cannot help but have sympathy for this point of view.

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Web life: *The Evil Mad Scientist Project*

URL: www.evilmadscientist.com

What is it?

Have you ever tried to electrocute a hot dog? Wondered how to make a robot out of a toothbrush, watch battery and phone-pager motor? Seen a cantaloupe melon and thought, "Hmm, I could make this look like the Death Star from the original *Star Wars* films"? If you have not, but you would like to – preferably as soon as you can find a pager motor – then this is the site for you. *The Evil Mad Scientist Project* (EMSP) blog is packed full of ideas for unusual, silly and frequently physics-related creations that bring science out of the laboratory and into kitchens, backyards and tool sheds.

Who writes the blog?

The main authors are the intensely creative husband-and-wife team of Windell Oskay and Lenore Edman. A former physicist who now works at a California-based engineering firm, Oskay is responsible for most of the electronics-themed entries. Edman, meanwhile, studied classical Greek, which she says "prepared her well" for a career working with scientists and engineers. Her posts tend to focus on topics like fractal biscuits and LED origami. Other contributors include Edman's young son Chris Brookman and the family's two cats; the site also lists several like-minded "honorary mad scientists" who work independently on similar projects.

Can you describe a typical project?

Any site that contains both Dalek-shaped pumpkins and an interactive LED kitchen table is going to be hard to summarize, but there are a few common threads. A huge number of projects involve nifty things to do with LEDs, and a sizeable minority require users to play with their food in ways that would make even the most innovative chefs gasp (edible googly eyes, anyone?). One intriguing idea that grew out of the site about a year ago is the Great Internet Migratory Box of Electronics Junk, a kind of round-robin letter for the digital age in which participants receive and pass on a small box of miscellaneous components in the confident hope that someone else will find them useful.

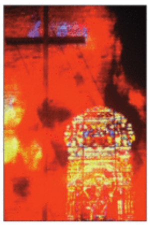
How often is it updated?

The authors aim to post new projects every Wednesday, but most weeks contain two or three new items. As of March 2009, there were 81 pages of archived entries stretching back to early 2006, so if recent projects do not interest you, there are plenty of others to look at instead. Older posts are semi-organized into topics like field trips, projects and "Play With Your Food", although there is considerable overlap between categories.

Who is it aimed at?

Fans of science fairs and TV programmes like the UK's *Scrapheap Challenge* will find much to appreciate on this site. The EMSP is part of loose-knit network of "Makers" – people interested in creating new things in a way that fuses art, science and engineering – and this well-illustrated blog offers a user-friendly introduction to this community. Most of the food-related projects and some of the simpler electrical ones could be made by children with a bit of adult help. Others require a working knowledge of basic electronics and specialist equipment. A few, like the electrocuted hot dog, are downright dangerous, and should be attempted by dedicated tinkerers only – but everyone can appreciate the results from a safe distance.

Between the lines: science and religion special



Ongoing debate
Four recent books look at the often fraught relationship between science and religion.

In their own words

Of all topics discussed in this magazine, few arouse such passions among readers as the relationship between science and religion. Many atheists (and more than a few religious folk) would object to the idea that science and religion have anything whatsoever to say to each other. Yet the question of whether a god exists – and what the answer might mean for science – has puzzled and intrigued scientists for centuries. *The Faith of Scientists* presents a series of excerpts from researchers' own writings on the subject, accompanied by short biographical sketches from editor Nancy Frankenberry, a religion scholar at Dartmouth College in the US. The resulting collection spans the period from Galileo Galilei to Stephen Hawking and encompasses both devout believers like Freeman Dyson and ardent atheists like Richard Dawkins. The excerpts include many of science's most quotable offerings on the subject, including Einstein's famous "Science without religion is lame; religion without science is blind" and Steven Weinberg's axiom "With or without religion, good people can behave well and bad people can do evil; but for good people to do evil – that takes religion". However, for practical reasons the collection does omit one group of scientists: those who had little to say about religion one way or another. These include Marie Curie, whose sole recorded utterance on the subject, according to Frankenberry, is that she and Pierre had no use for religion and never gave it any thought in their lives.

● 2008 Princeton University Press £21.95/$29.95hb 542pp

One scientist's faith

Since quitting theoretical particle physics in 1979 to train as a Catholic priest, John Polkinghorne has made something of a cottage industry out of writing about science and religion. Indeed, in 2002 he received a prize then worth £700 000 from the Templeton Foundation "for progress towards research or discoveries about spiritual realities". His latest offering, *Questions of Truth*, is a compilation of over 50 responses to queries he has received from readers and critics over the past few years. Written with longtime collaborator Nicholas Beale, the book is a curious mixture. Many of the questions clearly come from sceptics, who wonder how the authors can reconcile their Christian beliefs with what scientists know about the physical world. The chief concern of more religious-minded writers, in contrast, seems to be finding out what science has to say about morality and the reasons (if any) for the universe's existence. These two groups of readers – and all the variations in between – clearly want very different things, and Polkinghorne and Beale deserve credit for handling their diverse correspondents in a remarkably even-handed way. Many of the questions do, however, assume considerable prior knowledge of either Christian doctrine or philosophy – one, for example, begins with the daunting phrase "I wonder what Polkinghorne thinks of the Euthyphro dilemma?" – and this may limit the book's appeal to novices. On the other hand, lengthy appendices on the anthropic principle, the mind/body relationship and evolution contain lucid explanations of how these ideas relate to Christianity, and some scientific-minded readers may wish to start here. As for the rest, *Questions of Truth* at least offers some insight into the concerns of both sides – a valuable lesson for anyone wishing to wade into the science and religion debate.

