Highlights

Science and Technology Facilities Council

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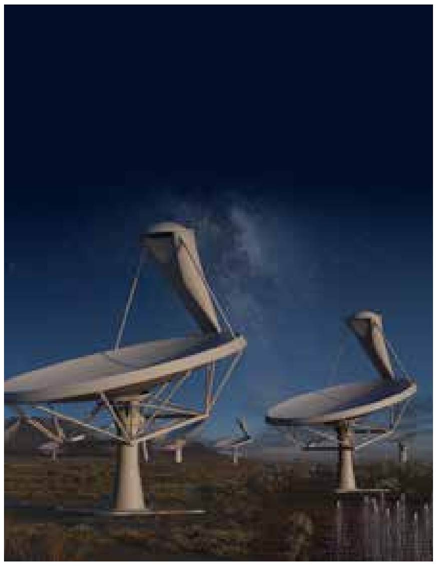

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Front Cover: Image Credit, ASDC, Explore Your Universe.

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"Investment in science is … about investing in our future, helping grow new industries and create more jobs – and that will mean more financial security for people across the country."

David Willetts, the Minister for Universities and Science

Credit: ALMA (ESO/NAOJ/NRAO), O.Dessibourg

Welcome to STFC's Highlights

Science matters. The unique and exciting combination of science, technologies and skills that STFC and our partners deliver brings real benefits to the UK economy and to our society. In our annual Highlights brochure we like to showcase just a small fraction of the work that we have been doing. The examples that follow show the scope of our work – from tiny nanoparticles to the unimaginable scale of galaxies and galaxy clusters.

David Willetts, the Minister for Universities and Science said: "Investment in science is … about investing in our future, helping grow new industries and create more jobs – and that will mean more financial security for people across the country." We agree.

We know that investment in big science projects, such as the Atacama Large Millimetre Array (ALMA) and the Square Kilometre Array (SKA) telescopes, will bring economic and societal rewards in the future, even though we can't always predict what those benefits might be. In fact, the impact of our science sometimes surprises even us – the World Wide Web, invented at CERN, celebrates its 25th birthday this year, but who could have predicted then the immense, and wide-ranging changes it would bring? ALMA and SKA will literally open our eyes to aspects of the Universe that were previously unknown to us, and give us the opportunity to answer some of the big questions that life here on Earth poses. But these insights will only be possible thanks to ground-breaking technological breakthroughs. The high-tech adaptive optics that will give the proposed European Extremely Large Telescope a clear view of what's happening beyond our atmosphere are already proving to be equally valuable in other fields, such as medical research. Together with the near-transparent zebrafish, they may lead us to a new understanding of, and treatments for, human heart disease.

We also know that many of the challenges we face – in energy, environment and health – need an understanding of the structure of materials and their properties at the level of atoms and molecules. We are investing in facilities like the Diamond Light Source, the ISIS neutron scattering facility, the Hartree Centre for high performance computing, and the next generation European Spallation Source, because they will give UK scientists the insights needed to develop better batteries for electric vehicles, solar cells to capture more of the sun's energy, and catalysts that enable chemical reactions to run with less energy and less waste.

We are very conscious that the future in which our science and technologies will be applied will be built by those currently at school, and we therefore devote significant resources in helping translate young peoples' initial interest in our sciences into life-long commitments to careers in the Science, Technology, Engineering and Mathematics (STEM) sectors. Our public engagement teams have in the past year made a real impact this year with our new 'Seeing the Universe in All its Light' touring exhibition and the 'Explore Your Universe' collaboration. Our science inspires, and we're proud of our ongoing role in inspiring the STEM students of tomorrow.

The highlights contained in this publication are just the tip of the iceberg. You can read more about our work in our other publications and on our website, our Twitter stream and our Facebook page. We'd love to see you at one of our public events. I hope that you will join us in celebrating another successful year of science, and support us in the coming year as we continue to work towards providing state-of-the-art solutions to the challenges that life brings.

John Womersley, Chief Executive

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How do you like your toast? White, wholewheat… or supergrain?

How one pioneering researcher is using Diamond Light Source to develop a super-nutritious grain that could turn wheat into a superfood.

Did you have a slice of toast for breakfast this morning, or cereal? A sandwich for lunch? Perhaps you had pasta for tea. For those of us lucky enough not to be sensitive to gluten, wheat forms a major part of our diet. In fact, together with rice and maize, wheat makes up two thirds of the diet worldwide, with over half a billion tons consumed each year – it truly is a staple.

The demand for wheat has focused the attention of plant breeders on creating more productive varieties, but there's evidence that modern wheat varieties have lower micronutrient levels than more old-fashioned ones. Here in the UK, obesity is the leading cause of preventable death, and there's evidence of a link to nutrient deficiencies. Obesity rates have quadrupled in the last twenty-five years, and now nearly a quarter of British adults are classed as obese. Elsewhere in the world, a billion people are hungry, and millions die from conditions related to nutrient deficiencies. An iron deficiency leads to anaemia and a lack of zinc contributes to deaths arising from diarrhoea, pneumonia and malaria.

Enhancing the nutrient content of staple foods like wheat, rather than trying to add new 'superfoods' to the diet, is one possible to solution to this crisis. Dr Andrew Neal, senior research scientist at Rothamsted Research, said: "Milling methods and our preference for white flour products over wholegrain means that much of the essential mineral content of wheat grains is lost during milling to produce white flour. We are looking for ways to increase iron and zinc quantities in white flour, ensuring they end up in our diet."

The problem lies in the fact that wheat grains are seeds, intended to feed a growing plant rather than humans. The nutrients they contain are locked up by a chemical called phytate, which humans can't digest, and the search is on for low-phytate grains from which we are able to absorb more nutrition.

Conventional breeding methods are capable of producing low-phytate wheat varieties, but the process is slow, and often involves plant breeders wasting time, money and effort on varieties that don't fit the bill. Dr Neal has been using the Diamond Light Source to carry out pioneering work that uses high intensity X-rays to pick out the most promising candidates, supported by the Biotechnology and Biological Science Research Council and Rothamsted Research.

When Diamond's X-rays are absorbed by wheat grains, fluorescence is emitted by the different minerals in the grain. This gives us a picture of how much iron and zinc are present, and where in the grain they are located. By using Diamond to identify which of the new low-phytate varieties have the highest micronutrient levels, Dr Neal is helping to develop a supergrain that could be growing in a field, and coming to a plate near you, very soon.

"Together with rice and maize, wheat makes up two thirds of the diet worldwide, with over half a billion tons consumed each year."

Micronutrients

We tend to think of our daily dietary requirements in terms of the main (or macro) nutrients – fats, proteins and carbohydrates. To stay healthy we need other things too, such as vitamins and minerals. These are called micronutrients, because we only need them in small quantities.

Credit: Juriah Mosin | Dreamstime.com

Taking the heat out of **hot spots** and **hot rods**

Ground-breaking research into improving energy efficiency has made use of multiple STFC facilities.

