ESRF news

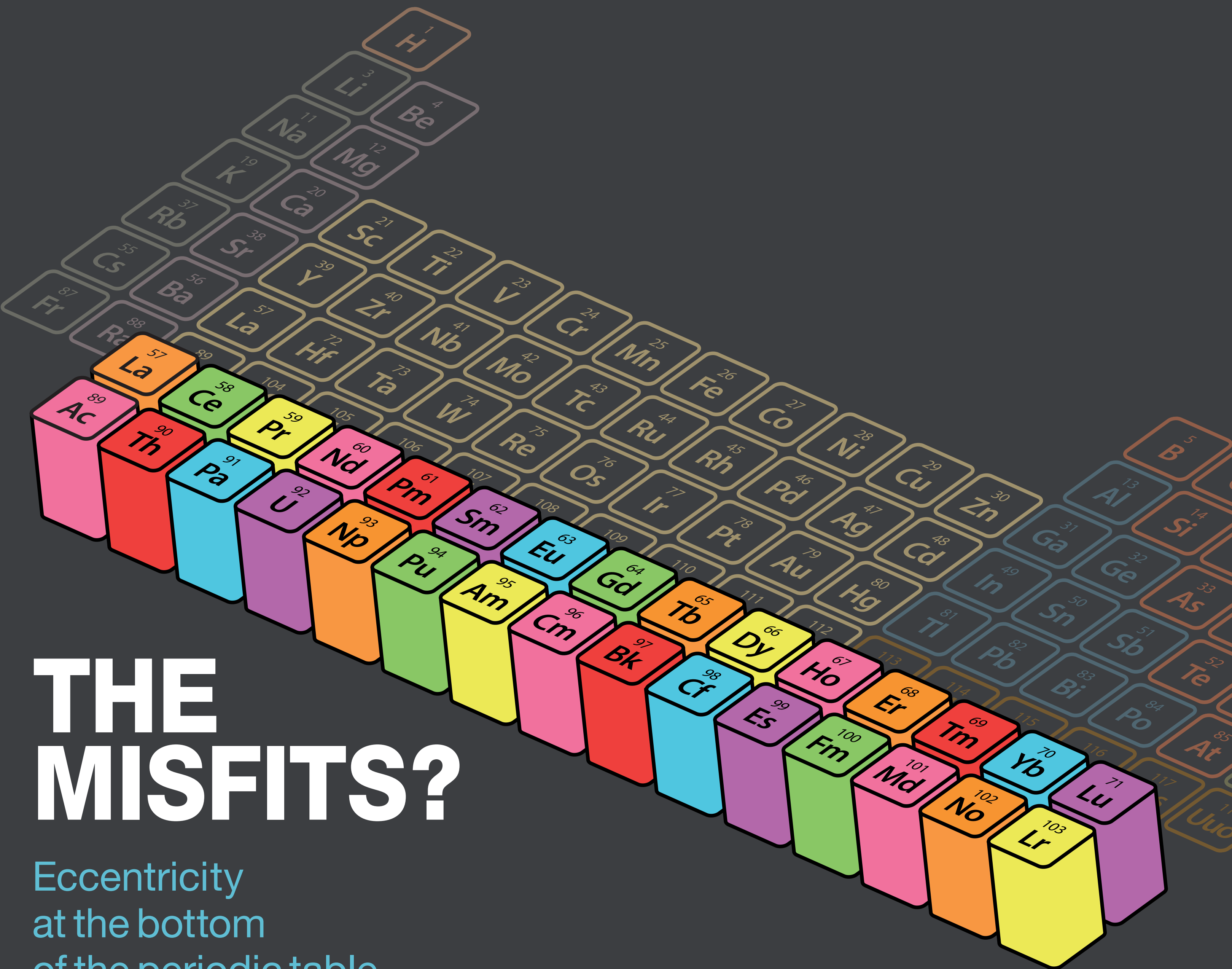
June 2019

ONE THOUSAND LABS
Antoine Petit on the future of the CNRS

STRETCHING BOUNDARIES
Tomography validates new test for tyre rubber

BREAKTHROUGH INNOVATION
Detector projects bag EC funding

PINK VS MONOCHROME
The benefits of EBS polychromatic beams



THE MISFITS?

Eccentricity at the bottom of the periodic table

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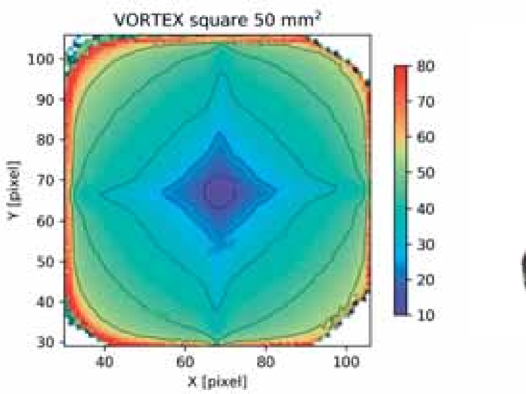

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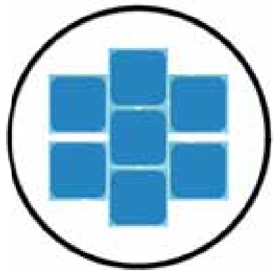
VORTEX ME-7 SDD— 38 mm diameter Detector - the same as the current VORTEX ME-4 SDD