● 2009 Westminster John Knox Press £9.99 /$16.95pb 160pp

A voice of dissent

It is a fair bet that Polkinghorne and Robert Park would find much to disagree about. Park, a noted sceptic and physicist at the University of Maryland in the US, begins his book *Superstition* with an attack on the Templeton Prize, calling it "the voice of antiscience" and an attempt to buy the debate with "sound effects meant to create an illusion that science and religion are finding common ground". He charges religious scientists (especially winners of the Templeton Prize) with intellectual dishonesty for "compartmentalizing" their beliefs. Parks' main target in the first part of his book is Christianity, especially its creationist and so-called intelligent-design offshoots. However, the world's other religions do not emerge unscathed. At one point, he quotes an 11th-century imam, al-Ghazali, as arguing that cause and effect is not allowed since it would limit the freedom of Allah. Later, he takes on New Age beliefs, reserving particular scorn for those practitioners who add the word "quantum" to unrelated topics like "healing" to give themselves an imprimatur of scientific respectability. After this point the book begins to wander, and the final chapter's attempt to blame religion for overpopulation seems like one idea too many for a book already packed with them. The result is an ending weaker than it could have been, but both religious and non-religious scientists are sure to find something of interest in the rest.

● 2008 Princeton University Press £17.95/$24.95 240pp

Of algebra and Allah

Quick! Name a scientist born before 1400! Plato and Aristotle probably spring to mind, but what about Musa al-Khwarizmi and Hassan ibn al-Haitham? The former's contributions include nothing less than inventing algebra, while the latter's writings on optics and integral calculus anticipated Newton (at least partially) by some 600 years. Ibn al-Haitham is perhaps better known in the West by his Latinized name Alhazen, and therein lies the problem: these scientists' importance, as well as their names, have become garbled in translation. In *Science and Islam: A History*, Ehsan Masood, a commissioning editor at *Nature*, aims to counter both the idea that scientific progress ceased between the fall of Rome and the Renaissance, and the impression that Islam today is irreconcilably hostile to science. The result is a rich if often sprawling narrative on Islamic scientists and the worlds they inhabited, from Cairo under the Fatimid dynasty to the Spanish empire of the Umayyad caliphs. Confusingly, the book frequently refers to scientists in passing long before their discoveries are actually explained – a pattern that may stem from the book's role as a companion to the 2009 BBC TV series of the same name. As a brief primer on an often-neglected epoch of scientific history, however, this ambitious effort is nevertheless worth a look.

● 2009 Icon Books £14.99 /$21.56 256pp


Photomultipliers

Careers

Riding the storm out

A career in severe-weather research offers flexibility and plenty of opportunities to experience the fascinating physics of the rotating fluid called the atmosphere. **Josh Wurman** describes the science of storm-chasing and why hurricanes are scarier than tornadoes

Take me to the weather Josh Wurman enjoys the freedom that being a freelance meteorologist affords him.

I am standing on a bridge near the North Carolina coast. There is a light breeze, and I am enjoying some hazy sunshine. But this calm is an illusion: in a few minutes winds of up to 45 m s^{-1} (100 mph) will sweep in again. The approaches to my section of the bridge are already drowned under 2.5 m of water, and my companions on this island are an eclectic mix of traumatized animals, including snakes, rats, wounded pelicans and frogs. Earlier, one of the snakes flew through the air past my truck. The animals and I have been drawn to this bridge by Hurricane Isabel, which has just slammed into the coastal islands of North Carolina, and at the moment we are in the calm, sunny eye of the storm. The animals are just trying to survive on the area's only dry ground. But I have come to the bridge with a radar system on a truck and have spent a night and a day on it because I want to know what is happening inside this hurricane.

Chasing innovations

Meteorological research is a highly mathematical subject, and I have been intrigued by maths since I was a small child. Once, I spent dozens of hours working out the digits of π using a printing calculator (this was the 1960s) and what I soon realized was a very slowly converging formula. But I also loved being outdoors, so in between my calculations I collected thousands of insects, pinned in boxes and stored in hundreds of pill boxes in my family's freezer.

As I moved beyond collecting numbers and bugs, I became interested in weather. The study of atmospheric motion is very mathematical, essentially applied fluid dynamics, and the real-world effects of these equations can be seen every day. The equations of motion for the atmosphere cause trees to be blown down, hail to fall and snowdrifts to pile up – all things that I could witness while growing up in Pennsylvania.

I started out as a physics major at the Massachusetts Institute of Technology (MIT), but my real interest was meteorology, in which MIT only had a graduate programme. Fortunately, the university was quite indulgent of me, and I was allowed to combine my physics classes with several graduate meteorology classes to earn a hybrid degree in interdisciplinary science.

While I was finishing my PhD on microbursts at MIT, a "tea hour" discussion with some friends got me thinking about constructing weather radar networks using "passive" rather than the traditional "active" radar sites. Passive radar systems are almost a hundred times cheaper than active systems, which require expensive components like powerful high-voltage transmitters and large antennas. I wrote to the heads of a few research labs and was surprised that they not only read my letters, but even wanted to fly me out to explain my ideas. One of these trips brought me to the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, where I became a visiting scientist in 1991 and began developing and testing my new radar-network concept.