Old-fashioned incandescent light bulbs convert just 5% of the energy they use into visible light. The rest is wasted as heat. In fact, all of our electrical appliances produce waste heat, as do our cars. One of our current challenges is to provide enough energy for our needs whilst reducing carbon emissions, and one way to do that is by increasing energy efficiency. Harnessing some of the energy we waste as heat would reduce our energy consumption. With this goal in mind, a team of researchers led by Royal Holloway, University of London, and supported by the Engineering and Physical Science Research Council, has been conducting a series of experiments on sodium cobaltate that could pave the way for a new generation of thermoelectric materials that generate electricity from heat energy.

To carry out their research, the team grew crystals of sodium cobaltate in the lab, and then took them to several European science facilities. At the European Synchrotron Research Facility in France (ESRF) they carried out X-ray scattering experiments, and they used both the Institut Laue-Langevin (ILL) and ISIS neutron source to perform neutron scattering experiments. Interpretation of the experimental results relied on the expertise of STFC's scientific computing department, as it required highly complex materials modelling calculations and access to the UK's national supercomputer facility.

According to Dr Keith Refson, Computational Scientist at STFC "these supercomputer simulations, based on STFC's world-leading expertise in this discipline, have given us a far deeper understanding of the findings from our cutting-edge experiments and are making it easier to realise environmental benefits from the future generation of electricity from waste heat."

We could potentially use thermoelectric materials to recover energy from car exhausts, or develop solid state refrigerators to keep silicon chips and scientific equipment cool enough for efficient operation. Supercomputers are currently limited by their power consumption and the heat they produce, but STFC is working on energy-efficient, 'green' computing technologies that will usher in the next generation of supercomputers. Thermoelectric materials that can make use of their waste heat could be one piece of the puzzle. This kind of energy recovery is also useful for any off-grid electrical applications, including deep space missions, and advanced thermoelectric materials could one day make it to Mars.

As well as reducing energy demands and carbon dioxide emissions, other environmental benefits might flow from this research. The current generation of thermoelectric materials rely on the use of harmful elements such as lead, bismuth or antimony, or the rare tellurium. This research is moving the world toward a new generation of advanced materials that are considerably more environmentally-friendly.

Credit: Juliengrondin | Dreamstime.com

Ensuring trains can take the strain

Researchers have been using our ISIS facility to help make the wheels on trains more durable and reduce the costs of railway maintenance for the UK economy.

Credit: Alex Saberi | Dreamstime.com

Railways have a long and illustrious history in the UK. The legendary Stockton and Darlington line in the north-east of England opened in 1825 and steam engine and railway pioneers such as James Watt and Matthew Boulton, Isambard Kingdom Brunel and Robert Stephenson are rightly celebrated for their contributions to our industrial heritage. Although the romance of steam has given way to electric and diesel trains, the rail network is still an important part of our infrastructure – in 2012/13 alone, UK passengers made 1.6 billion journeys.

The safety of train travel is a primary concern, and the rolling stock is subject to strict maintenance and replacement schedules. In contact with the rails for every mile of every journey, train wheels come in for a lot of punishment: each one needs to be replaced every five years on average, making up a significant proportion of the maintenance cost.

Train wheels are subjected to heating and cooling during the manufacturing process to further harden the wheel rim and therefore minimise the formation of cracks. But wear and tear will still eventually cause cracks to appear in the outer layers of the wheel. When this happens, the cracked outer layer is removed during maintenance, revealing a lower, slightly softer layer beneath. With the hardened rim removed, it's then easier for cracks to appear. The older the wheel gets, the more its resistance to cracking decreases.

A team of researchers from the University of Huddersfield's Institute of Railway Research has been using ISIS' ENGIN-X instrument to investigate how cracks begin to form in train wheels, and how that process is affected by current maintenance practices. Their work is funded by a consortium including the Rail Safety and Standards Board, the Association of Train Operating Companies, Siemens, Lucchini, and the Engineering and Physical Science Research Council. ENGIN-X's key feature is that it allows engineers to test large, heavy samples – such as real train wheels – rather than just metal samples. Neutron diffraction can show scientists what's going on under the surface, several centimetres down into the wheel.

Adam Bevan, who led the study, explains its aim: "We hope that our results will help people improve manufacturing techniques, optimise how they look after the wheels and also influence the choice of different materials. Siemens, who supply a lot of the UK rolling stock, and Lucchini, who manufacture the wheels, are co-funding the project in the hope of making cost savings without compromising on safety. Ultimately it could lead to a change in standards on how these wheels are manufactured and used."

Understanding

STFC has funded a research project to further our understanding of the Sun's corona

The Sun's corona is a cloud of plasma - ionised gas - that extends millions of kilometres into space. The Sun expels a near-continuous stream of charged particles, known as the solar wind, which streams over our planet. Sometimes it also ejects huge clouds called coronal mass ejections (CMEs), often in association with large explosions in the solar atmosphere known as solar flares. Magnetic loops in the solar corona, solar flares and coronal mass ejections are among the phenomena that scientists still cannot fully explain, and STFC have funded a three-year research project at the Universities of Dundee and Durham to investigate. The grant will fund research time for Professor Gunnar Hornig, Dr David Pontin, Dr Antonia Wilmot-Smith and two new full-time Postdoctoral posts at Dundee, and Dr Anthony Yeates at the University of Durham. Although this is fundamental research into solar physics, it will have practical applications. Solar phenomena influence the environment around the Earth and understanding these processes is a field now known as space weather. The Department for Business, Innovation and Skills has invested £4.6 million in space weather forecasting, and this spring the UK will become one of the few countries able to forecast the 'weather' in space.

When CMEs are directed towards us, if they contain southward-pointing magnetic fields then their interaction with the Earth's magnetic field puts on a stunning light show in the form of aurorae – the Northern and Southern Lights. Although witnessing these beautiful displays has

Credit: Brian Sedgbeer | Dreamstime.com

our Sun

become a popular attraction, this ‘space weather’ can also cause us some problems. Satellites, spacecraft, and even high-flying aircraft can be affected by CMEs, and on Earth’s surface CMEs have the power to cause electrical blackouts, and even to corrode oil pipelines. A better understanding of the basic physical processes that occur in plasmas in the Sun (and elsewhere in the Universe) might allow us to predict problematic CMEs, to give warnings and plan ahead.

As well as adding to our understanding of the Sun and other stars, and our ability to predict and cope with space weather, this exciting research is also likely to contribute to other areas where magnetised plasmas are involved – fusion energy research, for example. As Professor Hornig explains: “In fusion, we try to capture the same process that heats the Sun on Earth in machines that encase plasma in a magnetic field and they try to make fusion. The same type of problems that have so far prevented people from building a working fusion reactor are also affecting plasma on the Sun. So, by studying this, we also improve our understanding of how fusion plasmas work.”

Diagnosing breast cancer instantly

At our Central Laser Facility (CLF), in close collaboration with Exeter University, we are developing a technique that could diagnose breast cancer in a person on the same day as their mammogram – putting an end to the agonising wait for results.