38 mm

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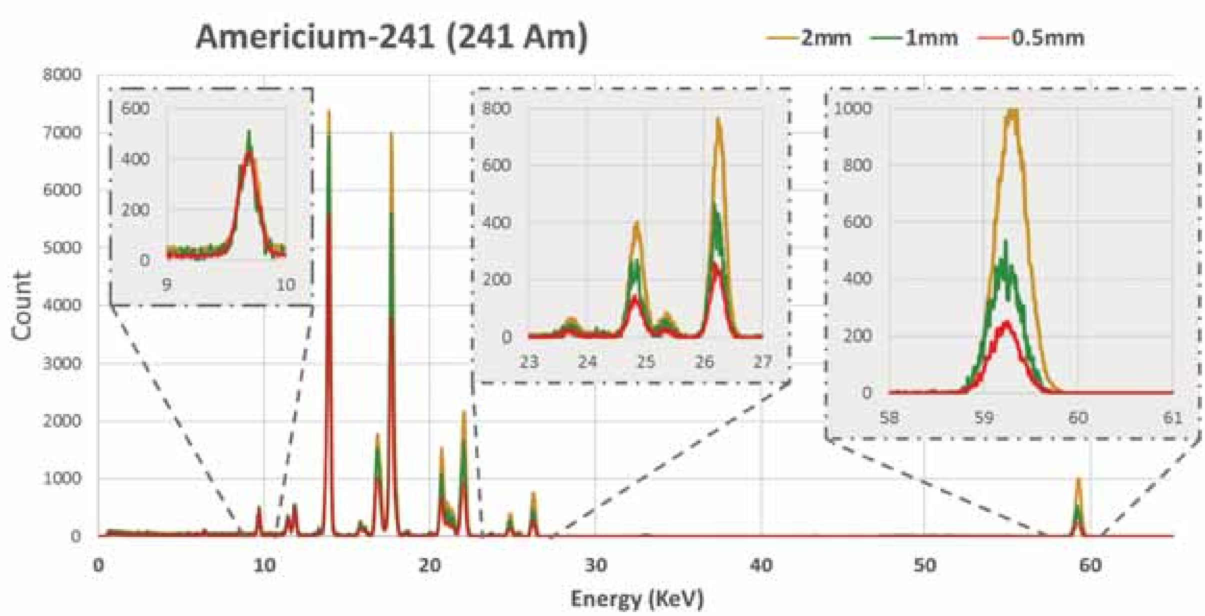

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www.hitachi-hightech.com/hhs-us/
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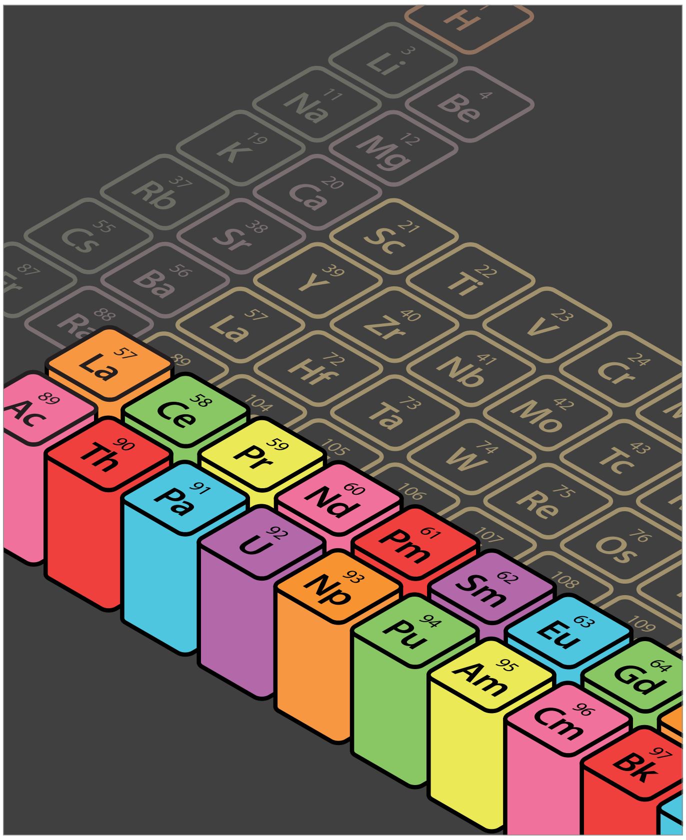

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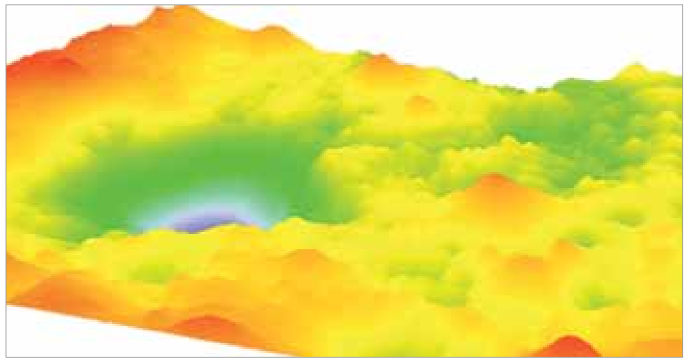

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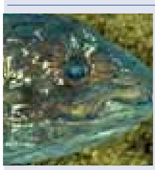