Before too long, however, I became distracted by how little we really knew about what was going on inside severe-weather systems. In the mid-1990s, no-one had yet mapped out the winds inside tornadoes, so no-one really knew how strong they were. After reading the relevant literature, I decided that a more ambitious technological and logistical approach could push back the veil of ignorance about these fascinating phenomena. So in 1994 I decided to shift focus, leaving NCAR for a faculty position at the University of Oklahoma, where I developed a prototype mobile weather radar system called the Doppler on Wheels (DOW).

A DOW is a cutting-edge Doppler weather radar that is mounted on a truck. The concept is simple. Instead of waiting for interesting weather to come to me, I drive to the weather (like Hurricane Isabel) and surround it with DOWs and other instruments. In its first few weeks of testing, the DOW made important new measurements inside tornadoes, which allowed my team to produce the first-ever 3D mapping of tornadic winds. With new data coming in every minute, we could watch the wind, debris and rain fields evolve in something close to real time.

Since 1995 the DOW and its descendents have observed and mapped the wind fields of more than 140 tornadoes. These include the most intense tornado ever documented, which hit Moore, Oklahoma, in 1999 with near-surface winds of 142 m s^{-1}; and the two largest tornadoes ever mapped, one of which occurred in the same 1999 outbreak and had a core circulation that was more than 1600 m in diameter. We have also mapped the fascinating behaviour of multiple vortices, which are like miniature tornadoes-within-tornadoes and which are believed to cause the worst tornado damage.

From tornadoes to terrorists

After nine years at Oklahoma, family considerations and a dislike of academic politics led me to return to Boulder, where I founded a not-for-profit company: the Center for Severe Weather Research (CSWR). There are only a few other severe-weather researchers working outside established universities or labs, but so far our experiment seems to be successful. The DOWs are now available to all National Science Foundation principal investigators as "national facilities", without charge to their grant programmes, and my group of three researchers, a technician, an administrator and me is continually finding new ways of using them.

In September 1996 my team and I took a DOW into Hurricane Fran, which was much scarier than a tornado. I can study tornadoes while remaining at a relatively safe distance where the winds are only 20–40 $m\,s^{-1}$, but a hurricane's storm surge will inundate many tempting DOW deployment sites and winds can exceed 50 $m\,s^{-1}$. Moreover, once we pick a spot, we cannot easily change our minds, because often escape routes can be blocked by flooding, downed power lines and felled trees.

In recent years, we have also taken DOWs to wildfires, to map out hot spots and wind shifts, and to observe aircraft dropping fire retardants. We have studied coastal storm systems off California, observed simulated releases of toxins from aircraft pretending to be terrorists, and assisted meteorology studies in France, Germany, Italy and Switzerland. The DOWs have proved extremely versatile, and are useful for any meteorology project that needs finer-scale observations.

A career in weird weather

The best thing about my career is that I have the freedom to pursue my passions and curiosities. If I can obtain resources or link up with colleagues with similar interests, then we can rush into these projects – studying tornadoes, hurricanes, fires, winter storms, toxin plumes, bird migrations, whatever. In all of these areas, there are still big questions that can be addressed by "mere mortals"; you do not have to be one of the four smartest people on the planet to make important contributions. Field research has also given me opportunities to travel to parts of the world that I would otherwise not have visited, and to experience local cultures in ways that I could not as a tourist. I have lived on a remote Polynesian island operating a radar, deployed instruments in some very odd places in the Pacific, and visited just about every town in the US High Plains.

I get literally thousands of meteorology-related e-mails each year, many proposing outlandish ways to destroy tornadoes or hurricanes. Of course, most of these writers are cranks, but because my career in severe weather research got started when I sent unsolicited ideas about radar networks to established scientists, I always try to remember that there might be a useful needle buried in this haystack (although I have not found one yet).

I am often asked how to get into this kind of research. The obvious answer – study lots of maths and physics – is correct, but I would take this half a step further. I and some others in meteorology actually prefer young researchers to have backgrounds in physics or mathematics, rather than just meteorology. For example, I recently hired a postdoc who earned Master's degrees in physics and teaching before doing her PhD in meteorology. Although several universities (such as Reading in the UK and Pennsylvania State in the US) do offer undergraduate degrees in meteorology, some of the best departments for meteorology research (including MIT) do not. So, I recommend getting a degree in physics with some maths courses that cover fluid dynamics and then specializing later.

The disadvantages of my career are typical of much of science: if you are smart, ambitious and want to make lots of money, or retire to play golf at 50, severe-weather research is a poor choice. A really smart person can probably make more money as a lawyer or even an online poker player. But in the end, I am thrilled with the career that I have chosen. It is different every day, and I have a lot of control over my direction and destiny. Most importantly, it is lots of fun.

Josh Wurman leads the Center for Severe Weather Research, a non-profit organization based in Boulder, Colorado, US, e-mail jwurman@cswr.org

Careers and people

'Past' prize for astrophysicists

Three astrophysicists have won the "past" division of the 2009 Dan David Prize for their work on imaging the cosmic microwave background. Paolo de Bernardis of the University of Rome La Sapienza and Andrew Lange of the California Institute of Technology received the award for leading the BOOMERANG experiment, while Paul Richards of the University of California, Berkeley, was honoured for his work on the MAXIMA experiment. The trio will share a $1m prize from the Dan David Foundation based in Israel, which has given three such awards – for achievements with an impact on the world's past, present and future – every year since 2002. Some 10% of the prize will go to support outstanding astrophysics doctoral students. Other recipients of the 2009 prizes are former UK Prime Minister Tony Blair for "present leadership" in the Middle East; and Robert Gallo, an AIDS researcher at the University of Maryland, for "future global public health".