Every year, around 93,000 UK women have a mammogram that produces a potentially positive result and have to undergo a needle biopsy to confirm whether or not they have breast cancer. After a stressful wait of around a week, the patient is required to return to the hospital to receive their results. Between 70 and 90 per cent of those needle biopsies come back negative (around 75,000), but this is currently the best way to ensure a correct diagnosis.

Spatially Offset Raman Spectroscopy (SORS), an investigative technique developed at our CLF, could one day change this process for the better - by delivering instant results on the same day that the mammogram is performed. SORS allows non-transparent objects, including human tissue, to be analysed deep below the surface, without the need to perform an invasive procedure.

SORS has many potential applications, including detecting explosives and counterfeit medicines and diagnosing bone disease. Its development for use in breast cancer detection is in the very early stages, but initial research performed in collaboration with the University of Exeter and Gloucestershire Royal Hospital was very promising, indicating (through tests on pork) that it can be viable to determine non-invasively whether the shadows picked up by mammograms are benign or malignant.

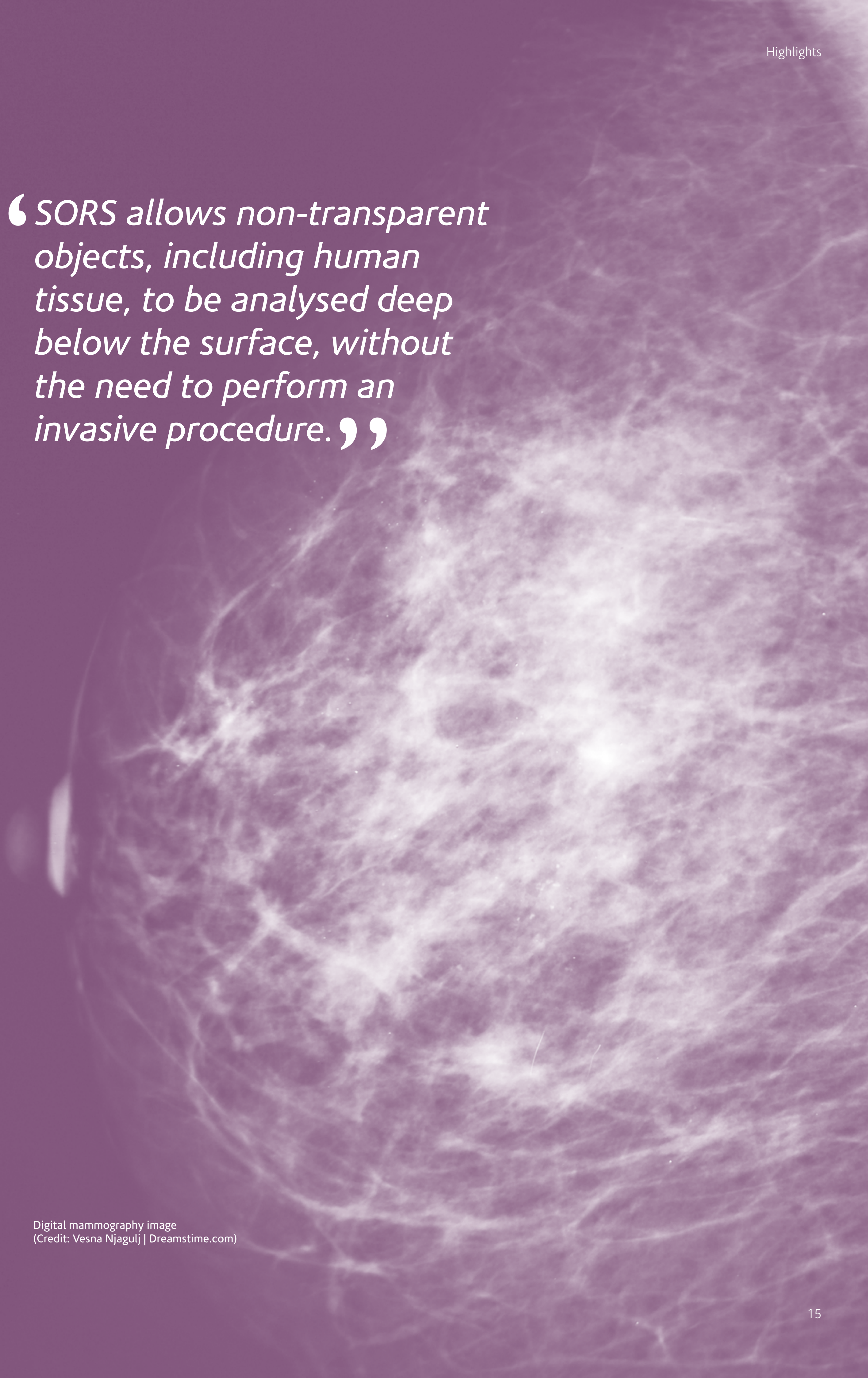
The next stage of the project is to extend the technique's penetration depth and evaluate it on real breast tissue, removed during operations and put forward for research by consenting patients. It is being funded by a grant from the Engineering and Physical Sciences Research Council (EPSRC) to the University of Exeter and STFC, in partnership with the Gloucestershire Hospitals NHS Foundation Trust.

Marleen Kerssens, whose PhD research proved that the technique could tell whether a tumour is malignant or benign, said she was "really pleased this line of research can be continued with the support of ESPRC. It is an exciting field of research and translation of the SORS technique to a clinical setting has the potential to reduce the amount of false positives and therefore reducing patient anxiety."

SORS works by shining a laser through the tissue under investigation. It then records the signatures received as the laser passes through the small calcifications (bone-like crystals) found in breast tissue, and these chemical signatures can be used to tell whether the tissue contains a malignant or benign lesion.