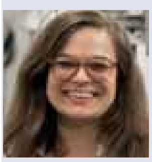

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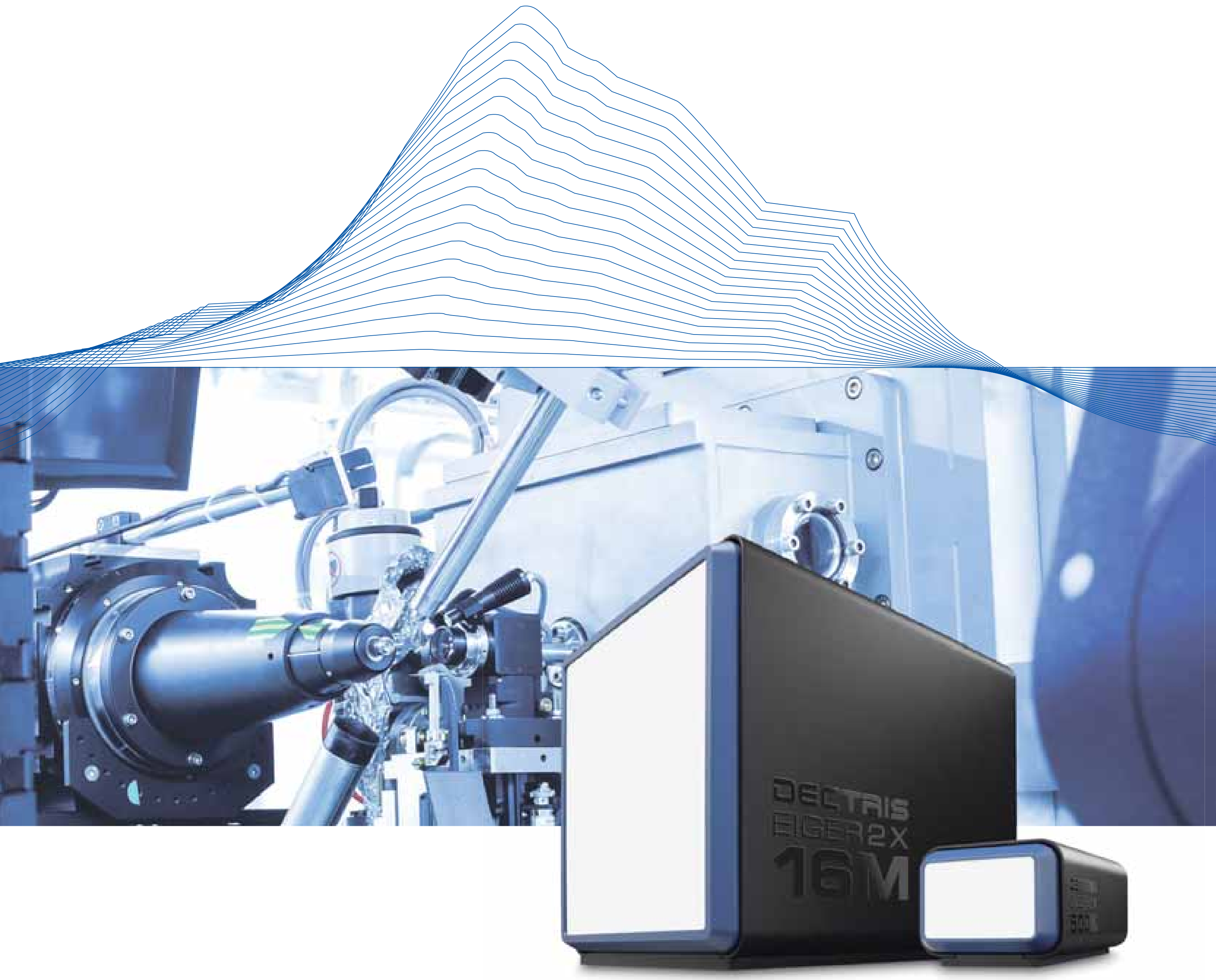

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Continuing Mendeleev's work

Harald Reichert
Director of research for physical sciences

Jean Susini
Director of research for life sciences

This year marks the 150th anniversary of Dmitri Mendeleev's periodic table, a rational way of organising the elements that has proved highly influential in our understanding of chemical relationships. The periodic table is almost double the size that it was back in the time of Mendeleev, but our understanding is far from complete, in particular regarding the two rows that are usually placed at the bottom: the lanthanides and the actinides. Due to the radioactivity of the actinides, the ESRF is one of few light sources able to safely study all these "bottom" elements, which have important applications in nuclear energy, electronics, biology and medicine. Now, thanks to an ERC grant, knowledge is advancing quickly. To celebrate the International Year of the Periodic Table, this issue takes a look at where this research on the lanthanides and actinides is taking us (p20).

"The ESRF is one of few light sources able to study these 'bottom' elements"

Pioneering synchrotron science

This year is also crucial for the ESRF itself, with the installation of the new storage ring for the Extremely Brilliant Source (EBS) upgrade (p14) and user service mode programmes. In preparation, the ESRF is organising a series of EBS workshops (p26), with the aim of gathering together users, staff and other experts to discuss and identify strategies for performing the best experiments and fully exploiting the EBS's unique properties. The international synchrotron user base is bigger and more diverse than ever before – a huge pool of talent to address the new and complex challenges facing our society. As a service to the international scientific community, the ESRF aims to train the next generation of scientists, who will help to make the best use of the new, extremely bright synchrotron technology.