Science-writing stars

Physicist and author Gino Segrè of the University of Pennsylvania is among five recipients of the 2008 science-writing awards from the American Institute of Physics. Segrè's book *Faust in Copenhagen* describes an April 1932 meeting of more than 30 leading theoretical physicists that concluded with the group enacting a parody of Goethe's play *Faust* (see *Physics World* November 2007 pp44–45 for a review of the book). Another winner, journalist Ann Finkbeiner of Johns Hopkins University, was honoured for her book on a group of physicists – known as the "Jasons" after the Greek hero – who meet for six weeks every year to work on research projects for the US military. Producer Julia Cort's documentary for NOVA scienceNOW on whether an asteroid will hit the Earth in 2036 won the prize in the broadcast category, while Alexandra Siy and Dennis Kunkel won in the children's category for their book *Sneeze!*.

Movers and shakers

Harvard University astronomer **David Charbonneau** will receive the 2009 Alan T Waterman award for early-career researchers from the US National Science Foundation in honour of his work on detecting extrasolar planets. The award comes with a $500 000 grant.

Qforma, a biotech modelling firm based in Santa Fe, New Mexico, US has appointed semiconductor physicist **William Howard** as director of its field operations.

Raymond Jeanloz, a planetary scientist and astronomer at the University of California, Berkeley, has received the American Physical Society's 2009 Leo Szilard Lectureship for his work on nuclear non-proliferation (see also pp34–37).

H Jay Melosh, a planetary scientist and impact specialist at the University of Arizona, has received this year's Eugene Shoemaker Memorial Award from the BEYOND Center for Fundamental Concepts in Science, a "cosmic think tank" based at Arizona State University.

Once a physicist: Vijay Iyer

Chris Drukker

Vijay Iyer is a jazz pianist based in New York, US, who was voted the number one rising-star jazz artist and composer in *Down Beat* magazine's international critics' poll for 2006 and 2007

Why did you choose to study physics?

I liked physics when I studied it at high school, though I did not have an advanced introduction to it until I was an undergraduate at Yale. It took me a while to develop what physicists call "intuition", but I always liked the connection between mathematics and physical reality.

How did you become interested in jazz?

My school had a jazz ensemble and I had been playing piano since childhood, so I auditioned a few times and eventually got involved. Our local library had a lot of jazz albums, so I began investigating, and a few of my friends and I started a quartet that mangled jazz standards. I kept at it throughout university and started writing music for small groups that I was leading. I saw the documentary *Straight, No Chaser* about the great composer-pianist Thelonious Monk around this time, and I was inspired – it was like I had been struck by lightning.

How did you switch from research to being a full-time musician?

When I moved to Berkeley, California, to begin my PhD, I found myself playing professionally around Oakland and San Francisco. I did not expect things to develop as rapidly as they did, but one thing led to another and I found myself pretty deeply involved in the Bay Area's music world. For a while I led a double life – budding physicist by day, musician by night. Soon it was not just about playing gigs; it started to be more about becoming an artist.

What made you decide to leave physics?

A couple of years into my PhD, I had done well in my classes but was reaching an impasse with my research project, which was in theoretical solid-state physics. I decided to put the research on hold, take a teaching assistantship, and regroup. It was a real soul-searching moment. In the early-to-mid-1990s, job prospects were sort of grim for physicists, so I had to face that reality. At the same time I was getting a lot of satisfaction as a musician, and I soon realized that I loved that more than anything else. All walks of life offer their own frustrations, and music and physics are no exceptions. But if you really want to be happy, I realized, you have to love what you do.

What did you do after you decided to leave physics?

I started touring in Europe and recorded my first album in 1995. I also hooked up with some key academic mentors – primarily David Wessel, a research pioneer in music perception and director of the computer-music centre at Berkeley. With guidance from Wessel and a few others, I switched to an independent interdisciplinary PhD programme that we created called "Technology and the arts". This allowed me to take music performance and composition seriously while doing academic research in music perception and cognition. I completed this PhD in December 1998 and immediately moved to New York, stepping right into the city's vast and diverse arts world. I have been a full-time artist for the last decade, while keeping a toe or two in academia.

Do you see any relationship between your music and physics?