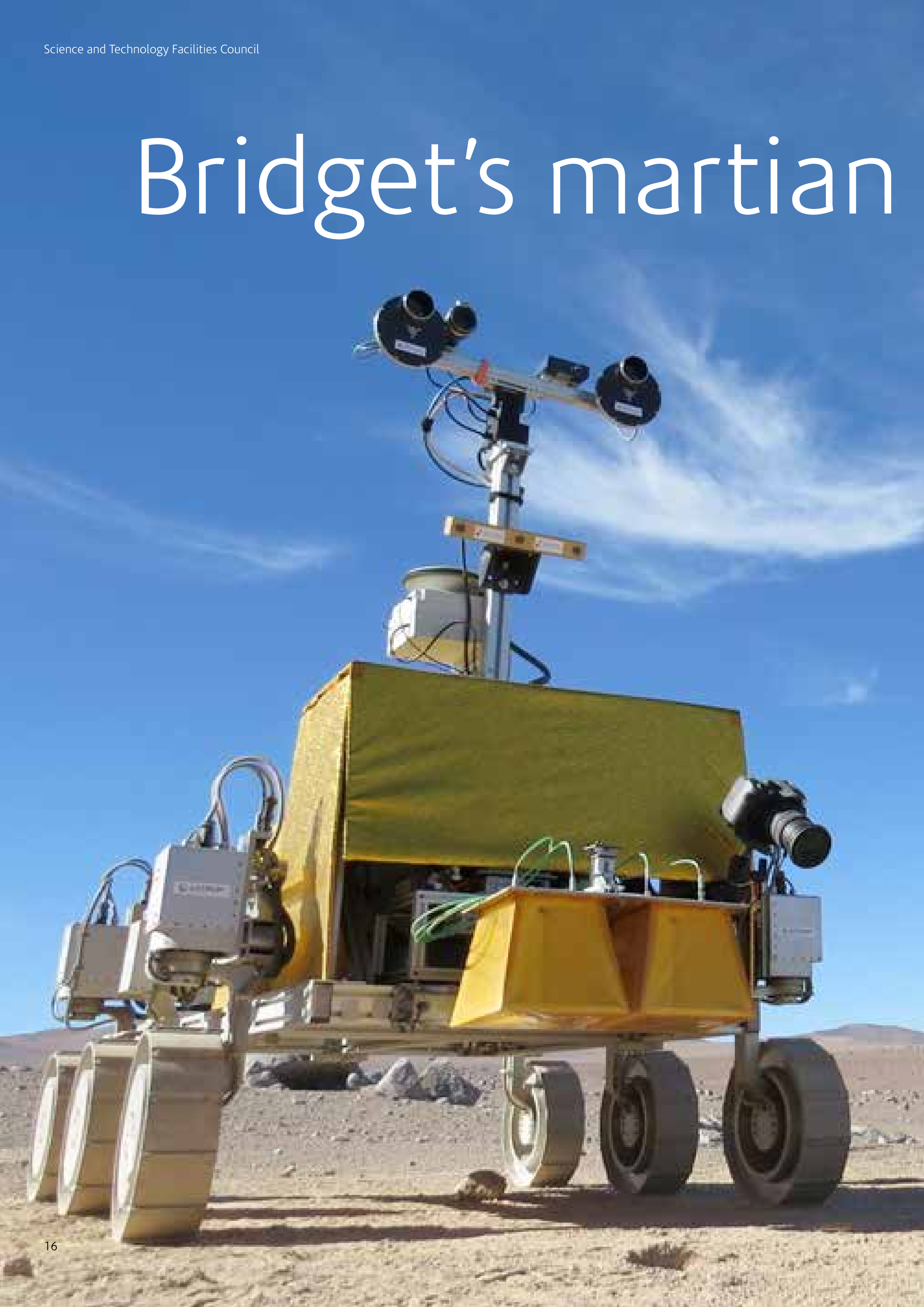
The researchers will be optimising the sensitivity and penetration depth of the technique, but it requires a lot of further research and refinement and it is likely to be a decade before this could be used as a routine test in hospitals. The potential benefits make it worth the wait – not only would instant results reduce the stress on healthy patients and give earlier detection for those affected, it would reduce the pressure on breast cancer clinics, freeing up resources as fewer women need to be seen twice.

“SORS allows non-transparent objects, including human tissue, to be analysed deep below the surface, without the need to perform an invasive procedure.”



Digital mammography image
(Credit: Vesna Njagulj | Dreamstime.com)

Bridget's martian



field trip

How do we know if a Mars rover will do what we want it to do on the red planet in 2018? We recreated Mars on Earth and tested it out.

Did you know that there are places on Earth that are quite a lot like Mars?

One of them is the Atacama Desert, which is one of the driest places on Earth and lacks vegetation. With its red-brown rocks, it even looks the part, making it an ideal place to put ESA's ExoMars rover through its paces.

The ExoMars mission is planned for 2018, and the SAFER mission (Sample Acquisition Field Experiment with a Rover) used an early version of the rover (named Bridget, and supplied by Astrium in Stevenage), equipped with three prototype ExoMars instruments - a panoramic camera, a close-up imager and ground-penetrating radar.

Two teams were involved in the mission. One team controlled the rover remotely, just as it would with the real mission, using a video wall in the Satellite Applications Catapult facility in Harwell Oxford. They monitored data from the rover and used it to select targets and plan routes for the rover, which were passed to the second team – on location in Chile. It was their job to relay the instructions to the rover, but to stay as invisible as possible to the team back at mission control.

To do this, the local team had to sweep away their footprints, and Bridget's wheel tracks, with a broom. The idea was to recreate, as closely as possible, the conditions that ExoMars and its support team will face in 2018, building up experience in remote operations of the rover. The team had to step in and do some digging however, when the mission required rock samples – Bridget wasn't supplied with a drill, although the real mission will have one.

Sev Gunes-Lasnet, project manager for RAL Space, said: "At our second simulated drill location the field team found a layer of rock starting at a depth of 60 cm. This comes close to the kind of features the team was looking for: analogues for locations on Mars which could hold traces of past or present life."

High desert winds and an encounter with a dust devil gave Bridget a real test, but the rover weathered them all without a hitch, while its human companions had to take shelter. And whilst the ExoMars mission is not expected to encounter life on Mars, Bridget unexpectedly tested that scenario too – during a close encounter with a desert fox!

SAFER rover (Credit: Astrium - E Allouis)

I spy, with my little eye…

The UK's astronomy community and STFC are touring a new exhibit showcasing the latest developments in telescope development – 'Seeing the Universe in All its Light'.

Do you remember the feeling you had when you first looked down a telescope? Of being able to see things you'd previously only been told about? That there was a whole new world opening up to you? Astronomy has always been about opening our eyes to the Universe around us, although these days the technology involved is a little larger.

Since July 2013, the Seeing The Universe in All its Light roadshow has visited 14 venues, travelled nearly 3200 miles and captured the imagination of more than 26,000 visitors of all ages. Wherever the roadshow has been, from the Houses of Parliament and BBC Stargazing Live events to Isambard School in Swindon, we've had young scientists on hand from UK university astronomy departments to explain what they do and answer any and all questions about astronomy. And we're not finished yet – the exhibition continues touring through 2014, so check out the STFC website to see when it's coming to you.

For those who like a little history with their science, the attractions on offer include a replica model of English astronomer Thomas Harriot's first telescope. For something a little more 21st century, there are scale models of the big telescopes – ESO's Very Large Telescope (VLT), the Atacama Large Millimetre Array (ALMA), the Herschel Space Observatory, and the James Web Space Telescope (JWST) scheduled for launch in 2018.

These are backed up with hands-on exhibits that explain why we need telescopes across the whole range of wavelengths. An interactive control desk provides details on the full spectra of wavelengths used by astronomers, and visitors can learn more on topics such as 'seeing the invisible', 'adaptive optics' and 'micro autonomous robots'.