ESRF news

Editor
Jon Cartwright
Tel +44 (0)117 2303080
E-mail jon.a.cartwright@icloud.com

Editorial committee
Nick Brookes
Delphine Chenevier
Andy Fitch
Michael Krisch
Gordon Leonard
Joanne McCarthy
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Contributor
Anya Joly

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Managing editor
Susan Curtis
Art director
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Alison Gardiner
Technical illustrator
Alison Tovey
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LAURENT BALLESTA, GOMBESSA EXPEDITIONS, ANDROMEDE OCEANOLOGY LTD

Old fish imparts brainy secrets

Thanks to imaging performed at the ESRF, scientists have gathered some of the first clues about the origin of the small brain of *Latimeria* – a rare fish that is an important evolutionary relative of amphibians, reptiles and mammals.

Along with lungfishes, *Latimeria* are the only living examples of lobe-finned fishes, and therefore hold a pivotal position in the family tree of vertebrates. The genus was believed to be extinct for 70 million years by scientists until one was spotted in the catch of a local South African fisherman in 1938, after which dozens more live specimens have been found and preserved. Most of these are adult, but Hugo Dutel at the University of Bristol in the UK and his co-workers came to the ESRF beamline ID19 to study some of the few specimens at earlier stages of development, including a foetus just five centimetres long.

At ID19, the researchers could plug some of the gap in knowledge of *Latimeria* development by using X-ray micro-computed tomography to image the specimens in 3D without damaging them (see fig. 1). Building on initial data taken from medical computed-tomography scans and magnetic resonance imaging, they found out how the skull and brain of the fish grows as it gets older.

"These are unique observations, but there are still more questions than answers"

A genus in the order coelacanth, *Latimeria* has a braincase that is, unusually, hinged, and contains a brain just 1% of its size. Dutel and co-workers found that the brain is actually similar in size to the braincase in a foetus, but diminishes relatively during maturation. The transition coincides with an enlargement of a lower region known as a notochord, which the researchers believe could prompt the formation of the braincase's hinge, and perhaps limit the brain growth, too (*Nature* doi:10.1038/s41586-019-1117-3).

"These are unique observations, but they represent only a tiny step forward compared with the amount we know on the development of other species," says Dutel. "There are still more questions than answers."

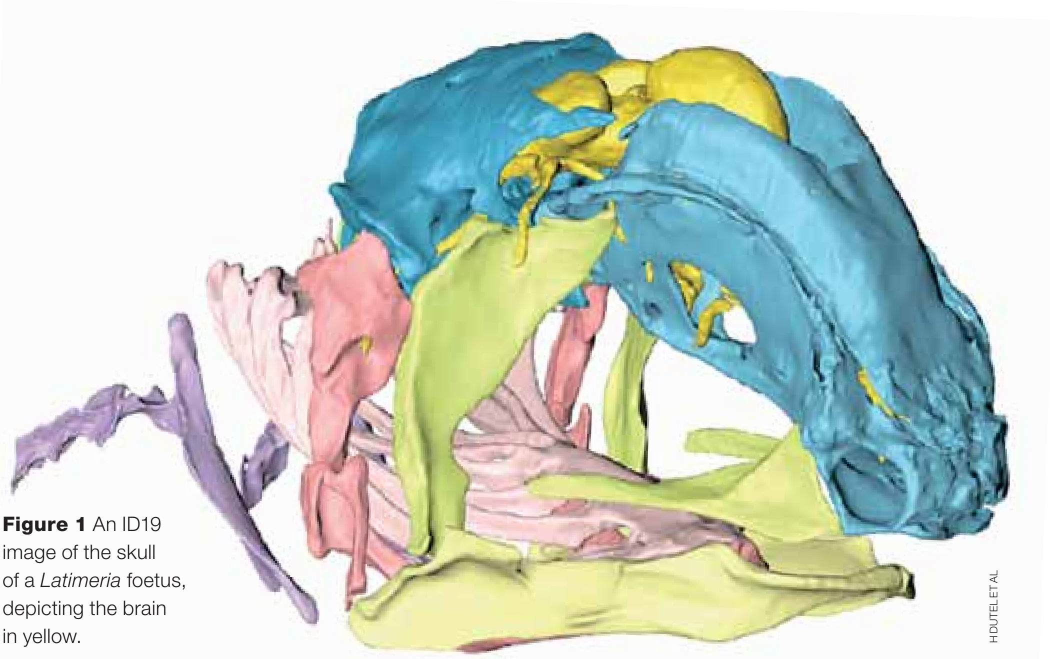
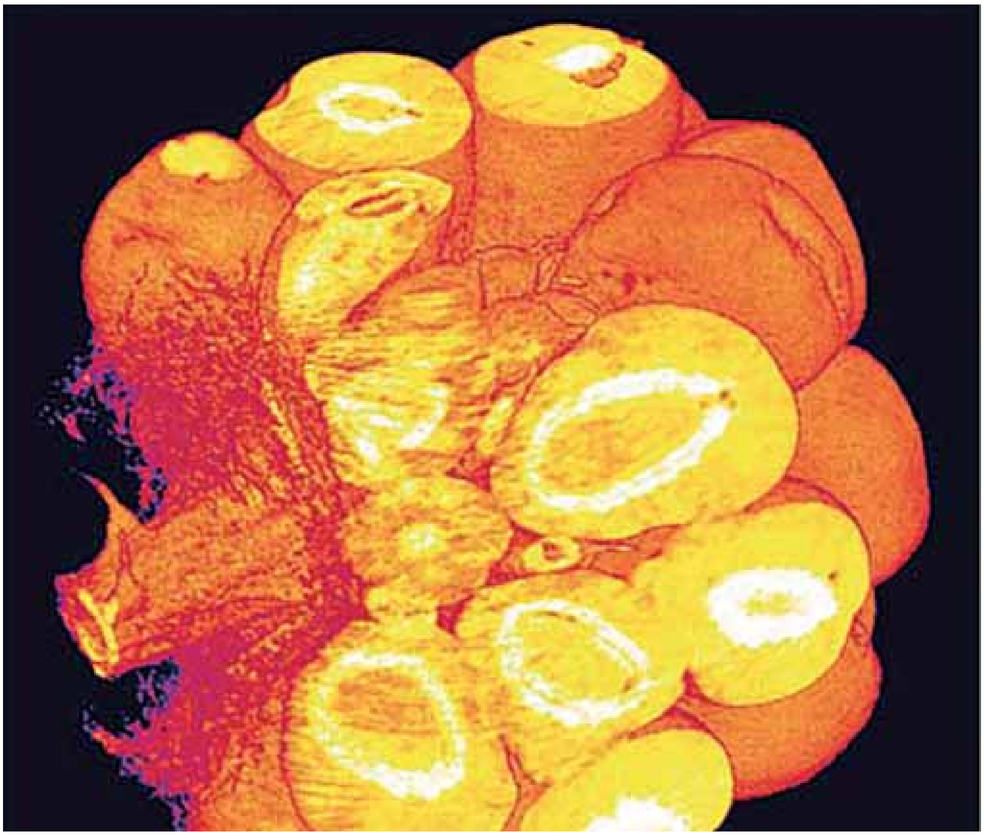