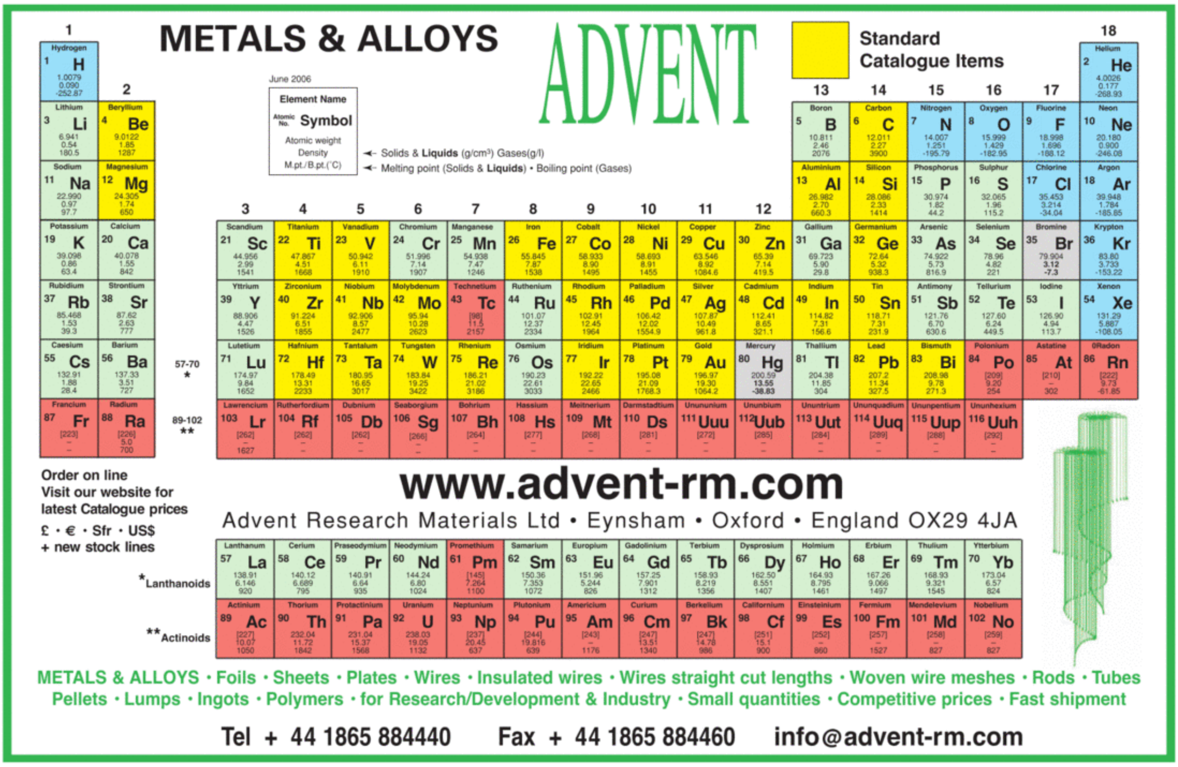
I have this love for mathematical rigour and elegance, which influences the rhythms, forms and structures of my compositions. Often, I approach composition as solving problems with constraints. I look for the simplest solution, which is a cherished aesthetic for physicists. I always admired this about Paul Dirac, for example. There are other connections, too. Rhythmic periodicities can be likened to the crystalline lattices of solid-state physics; once I went so far as to consider the implications of a rhythmic Brillouin zone. I also think about harmony in terms of the physics of sound: the overtone series, resonances and psychoacoustics. But let's face it – I am not doing quantum mechanics anymore. I "left" physics for music. I think that the playing of music gives me what physics did not: a visceral excitement, and the spark of real-time collaboration. I am sure that physics can do those things too, but in my case music did it first.

Do you still keep up to date with physics?

I read the science section of the *New York Times* each week, but because of my research in music perception, my scientific interests have drifted more to neuroscience, so I follow that a little more closely.

What are you working on now?

There are a couple of new albums that will surface in 2009 under my name, and I will be touring Europe several times in the coming year with my various ensembles. I am also developing a couple of new projects: one a site-specific installation in collaboration with a filmmaker named Bill Morrison at an abandoned prison in Philadelphia, and another with the poet Mike Ladd about veterans of the recent wars in Iraq and Afghanistan. And I have been asked to think about "interplanetary" music in conjunction with some physicists who are working on the atmospheric acoustics on Mars, Titan and Venus.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* Please note that applications are only considered from nationals of one of the following States: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and Canada.

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The Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE) has an opening for a Research Associate to work on research and development for a broad range of topics involving RF superconductivity for particle accelerators.

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Applications should include a curriculum vita, publication list, summary of research experience and interests. Electronic to search@lepp.cornell.edu. For a complete description of the ad, please visit www.lepp.cornell.edu and click on Jobs.

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Imperial College London

Institute for Shock Physics
Department of Physics
South Kensington Campus

Professor/Reader & 2 Lectureship Posts in Shock Physics

The Institute of Shock Physics is a major new cross-disciplinary research initiative housed within the Faculty of Natural Sciences. It is being established to bring together expertise within the UK and abroad to study the response of materials to high-pressures, such as those created by strong shocks generated in a variety of environments. The vision for the Institute is to be world-leading in experimental, theoretical and computational shock physics. The Institute's initial funding comes in part from AWE Plc and further funding is being sought from other funding agencies (including the UK Research Councils and other industrial companies).

Applications are invited for the following posts which are available from **1st September 2009** and have an academic affiliation to the Department of Physics:

Professor/Reader (Ref: NS2009038GA)

Minimum starting salary: £66,150 p.a. (Professor)/£51,870 p.a. (Reader)
Permanent

The postholder will work with the Director of the Institute of Shock Physics and other academic staff of the College to develop and implement a coherent College-wide vision for shock physics and to conduct an innovative research programme of international quality in an area complementary to the scientific remit of the Institute. He/she will take a lead role in designing and directing the Institute's experimental research programme relating to a new high velocity gas gun to be installed at the College, will contribute to teaching and organisation of an MSc programme, and be expected to represent the Institute and its interests and contribute to administrative tasks at both Institute and College level.

Candidates should have an international reputation for research in an area directly related to shock physics (either experimental or computational), and have experience of leadership in research institutions or similar bodies with evidence of a comprehensive understanding of gas gun facilities, impact science and associated experimental research activities.