Kiz Natt from the Open University, one of the astronomers helping with the roadshow, said: "The roadshow gives an excellent overview of all of the telescopes and the different 'eyes' on the Universe. One of the main themes is showing how telescopes operate at different wavelengths. People were amazed that an object such as a supernova remnant or nebulae – the same object - looked completely different at each wavelength." Professor Paul Roche, Chair of Astronomy Education at the University of South Wales, joined thousands of visitors at the roadshow in Cardiff, and said: "The exhibition is a fantastic showcase for the UK's involvement in cutting-edge science, and really shows that we punch above our weight when it comes to the technological and scientific advances in astronomy and space science. It's a great way to demonstrate to a wider audience some of the exciting developments that are happening right now, which could potentially revolutionise our view of the Universe".

Our expanding view of the Universe is not the only thing on which this exhibition sheds light – it also demonstrates the UK's scientific and high tech expertise, and the economic benefits that astronomy can deliver. The future of UK astronomy is bright, when you're seeing the Universe in All its Light.

For more information about Seeing the Universe in All its Light, visit: www.stfc.ac.uk/sual

Above: SUAL exhibit at the Welsh Assembly, November 2013. (Credit: Andrew Hazard Photography)

Right: SUAL exhibit at the House of Commons October 2013. (Credit: STFC)

"The exhibition is a fantastic showcase for the UK's involvement in cutting-edge science… It's a great way to demonstrate to a wider audience some of the exciting developments that are happening right now, which could potentially revolutionise our view of the Universe."

Professor Paul Roche, Chair of Astronomy Education at the University of South Wales

Why do we need different telescopes?

The electromagnetic spectrum of light stretches all the way from radio waves, through the visible colours, to gamma rays. Different kinds of telescope are needed to capture the different wavelengths, allowing us to see different aspects of the Universe around us. Optical telescopes show us 'conventional' colour images and are good for looking at stars in our galaxy. Radio telescopes can show us the jets of hot material spewing from the centre of the galaxy. Infrared telescopes can show us what's happening inside swirling dust clouds. Together they give us a complete picture, and allow us to develop our understanding of the Universe.

Biofuel's no trouble for gribbles

A team of researchers have used the Diamond Light Source to make a vital discovery that could address energy concerns in the future.

Close-up of the gribble. (Credit: Dr Simon Cragg and Graham Malyon - Institute of Marine Sciences, School of Biological Sciences, University of Portsmouth, UK.)

In 'Taking the heat out of hot spots and hot rods' we showcased an emerging technology that could improve energy efficiency. Another possible solution to the energy challenge is to search for renewable sources of energy. Woody plant biomass could be a major resource – its high cellulose content contains lots of potential glucose. Crop and timber residues and straw are plentiful sources of this woody biomass, as is much of the waste we currently send to landfill. But there's a major problem with turning biomass into useable liquid biofuels – breaking down the lignocellulose into simple sugars we can ferment into biofuel is hard.

As humans, we know that we can't digest cellulose; after all, we don't normally tuck into wood for breakfast. We don't have the digestive enzymes needed to break down the cellulose polymers into usable sugars. In fact, most plant-eating animals don't have them either. They rely on bacteria in their gut to digest their dinner for them. Fungi can perform the same trick, which is how wood slowly decomposes on the forest floor. If we're going to turn woody plant material into liquid fuel, we need the enzymes they use to do the job, but their production is expensive and at the moment this method of producing biofuel is not cost-effective.

This is where the gribbles come in. As a crustacean with a taste for ancient ships and the salt-laden timbers of modern piers, the gribble may sound more like the grumpy anti-hero of a children's story than the key to sustainable energy. Nesting in ship wrecks and driftwood, but just two millimetres long, the gribble - an isopod marine wood-borer - is hardly a sea monster of legend, even if it looks a little fearsome up close. However, a team of researchers from the University of York and the University of Portsmouth have discovered that the four spot gribble (Limnoria quadripunctata) uses an unusual mechanism for digesting wood. Instead of relying on bacterial or fungal assistance, the gribble has developed its own enzymes, and somehow maintains a completely sterile gut.

The team made crystals of one of these enzymes, a cellulase that converts cellulose into glucose, and brought them to the Diamond Light Source for examination under the high intensity X-ray beam. This allowed them to take a series of images of the crystals that showed them the positions of every atom in the enzyme. With the help of the Kraken and Red supercomputers at the National Renewable Energy Laboratory in the US, these images were turned into a 3D model showing the exact structure of the enzyme.
One of the features that make this enzyme particularly interesting is its ability to function in salt water, at salt levels seven times higher than you'd find in the sea. That kind of environment usually stops enzymes working. The ability to survive in salt water, and therefore in industrial environments that other enzymes find hostile, offers the possibility of cost savings. The team think this ability may come from the enzyme's highly acidic surface.

Armed with the 3D model, the team have been able to transfer the genetic blueprint of this enzyme to an industrial microbe capable of producing it in large quantities in the same way that the enzymes used in biological laundry detergents are produced. Since a key barrier to large-scale conversion of lignocellulose to biofuels is the limited availability of low-cost enzymes, this discovery could unlock a major source of renewable energy, and provide economic benefits at the same time. It should allow us to turn agricultural and industry wastes such as paper, timber off-cuts and straw into useable energy, avoiding the problematic use of food crops, or arable land, for biofuel production. As research team leader Professor McQueen-Mason explained:, "The robust nature of the enzyme makes it compatible for use in conjunction with sea water, which would lower the costs of processing. Lowering the cost of enzymes is seen as critical for making biofuels from woody materials cost effective."

From bags to ba

Scientists have found a way to turn waste plastic bags into lithium ion batteries thanks to work using STFC's ISIS facility.

Lithium ion batteries are a major feature of modern life, appearing in everything from computers and smartphones to electric cars and aeroplanes. They're much lighter than lead-acid batteries, and they can store up to six times more energy – but we're reaching the limits of performance of the materials currently used to make their electrodes and electrolytes. To build better batteries we need to understand these materials better.

In lithium-ion batteries, lithium ions flow between the electrodes: usually a carbon anode (the positive electrode) and a metal ion cathode (the negative electrode). Over time, as the battery is charged and discharged, the electrodes wear out and degrade, and the capacity of the battery is reduced. This puts a limit on their useful lifespan.

The properties of carbon materials depend on their low-level structure, down at the nanometre scale. A team of researchers from the Argonne National Laboratory in the USA have been using the Nimrod instrument at ISIS to investigate the internal structure of a particular carbon material, which could find its way into industrial products as diverse as batteries and engine lubricants.
The research is carried out using recycled polyethylene plastic from carrier bags. When heated at high temperatures and pressures, it forms hard carbon spheres, microparticles that are nearly as hard as diamond, and yet have electrochemical properties that are similar to those of graphite (pencil lead).

The first stage of the investigation used X-ray diffraction to study how the polyethylene evolved as it was heated. Then the researchers turned to neutron diffraction at ISIS to determine the internal structure of these carbon spheres, which form abruptly when the heated sample is allowed to cool to 350°C. Neutron diffraction shows that the carbon has adopted a layered structure; heating the polyethylene to 2800°C before allowing it to cool increases the layering effect, and improves the carbon's electrochemical properties. Understanding how the manufacturing process changes the carbon microparticles means that they can be tailored for use in different technological applications. In lithium-ion batteries, they could be used to form carbon anodes that maintain their shape and don't degrade – prolonging the life of the battery.