Figure 1 An ID19 image of the skull of a *Latimeria* foetus, depicting the brain in yellow.

H DUTEL ET AL

S BERUJON AND E ZIEGLER



ESRF projects ATTRACT funding

Fresh idea: A raspberry, as reconstructed by a speckle algorithm. One of the ESRF projects selected by ATTRACT, speckle imaging boosts the sensitivity to detail possible in non-synchrotron imaging.

The consortium behind an EU project designed to bring cutting-edge research-instrumentation technology to the market has allocated seed funding for 170 "breakthrough ideas" – four of which involve the ESRF. The EU's ATTRACT project will provide €100,000 to each of the four ESRF projects: algebraic speckle tomography for clinical studies of osteoarticular diseases; a novel readout concept for the front-end of 2D pixellated detectors; the transferral of indium-gallium-nitride epilayers onto substrates for full-spectrum LEDs; and artificial intelligence for the automatic segmentation of volumetric microtomography images.

Funded by the European Commission, ATTRACT is led by the European particle physics lab CERN, and brings together eight other partners – Aalto University in Finland, the European Industrial Research Management Association, The European Molecular Biology Laboratory, ESADE Business School in Spain, the European Southern Observatory, the ESRF, the European X-ray Free Electron Laser facility and the Institut Laue-Langevin in Grenoble. It aims to boost Europe's economy by creating products, services and jobs based on the innovative use of detection and imaging technologies.

In the recent call for ideas, the ATTRACT project's independent committee whittled down more than 1200 proposals. "The 170 breakthrough ideas were selected based on scientific merit, innovation readiness and potential societal impact," says Sergio Bertolucci, the chair of the committee.

"I am very pleased with the overwhelming number of applications submitted to the ATTRACT initiative," says Francesco Sette, the ESRF's director-general.

From augmented reality to smart sensors and devices, many of the chosen ideas hope to result in "disruptive" technologies that will improve clinical diagnosis, health monitoring and personalised treatments for diseases such as cancer, Alzheimer's, malaria, and heart and neurological conditions. Others intend to develop novel sensors and smart devices that will improve environmental monitoring, energy generation and manufacturing.

"The ESRF is very proud to be associated with four projects supported by ATTRACT, all of which represent areas of X-ray detection critical to the advancement of X-ray science," says Sette.

C ARGOUD/ESRF

User bags international 'rising talent' award

A long-time user of the ESRF who studies why the properties of materials change in the transition to the nanoscale has won an international award for rising female talent in science. Kirsten Marie Ørnsbjerg Jensen of the University of Copenhagen in Denmark was one of just 15 scientists to receive the award from the L'Oréal Foundation and UNESCO – the United Nations organisation for education, science and culture – out of 275 participants from across the world, all of whom were existing L'Oréal–UNESCO national laureates.

"These [15] young women are the very future of science and recognising their excellence will help ensure that they reach their full potential," reads a UNESCO statement.

Jensen is a frequent face at the ID11 and ID15 beamlines, where she uses X-ray scattering techniques to follow material synthesis in real time. Her goal is to develop a process of "materials by design", in which nano-structured properties can be tailored for applications in catalysis, solar cells and other energy technologies. Many of these materials exhibit no long-range order, and so Jensen employs pair distribution function analysis to obtain structural information.

"It wasn't until the development of [the right] computing and software, and the availability of high-flux, high-energy synchrotron radiation that the technique became possible to use about 15 years ago," she says. "Now, it's becoming a more and more established method for structural analysis of nanomaterials, and is only growing in importance."

Last year, Jensen won a €1.5m starting grant from the European Research Council to support her work.