2 Lectureship Posts (Ref: NS2009039GA)

Salary: £42,060 – £46,970 p.a.
Fixed-term positions - 3.5 years in the first instance

The postholders will be required to develop leading research programmes in the area of shock physics and contribute to teaching activities on the new MSc in Shock Physics. Candidates should have proven ability in an area of shock physics research and should have a PhD or equivalent in a relevant research field.

Informal enquiries are welcomed and should be directed to the Institute Director, Professor Steve Rose, +44 (0)20 7594 7635, s.rose@imperial.ac.uk

Our preferred method of application is online via the Imperial College London employment website www.imperial.ac.uk/employment Further particulars for all posts are available on the website searching with the reference numbers above.

Alternatively, if you are unable to apply online or have any queries about the application process, please contact Maria Monteiro, m.monteiro@imperial.ac.uk, telephone +44 (0)20 7594 5498 (for Professor/Reader) and Sarah Dodman, s.dodman@imperial.ac.uk, telephone +44 (0)20 7594 7657 (for Lectureships) to request an application form. Please quote the appropriate reference number.

Closing date: 11 May 2009.

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We are looking to recruit a physicist to join our small team producing world class optical thin film coatings, based in Plymouth, Devon. Candidates should have experience of design of optical thin films including rugate filters. Experience in a commercial environment would be an advantage, but is not essential. The successful candidate may be required to undertake security clearance. Some overseas travel will be necessary.

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Announcement

The International Center for Condensed Matter Physics of the University of Brasilia has openings for postdoctoral positions in the theoretical areas of Non-Equilibrium Nanostructures and *Ab Initio* Calculations for Nanostructures and Correlated Systems and for the experimental Material Sciences group.

All positions will be available from May 2009. Applications should be made by e-mail before next April 13th. Later applications may also be considered depending on developments. For more detailed information please visit our website http://www.iccmp.br, contact by e-mail the leader of the research group you wish to join or by e-mail visitors@iccmp.web.br.com.

UNIVERSITY OF LEEDS

Faculty of Mathematics and Physical Sciences
School of Physics and Astronomy

Lecturer or Senior Lecturer in Experimental Soft Matter Physics

The School of Physics and Astronomy is looking for an enthusiastic and self-motivated experimental scientist to join the Polymers and Complex Fluids group as a Lecturer. You will participate in teaching duties at all levels within the School.

With a PhD in Physics or a closely related discipline, you will have a strong track record of experimental research and a history of attracting research funding commensurate with your experience. You should be eager to collaborate widely in an interdisciplinary environment, and demonstrate a clear research vision. Ideally your expertise will be in the dynamics and/or flow of complex fluids and/or biological materials, which complements our current research interests in polymer physics, non-equilibrium physics of complex fluids, statistical mechanics, and biophysics. However, excellent candidates in any area of experimental Soft Matter Physics that complements the current expertise in the School are encouraged to apply.

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Informal enquiries to Professor Peter Olmsted tel +44 (0)113 343 3830 email p.d.olmsted@leeds.ac.uk

To download an application form and job details please visit www.leeds.ac.uk and click on jobs. Alternatively these may be obtained from Recruitment tel +44 (0)113 343 5771 email recruitment@adm.leeds.ac.uk

Job ref 327006 Closing date 1 May 2009

We welcome applications from all sections of the community. Textphone for deaf applicants only +44 (0)113 343 4353. All information is available in alternative formats please contact +44 (0)113 343 4146.

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Further information can be found at http://bcp.phys.strath.ac.uk/ultrafast/ or by contacting Professor Klaas Wynne: klaas.wynne@phys.strath.ac.uk

A PhD in physics or physical chemistry and a background in laser spectroscopy are required. Previous postdoctoral experience and experience in ultrafast spectroscopy and (soft) condensed matter physics or chemical physics are desirable.

For an application pack, visit http://vacancies.strath.ac.uk or contact Human Resources, University of Strathclyde, Glasgow G1 1XQ, UK. Tel. +44 (0)141 553 4133, quoting ref: JA/R24/2009.

Closing date: 14 April 2009.

We value diversity and welcome applications from all sections of the community.

DEDOM erc

Research Scientist

1 Research Scientist position (up to **4 years**) is available at the **Theoretical and Computational Division** of the National Nanotechonology Laboratory of CNR-INFM, Lecce, Italy (http://www.theory-nnl.it).

Research topics include: density-functional theory (DFT) modelling of interfaces between organic molecules and noble metals surfaces; development of embedding approaches, orbital free DFT and surface green functions; development of advanced DFT methods and orbital-dependent exchange-correlation functionals. This position is funded by the ERC-Staring-Grant Project DEDOM (http://www.theory-nnl.it/dedom).

The monthly net-salary will be in the range €1800-€2500 (depending on experience). Applicants should have a Ph.D. in theoretical chemistry/physics. Applications should include: curriculum vitae, list of publications, description of research experience, description of simulation methods implemented by the candidate. Contact: **fabio.dellasala@unile.it**

physicsworld

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Applications of students from all countries are welcome. To be eligible for PhD studies at the University of Heidelberg, applicants should have a Master of Science degree (or equivalent) and excellent grades. International applicants whose mother-tongue is not English or German are advised to provide a proof of English proficiency.