Dr Vilas Pol, who led the study, said: "This research has shown that plastic waste from carrier bags could be transformed into carbon architectures that might have real practical applications, improving the performance of lithium-ion batteries or a lubrication additive to reduce wear and tear in engines."

Credit: Anton Starikov | Dreamstime.com

tteries

Credit: Macker54321 | Dreamstime.com

Seeing the Universe

Thanks to ALMA (the Atacama Large Millimetre Array) and SKA (Square Kilometre Array) we'll be able to get our closest look at the Universe yet.

ALMA is online

ALMA will show us, in unprecedented detail, the birth of stars and planets, and even the infant galaxies of the early Universe. Consisting of 66 individual antennas that give the telescope an effective diameter of up to 16 kilometres, ALMA is the most complex ground-based telescope in existence.

In March 2013, an inauguration ceremony in the Chilean Andes marked the completion of a decade of work by the international team working on ALMA. The UK made a major contribution to the construction phase, through the Universities of Manchester, Cambridge and Kent, STFC's technology department, RAL Space and UK ATC (UK Astronomy Technology Centre). STFC's technology department designed, manufactured and delivered the cryostat cooling units that keep the sensitive instruments in each antenna at their operating temperature. RAL Space hosted and operated Europe's Front End Integration Centre, integrating and testing crucial components. UK ATC developed The Observing Tool, essential software, and the University of Manchester is home to the UK ALMA Regional Centre Node, offering support to scientists using the telescope.

Bringing together components from four different continents, in a desert location 5000 metres above sea level, is no mean feat – and UK industry won €44 million during the construction phase.

UK scientists have already used ALMA to examine the dusty remains of a recent supernova 160,000 light years from Earth. "Really early galaxies are incredibly dusty and this dust plays a major role in the evolution of galaxies," said Dr Mikako Matsuura of University College London (UCL). "Today we know dust can be created in several ways, but in the early Universe most of it must have come from supernovae. We finally have direct evidence to support that theory."

ALMA Antennas on the Chajnantor Plateau
(Credit: ALMA (ESO/NAOJ/NRAO), O. Dessibourg)

What is the SKA?

The Square Kilometre Array will be one of the most complex scientific instruments ever built. It will combine 4000 individual dishes into one large radio telescope with a collecting area of a square kilometre. It will be 50 times more powerful than existing radio telescopes, allowing astronomers to investigate the evolution of the earliest galaxies, and to see through the dust into regions where new stars are forming.

Artists' rendition of the SKA Dish arrays in operation at night time.
(Credit: SKA Organisation)

SKA is on the way

The UK government has committed £100 million to the SKA, which will be the world's largest and most sensitive radio telescope. Sensitive enough to detect a signal similar to airport radar on a plant tens of light years away, we hope it will help us answer some of the big questions in astronomy, shed some light on the role of dark matter and dark energy, and perhaps even let us know whether we are alone in the Universe.

The SKA Organisation has opened its new international headquarters, based at the University of Manchester's Jodrell Bank Observatory. This state-of-the-art new building will be the central hub for the global team building the SKA over the next decade, eventually home to around sixty members of staff as well as visiting scientists and engineers.

Work has begun on the detailed final design for the SKA. The UK is playing a leading role, with major contributions from the Universities of Manchester, Cambridge and Oxford, together with STFC and other UK academic and industry partners. The UK is heading up two consortia, tasked with finalising different parts of the design. The Science Data Processor (SDP) consortium has to figure out how to process all that data into useful information for scientists. The Signal and Data Transport (SaDT) consortium is responsible for the design of data transport networks that can routinely handle similar levels of data traffic that the entire world internet saw in 2011.

Dr Keith Grainge, Deputy Lead of the Signal and Data Transport consortium, University of Manchester, said: "The SKA will be an extraordinary project. The amount of data we need to transport from the antennas to the processors is equivalent to the entire world's internet traffic rate in 2011. In addition, we will need to synchronise the clocks at each antenna to a thousand-billionth (0.000,000,000,001) of a second. With the team of experts we have round the world, we are confident that we can meet these challenges and we are all looking forward to exploring some fascinating new areas of science with the telescope."

The SKA will be made up of thousands of dishes and millions of linked radio receptors in two locations: South Africa and Australia. The chosen locations are both remote and radio-quiet deserts, away from the possibility of man-made interference. The array will have the equivalent collecting area of a square kilometre (hence the name), which is a million square metres, or roughly the same area as 140 football fields.

Twinkle twinkle, little heart

Researchers are using technology normally used in astronomy to improve our understanding of how the heart operates.

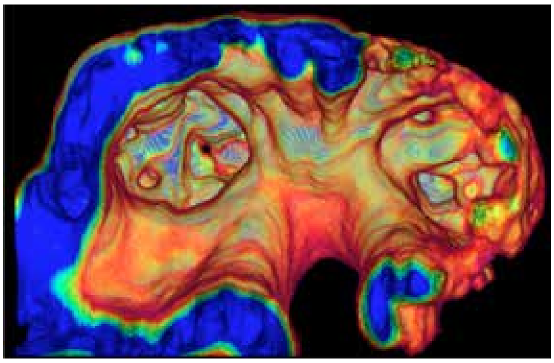
Credit: Mikhailg | Dreamstime.com

About 89 per cent of nights in the high Atacama Desert in Chile are cloudless and clear, making it a perfect location for ground-based astronomy. That's why it was chosen by the European Southern Observatory as the location for the world's largest telescope – the E-ELT, or European Extremely Large Telescope will be built in Cerro Armazones, and astronomers expect to see first light from its 39 metre main mirror in the early 2020s. Four or five times larger than the current state-of-the-art facilities, this huge mirror will collect fifteen times more light.

But even with cloudless skies, and at an altitude of 3060 metres, the E-ELT will have to cope with the turbulence in the Earth's atmosphere that makes stars appear to 'twinkle', causing distortion of the incoming light. This reduces the resolution of optical telescopes. The speed at which the distortions change means that we need have to employ a high-tech solution to the problem. Adaptive optics use computer-controlled, deformable mirrors to correct for distortions in real time.

Using adaptive optics will give astronomers at the E-ELT the clearest possible view as they look out into the Universe, but in the meantime they're also being put to good use by researchers looking at much smaller structures than distant galaxies.

A team from two of Durham University's research institutes - the Biophysical Sciences Institute (BSI) and the Wolfson Research Institute for Health and Wellbeing - are collaborating on a project called Beating Hearts at High Resolution. The project, supported by the British Heart Foundation and EPSRC (Engineering and Physical Sciences Research Council), involves using adaptive optics to get a clearer picture of beating zebrafish hearts using a specially developed microscope. The new instrument incorporates high speed imaging and adaptive optics to effectively 'freeze' the motion of the beating heart and remove the distortions on the image caused by having to look through the zebrafish tissue to see the heart. Using this technology enables features within individual cells to be observed with very high clarity. Professor John Girkin, Director of the BSI and Wolfson Fellow at Durham University, said: "The high speed imaging allowed by adaptive optics is crucial because the hearts are moving and embedded in the body of an animal, meaning it must be imaged at depth."