STEF CANDÉ

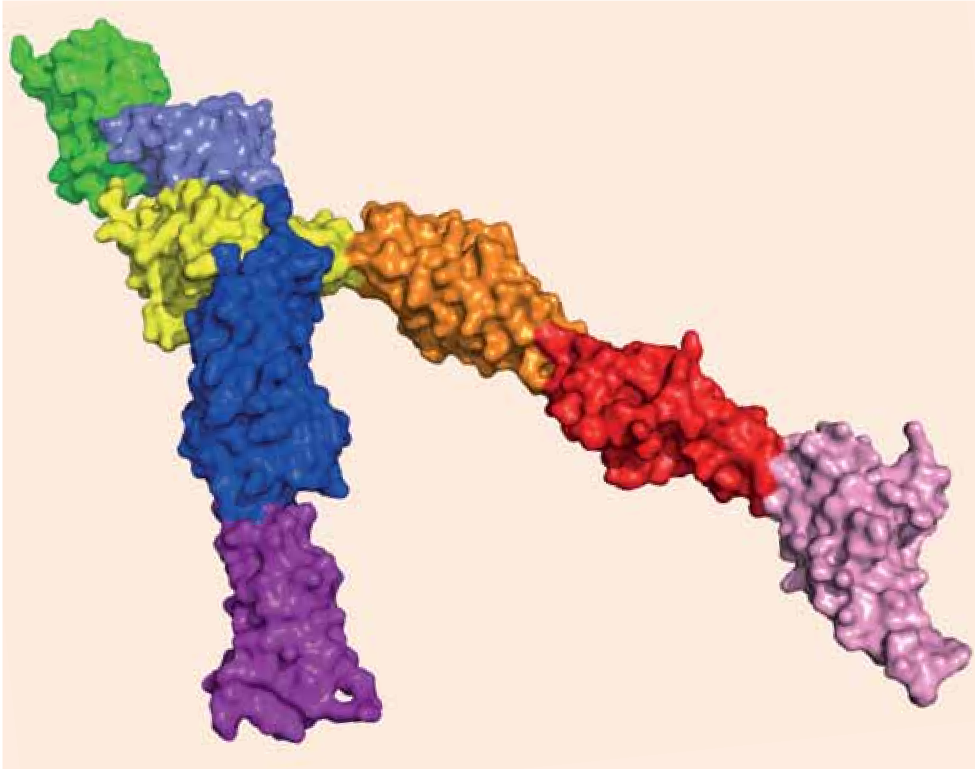
Cryo-EM spots unique virus binding

Human adenoviruses (HAds) are a category of viruses that can cause various respiratory illnesses – from the common cold to bronchitis – and are also potential therapeutic agents against cancer. Now, a study performed at the ESRF using the cryo-electron microscope facility (CM01, above) has shed new light on how HAds infect human cells. By obtaining the structure of an adenoviral "type 3 fibre knob" protein in complex with a "human desmoglein 2" cell receptor, Emilie Vassal-Stermann of the Institut de Biologie Structurale on the EPN campus and co-workers observed an unusual mode and stoichiometry of virus-to-cell binding never seen before, and found that a single mutation of the adenoviral protein could abolish receptor binding. The result could help in the design of HAd-derived therapies (*Nat. Commun.* **10** 1181).

New strategy tackles fast biochemistry

For the first time, energy-dispersive X-ray absorption spectroscopy (EDXAS) and ultraviolet-visible spectroscopy have been combined to determine the kinetic constants of fast bimolecular chemical reactions in solution. Together with ESRF scientists from the ID24 beamline, Giorgio Capocasa of the Sapienza University of Rome and colleagues combined the two techniques to obtain the kinetic constants from oxidation reactions of organic substrates by a "non-heme" iron-activated species (*J. Am. Chem. Soc.* **141** 2299). The result demonstrates that EDXAS and ultraviolet-visible spectroscopy could be an important strategy to help uncover the structural evolution of species involved in fast chemical reactions.

Y OPATOWSKY



Crystallography hones in on neuronal circuits

The function of a healthy brain comes from billions of neurons forming trillions of neuronal circuits. To do this, the neurons sense the right paths with special protein receptors – but how such receptors work has not been clear. Now, ESRF users have helped clarify the process by uncovering the molecular mechanism that allows a key guidance receptor, Robo, to react to the environment. The discovery could help in the development of new cancer drugs.

Robo, together with Slit, a secreted protein that acts as its external guidance cue, is present in virtually all animals with a nervous system. However, despite a lot of recent progress in understanding the developmental responses that the Slit-Robo function triggers in the brain, scientists have not understood how Slit activates Robo, nor what keeps Robo inactive in Slit's absence. It is known that a deficit of either protein can be linked to brain dysfunction.

Yarden Opatowsky of Bar-Ilan University in Israel and co-workers have been collecting diffraction data from Robo crystals for the past decade. However, it was only recently, at the ESRF beamline ID29 and the BESSY II synchrotron in Germany, that they could gather sufficiently high-resolution diffraction patterns to obtain the extracellular portion of Robo's structure. The structure showed how two of the receptors can link, and how that linkage is prevented in the absence of Slit. "I cannot imagine a successful conclusion for this project without having almost immediate access to state-of-the-art facilities, and most importantly to the brilliant and devoted beamline scientists at the ESRF and BESSY II," says Opatowksy.

"For the first time, we have the information to design drugs that target Robo receptors"

Tests on the nematode *Caenorhabditis elegans* – the only organism for which complete neuronal circuits are known – supported the researchers' structural model (*Cell* **177** 272). Opatowksy and colleagues believe that the same molecular mechanism as in the nematode also exists in humans, and could be targeted by new drugs for cancer, in which some receptors are hijacked to drive tumour formation. "Our discoveries provide, for the first time, the information necessary to design effective drugs that target Robo receptors," says Opatowsky.