Applications for this round must be received by May 1st, 2009. Each applicant has to initiate his/her application by registering online at **http://www.mpi-hd.mpg.de/imprs-qd/** and following the steps outlined there. In particular, applicants should not send any material until they are encouraged to do so.

The University of York

Department of Physics

Postgraduate Opportunities

- Research in the Physics Department at The University of York spans a wide range of fields in fundamental and applied physics and is organised in four internationally recognised groups: Nanophysics, Condensed Matter Theory, Nuclear Physics and Plasma Physics.
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- PhD studentships for entry in October 2009 are available (funded by EPSRC/ STFC, Industrial Sponsorship or the University of York).
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http://www.york.ac.uk/depts/phys/gsp/taught/index.htm

For how to apply and further details of research projects visit our website
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Taught MSc: Fusion Energy

Centre for Plasma Physics - CPP
(School of Mathematics and Physics)

PhD STUDENTSHIPS in Plasma Physics

Three studentships are available for research in a number of projects at the Centre for Plasma Physics at Queen's University Belfast. The projects are:

Protein analysis and control using ultrafast lasers
Principle Supervisor: Dr Jason Greenwood

Numerical simulations of microplasma interactions
Principle Supervisor: Dr Timo Gans

These projects are funded by the Northern Ireland Department of Education and Learning. Applicants must be UK citizens or be EU citizens qualified by a period of residence in the UK.

Plasma phenomena of astrophysical interest
Principle Supervisor: Prof Marco .Borghesi

This project is funded by Queens University and citizens of any country are eligible to apply.

More details of the Centre for Plasma Physics and these research projects can be found on the CPP website at **http://www.qub.ac.uk/mp/cpp/** or by direct contact with the supervisors.

Successful applicants will receive a three-year studentship which will cover approved tuition fees and a stipend to cover living expenses which is currently £13,290 per annum. The normal start date for the studentships is October 2009

To apply: Applications must be made through the University electronic website at https://pg.apply.qub.ac.uk/home/. However applicants are also strongly encouraged to contact the project supervisor. Contact details are available on the CPP website.

Closing date: 17 April 2009.

Queen's University Belfast

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University of Salford
A Greater Manchester University

PhD Studentship Computational Simulation of Nano-materials

The University of Salford's Institute for Materials Research has recently gained funding from EPSRC for a project (P.I. Prof. D.K.Ross) involving investigations of the dynamics of polycrystalline nano-materials and hydrogen storage compounds using coherent inelastic neutron scattering matched to numerical simulations. Applications are invited from UK+EU candidates interested in studying for a PhD in this area.

Prospective applicants are encouraged to make informal enquiries by contacting Dr Daniel Roach - d.roach@salford.ac.uk Applicants should normally have, or expect to achieve, a first class (or equivalent) MPhys/MSci degree in Physics or a related subject, although exceptionally applicants with a BSc(Hons) will be considered. Applications will be processed when received but the closing date will be 1st May 2009.

The downside of technology

Question: What is the difference between science and technology? Answer: Technology is the application of scientific discovery for the benefit of society.

Hah! I sometimes think that while science is the noble study of the natural world, technology is an enterprise that has produced a great many gadgets that have an alarming tendency to fail when most needed. Yes, yes, I know that electricity, cars, trains and mobile phones all have their uses, but there is a problem with technology – the problem of reliability.

In my view, the trouble springs from two main sources. The first is *device failure*: anything made by humans will likely feature a certain fallibility (think cars made on Monday mornings). The other is *operator failure*: many of us employ familiar devices in a limited fashion, unwilling to take the time to learn how to use them properly.

An obvious example of device failure is the ubiquitous mobile phone. A stunning revolution in telecommunications technology, this device has transformed the world. Well, most of the world. Why do none of the major networks offer coverage in my village? Is it because the village is too small to be cost-efficient? Or because outsiders march in protest against new phone masts? We will probably never know. What we do know is that society now expects us to be contactable on our mobile phones in the evenings – so those living in my village have gone backwards instead of forwards.

Indeed, mobile-phone reception is notoriously unreliable worldwide, from problems of coverage in remote regions to issues of microwave reflection in built-up areas, not to mention what happens when too many users decide to all use the network at the same time. I was intrigued to learn a few years ago that the rescue services consider anybody who relies on a mobile phone for emergency communication to be certifiable.

Another example of device failure is the banknote machine, which can read banknotes. Or at least most banknotes. In fact, every user knows that the machine in the car park may or may not accept your tender. If it does not, then you had better hope that there are shops open that can give you change – a clear example of a technology that is not yet reliable.

Finally, there is the humble printer. Perched at the interface between cyberspace and the outside world, the printer is a special case. Most of the time, printers work fine, but every now and then, they go offline for reasons of their own. If you do not believe this, then you have never used a shared printer.

Of course, one could argue that the key word in the last sentence is "shared", and this brings us neatly to the second problem. The issue of operator failure is a complex one. This little article was written using Microsoft Word, the ubiquitous software package that is relatively easy to use. Or is it? Why does the use of one bullet point set it off into an orgy of unwanted bullet points? How do I switch this annoying feature off? What is it with the incessant capitalization? How do I get rid of the irritating little figure that keeps saying "I think you're writing a letter"?

Indeed, the "how do I get rid of this?" question is all too common in software. Most packages are simply far too clever (or, possibly, far too clever for me). They offer a vast number of functions that few users will ever require.