Cutaway reconstructed image showing internal trabecular structure of the developing zebrafish heart, 4 dpf. (Credit: Dr Jonny Taylor)

Zebrafish are useful for research into hearts because they are nearly transparent. Their hearts react to many drugs in the same way that human hearts do and (unlike humans) they retain their ability to repair themselves throughout their life. It's possible that zebrafish could be used to help screen new drugs for human heart patients. The team are working towards improving our understanding of the human heart, and developing improved treatments for heart conditions.

Research into adaptive optics could also lead to 'true' 3D images that make for more comfortable viewing at the cinema, and as part of new techniques for more accurate eye tests when you go to the opticians. Adaptive optics, originally designed for observing the largest possible objects, are now finding their way into a wide range of instruments and products that play a role in everyday life.

Particle Physics Masterclasses

A Level students during a Particle Physics Masterclass at Daresbury Laboratory
(Credit: STFC)

In March 2014, over 1000 physics students got the chance to see their learning come to life, when STFC kick-started its annual round of Particle Physics Masterclasses at Rutherford Appleton Laboratory and Daresbury Laboratory.

Our Particle Physics Masterclasses are part of an exciting national programme founded and co-ordinated by the Institute of Physics and run by researchers from around 20 different organisations up and down the country. At our Rutherford Appleton Laboratory, we have been successfully hosting Particle Physics Masterclasses since 1996 when they were first set up.

With a wealth of in-house expertise and access to world-class facilities, STFC is in a unique position in the UK to deliver an exciting, varied programme of these Masterclasses. Designed to support students' learning by demonstrating some of the real-life applications of their subject, our Masterclasses convey the excitement in ground-breaking particle physics and materials science research. By showing participants the impact our particle physics community are making in the world, we hope to inspire the next generation of particle physicists.

Masterclasses consist of a range of interactive activities, including tours of our facilities (location dependant), exciting talks by resident physicists and university researchers, hands-on experiments to complete using real data, and exclusive access to some of our exhibitions.

Our Particle Physics Masterclasses have gone down so well that they were even described by one teacher as "the best school trip ever."

If you're attending a Particle Physics Masterclass, join the conversation on Twitter and let us know what you learned! Tweet us @stfc_matters using #PPMC.

To find out more or to find out when our next Particle Physics Masterclasses are taking place, please visit: www.stfc.ac.uk/2763

Borrow the moon

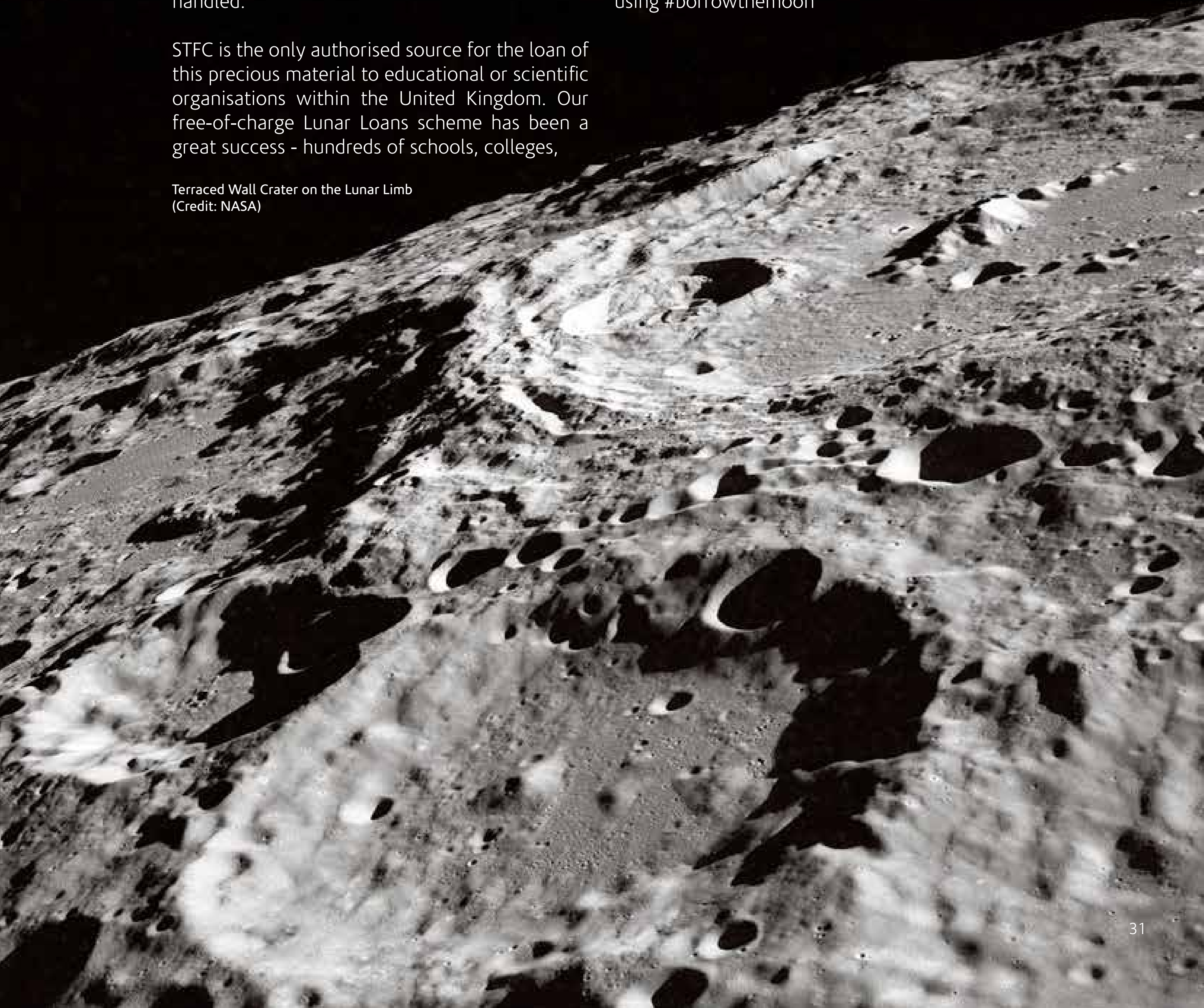
During NASA's manned space missions to the moon in the late 1960s and early 1970s, the Apollo astronauts collected 382 kilograms of lunar material (moon rock, moon soil and meteorite pieces) and brought it back to Earth.

NASA decided to use a small proportion of the rock and soil to develop lunar and planetary sciences educational packages, where these pieces of the moon could be shared and experienced in an educational environment. Each of the lunar samples are presented in encapsulated discs and thin sections for viewing through a microscope (for university students), and each set contains chunks of meteorites than can be picked up and handled.