Plankton farmers betray their methods

Microalgae help some plankton to survive by capturing carbon dioxide via photosynthesis, and giving up some of the resultant carbon as feed. Now, an international team of scientists have studied plankton samples using a range of techniques, including X-ray fluorescence imaging at the ESRF beamlines ID21 and ID16B, to shed light on this murky symbiotic relationship. Johan Decelle of the University of Grenoble Alpes and co-workers found that the host cells act like farmers, transforming the microalgae to maximise their photosynthetic activity (*Curr. Biol.* **29** 968). "These results represent a radical change in the understanding of the functioning of a key symbiotic relationship of marine ecosystems," says Decelle.

Röntgen gives water surplus phase

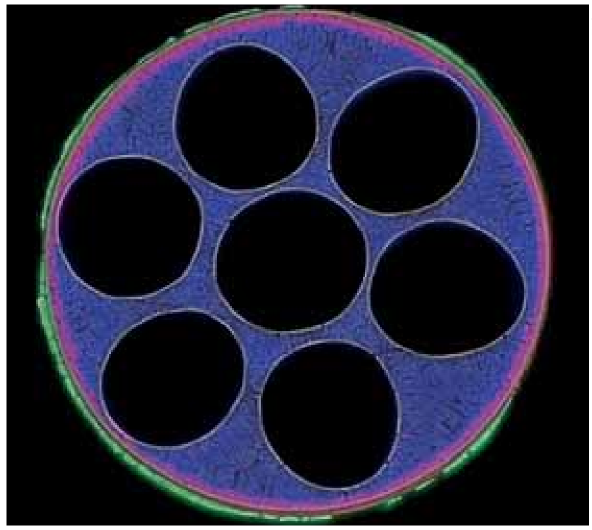
With an ability to dissolve a huge range of particles, and a solid state that is, weirdly, less dense than its liquid state, water is unlike any other compound. In the late 19th century, the X-ray pioneer Wilhelm Röntgen was the first to suggest that liquid water must be made up of two phases – gas and ice like molecules – a notion that many scientists expected X-ray spectroscopy to back. Now a study led by Alexander Föhlisch of the Helmholtz-Zentrum Berlin (HZB) in Germany and co-workers has revealed a different picture. The researchers found that high-resolution spectroscopic data on ambient water collected at the ESRF's ID20 beamline, as well as at the Swiss Light Source and HZB's BESSY II synchrotron, could be explained with no need for two distinct phases. The findings support an alternative "continuous distribution model", which is already used in computational simulations of water in chemistry and the bio-sciences (*PNAS* **116** 4058).

Fuel cell revs up at ID15A

ESRF users have helped to characterise a new ceramic solid-oxide fuel cell that has the potential to deliver a more stable and higher power output than existing commercial devices.

Ceramic fuel cells are already used in some applications thanks to their lower carbon footprint than conventional methods of energy generation, but two of the main designs suffer big drawbacks. Planar designs provide high power output at the expense of sealing stability at high temperatures; conversely, tubular designs have better sealing but many times less power.

Developed by Kang Li at Imperial College London and others, the new design is based on a honeycomb structure, which aims to deliver the best of both worlds. To characterise it, a team at University College London and the industrial consultancy company Finden in the UK, came to the ESRF's ID15A beamline, where X-ray diffraction computed tomography (XRD-CT) revealed the device to maintain stability while delivering a power density of 1.27 Wcm^{-2} at 800°C – among the highest ever reported (*Nat. Commun.* **10** 1497).



TAO LI

"The results speak for themselves"

"This is the first time XRD-CT has been applied to a complete solid-oxide fuel cell while it is functioning," says Marco Di Michiel, scientist in charge of ID15A. "The results speak for themselves."

Farewell to instrumentation expert

ESRF staff have been paying tributes to Pierre Thiry, the former head of the ESRF's technical services division, who died on 30 March.

Thiry led the technical services division between 1999 and 2010, when he retired. He was renowned for his contributions to state-of-the-art instrumentation for synchrotron science in Europe, as well as at Brookhaven National Laboratory in the US, particularly in the field of high-resolution angular-resolved photoemission. During his time at the ESRF, he contributed greatly to consolidating the operation of the ESRF, and he was directly involved in the initial conception of the technical implementation of the ESRF Upgrade Programme Phase I.

After retiring, Thiry and his wife moved to the south of France, where he lived until his death. "We are saddened by this news, and will always remember him for his competence, discretion and hard work to support the advancement of the ESRF programme: thank you Pierre," read a statement from the ESRF management. "Our thoughts at this difficult moment go to his family."