Photolibrary

Most software packages offer a vast number of functions that few users will ever require. Worse, one cannot switch them off

Worse, one cannot switch them off. A simple rule for product designers: if I had wanted these extra features, then I would have asked for them.

Now, some will argue that this is an example of design failure rather than operator failure. The program could have been designed with an emphasis on basic functions, rather than including unwanted extras as a default. However, at least part of the problem is that users rarely take the time to learn how to use a package properly. Instead, we confine ourselves to using it in a limited way, vaguely aware that there is probably an easier way of doing things.

Which brings us back to the mobile phone. Students love to use predictive text. But how do you switch this blasted function off? Does anyone over the age of 25 know? God help you if you accidentally switch it on by hitting the wrong key. Even if you do manage to contact the rescue services in an emergency, the text they receive will probably read something like "lkgfk jpng rttkkywz".

And then there is digital radio. All over the world, people of a certain age wait patiently for young relatives to visit. Why? Because once lost, digital radio stations can only be re-installed by a well-disposed teenager.

What is the solution to these woes? I suspect the solution to device failure is simply time – technology has progressed at such a pace that the support infrastructure has simply not been able to keep up. Another solution might be an increased emphasis on the Sputnik principle: the simpler the design, the more reliable the device. In the case of operator failure, we need to accept that any device is only as good as the person using it. So out with complex manuals written by someone who has never seen the gadget. In with clear instructions and an emphasis on basic functions. In short, we need to transform "user-friendly" from aspiration to reality.

Finally, none of the above has addressed the technologies society could have done without – jet skis, sport utility vehicles, nuclear weapons and so on. Something must be done before we all grow to hate technology…

Cormac O'Raifeartaigh is a physicist at Waterford Institute of Technology, Ireland, and author of the blog *Antimatter*, e-mail coraifeartaigh@wit.ie

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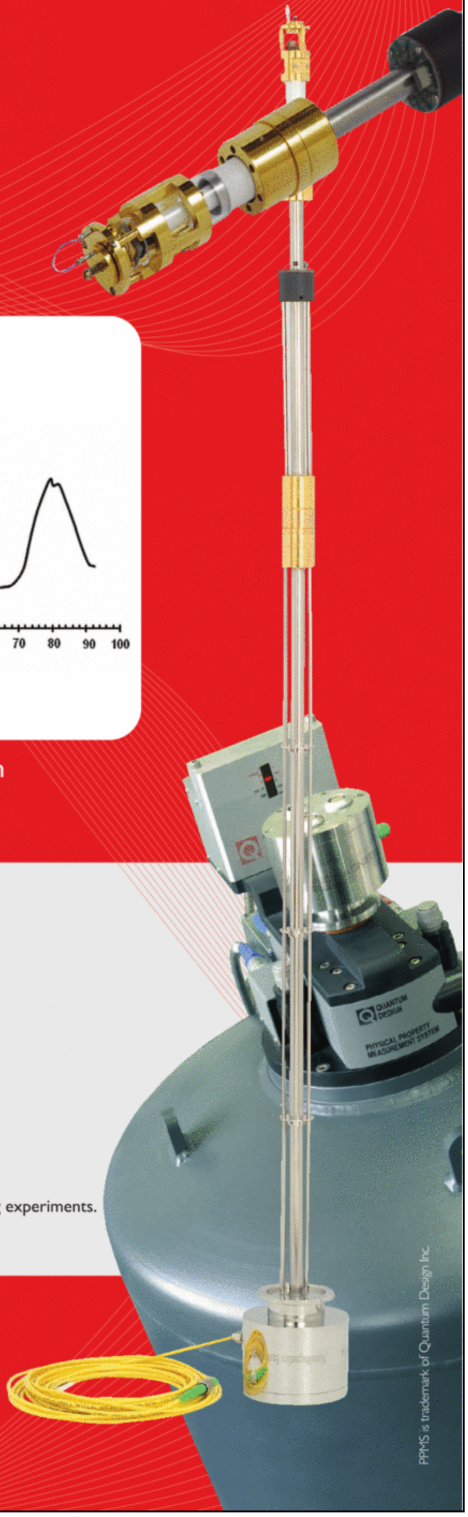

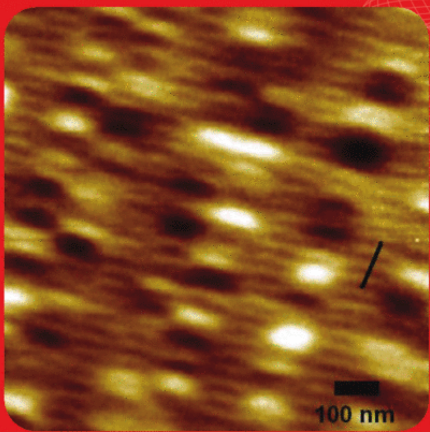

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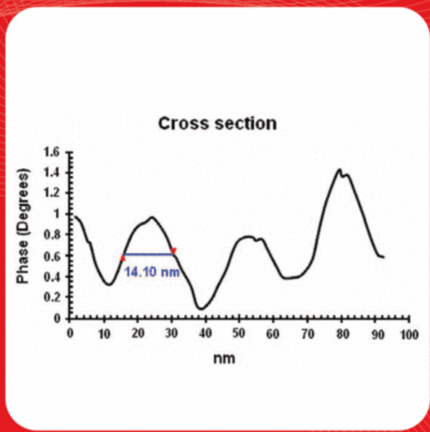

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