STFC is the only authorised source for the loan of this precious material to educational or scientific organisations within the United Kingdom. Our free-of-charge Lunar Loans scheme has been a great success - hundreds of schools, colleges, universities, museums and astronomical societies throughout the UK have enjoyed the fascinating samples since the scheme began.

The lunar material has proven interesting to everyone, from young children to geology students, and we provide comprehensive support material to complement each set of lunar samples. Five educational packages are available (including special security delivery/collection) for short-term loans of lunar samples and meteorite.

For more information about our unique Lunar Loans scheme, visit www.stfc.ac.uk/1360 or you can tweet us @stfc_matters using #borrowthemoon



Terraced Wall Crater on the Lunar Limb
(Credit: NASA)

Higgs Nobel Win

CERN Director-General Rolf Heuer addresses members of the ATLAS and CMS collaborations on receiving the news of a Nobel prize for Englert and Higgs (Image: Maximilien Brice/CERN)

University of Edinburgh's Professor Peter Higgs and Professor François Englert of Belgium were jointly awarded the 2013 Nobel Prize for Physics for their prediction of the existence of the Higgs boson in the 1960s.

The prize could not have been awarded without proof of the existence of the Higgs boson, and the hugely sought-after particle was finally discovered in 2012 with the use of the Large Hadron Collider (LHC) at CERN. Many scientists and engineers have been involved in the search for the Higgs boson, culminating in confirmation of its detection by the CMS and ATLAS particle physics experiments. Finding the Higgs boson marked a significant breakthrough in our understanding of the fundamental laws that govern the Universe, but there's plenty of science still to be done, and we're looking forward to the LHC coming back online - at higher energies - later this year.

Funding for the Higgs Centre

Aerial view of UKATC (Credit: STFC)

In December 2013, the Treasury announced £10.7 million of capital funding to build the Higgs Centre for Innovation at STFC's UK Astronomy Technology Centre (UK ATC) in Edinburgh. STFC is contributing £2 million over five years to fund the running of the centre, which aims to bridge the gap between the lab and the market, whilst inspiring the next generation of scientists and engineers. The new centre will focus on two of the 'eight great technologies' that unite UK science and business strengths - big data and space - and will bring together cutting edge academic instrumentation and big data capabilities to support high-tech start-ups and academic researchers specialising in astronomy and particle physics. The centre, due to open in 2016/17, will house up to 12 small businesses, building on STFC's existing expertise in business incubation and technology access, as well as a myriad of test facilities and integration labs and provide PhD students with the opportunity to gain entrepreneurial experience.

Professor Gillian Wright OBE, Director of UK ATC, said: "The Higgs Centre for Innovation will bring together expertise in physics, astronomy and space science with high-tech start-ups and business support. It will significantly increase the positive impact of our fundamental research, in terms of economic benefits for the UK."

FAIR and NuSTAR

Prof. John Womersley, Dr. Janet Seed and a delegation of UK scientists gather at the signing of an official agreement for the UK to become an associate partner of FAIR.
(Credit: Gaby Otto for FAIR)

FAIR (Facility for Antiproton and Ion Research) will be to nuclear physics what CERN is to particle physics – the most impressive and advanced nuclear physics research facility in the world, based near Darmstadt in Germany.

The UK (through STFC) is an associate member of FAIR, giving our researchers access to this state-of-the-art facility. The UK is predominantly involved in the construction of one of the four main experiments, NUSTAR (NUclear STructure, Astrophysics and Reactions). NUSTAR will be able to study extremely rare nuclear species, many of which were created in stellar events such as exploding stars - supernovae. This will enable scientists to gain an understanding of the creation of the elements in our Universe. Fundamental research at FAIR is also likely to lead to practical applications, such as using new medical imaging techniques to improve cancer diagnosis, developing our understanding of the risks of high-radiation conditions to future manned space missions, and contributing to fusion energy programmes.

Gaia

Gaia's test image of a young star cluster, NGC 1818, in the Large Magellanic Cloud. This shot covers just 1% of Gaia's full field of view. (Credit: ESA/DPAC/Airbus DS)

On 19 December 2013, the European Space Agency's Gaia spacecraft was launched to begin its five-year mission to survey the galaxy. In that time it will survey a billion stars, which is still less than 1 per cent of the total number of stars we estimate are in the Milky Way. Even so, it will provide the most complete catalogue of stars ever made and will enable us to understand our place in our home galaxy. The UK contributed around 80 million of work to the project, helping to build the spacecraft and the billion-pixel camera that is at its heart. We are also providing one of the six state-of-the-art data centres that will turn the raw data into the largest stellar catalogue ever made. Gaia will make an average of 40 million observations every day, returning to observe each star 80 times over the course of five years – showing us not only where the stars are, but how they are moving. After a period of commissioning, Gaia will start the survey by June 2014 and the first catalogue will be available at the end of 2015.

Explore Your Universe

Explore Your Universe: Atoms to Astrophysics provides hands-on activities for young people and families across the UK. (Credit: ASDC/STFC)

Explore Your Universe is a national programme of events, experiments and activities that engage schools and family groups with STFC research, though our partnership with the UK's Science Centres sector. Visitors of all ages take part in hands-on activities, e.g. using a thermal imaging camera or a cloud chamber, handling meteorites and performing optics experiments. Trained explainers guide the participants and link the activity to cutting-edge research (for example, the cloud chamber introduces the Large Hadron Collider at CERN). At 'Meet the Researcher' events, participants can quiz researchers about their science and careers. Over two years, Explore Your Universe has reached more than 156,000 people, and will continue to inspire as the equipment remains in use and STFC sponsorship continues. An important facet of this programme is that it delivers benefits equally to boys and girls, and is a step towards correcting the under-representation of women in STEM careers.

VELA

VELA, the Versatile Electron Linear Accelerator based at Daresbury Laboratory, saw first light in 2013, followed swiftly by its first commercial user. VELA has been designed and built for industrial users, supported by over 80 companies, including three major commercial partners – Siemens, Rapiscan and e2V. Its exceptional repeatability and flexibility make it ideal for application development, across a broad range of key market sectors. Possible applications include developing novel technologies for baggage scanning, shrink-wrapping, curing ink and new radiotherapy machines. VELA has been brought online in record time, following a £2.5 million investment in accelerator technology developments at Daresbury Laboratory in 2011.

A section of VELA at Daresbury Laboratory.
(Credit: STFC)

This Highlights brochure captures some of the many successes our research departments, facilities and funded programmes have delivered. Our thought-provoking science challenges assumptions, changes perceptions and benefits people's lives; and the world-class research, innovation and skills we deliver all contribute to breaking down barriers, releasing potential and fashioning the future - as this small selection of current and recent achievements demonstrates.

From research into improving energy efficiency and developing super-nutritious grain, to unveilling the details of our early Universe and pioneering techniques to make breast cancer diagnosis quicker, this issue of Highlights is only one small peek into the impact of our science.

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