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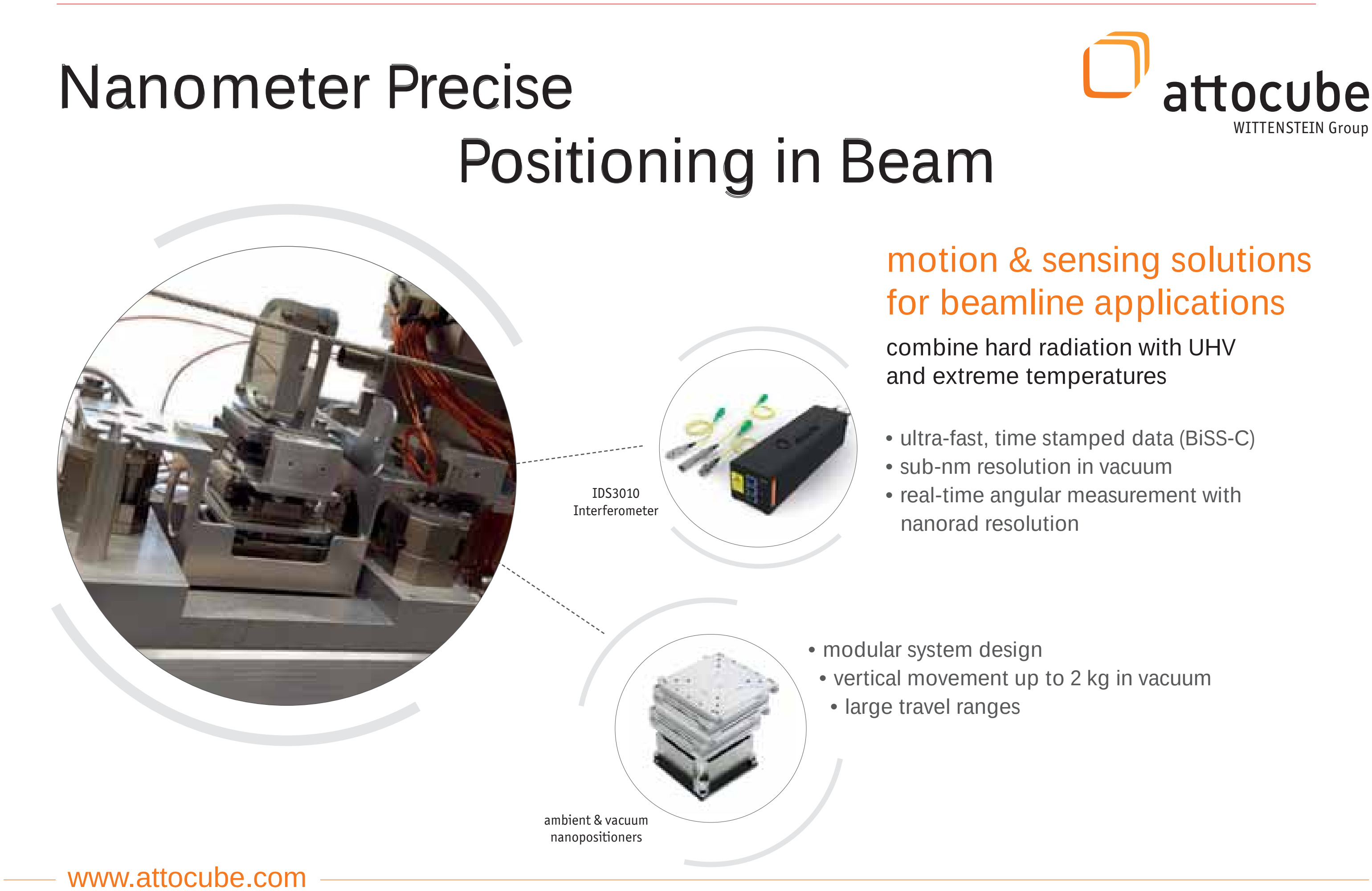
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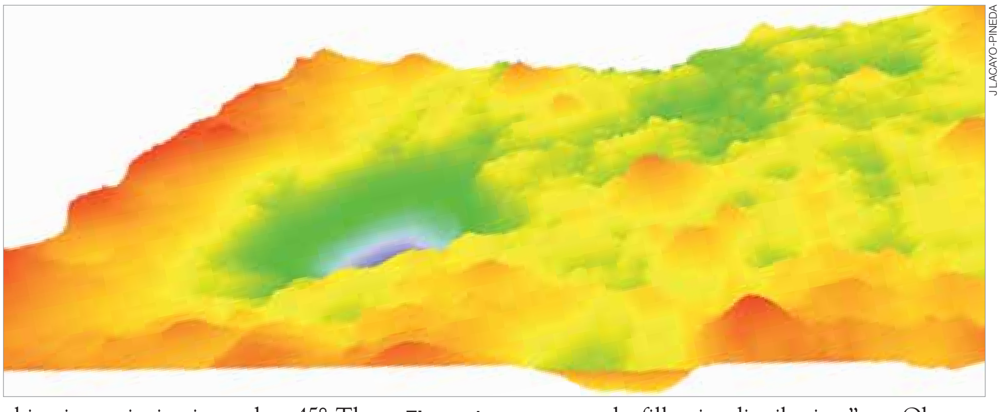
Tomo gets to grip with tyres

ESRF provides gold standard for the testing of a new microscopy technique with tyre manufacturer Continental.

Car tyres are mostly made from rubber, but they also contain filler materials such as carbon black and silica, to improve wear, strength, and other performance characteristics. Now there may be a better way to check that filler materials are well distributed, thanks to testing at the ESRF by the University of Applied Sciences in Darmstadt, in cooperation with the German tyre manufacturer Continental.

The science of how filler dispersion affects rubber quality has been around for nearly 70 years. For much of that time, tests were performed on the tyre materials themselves, with filler dispersion inferred from their mechanical characteristics. More recently, researchers have turned to optical methods, in particular dark-field microscopy, to assess filler dispersion more directly. In dark-field microscopy, the central source of illumination is eclipsed, so that only rays diffracted by a sample of freshly cut rubber are observed; the bumps, or "nodges", of filler particles on the surface of the rubber appear as white spots in the dark-field images. Estimating the size distribution of filler particles from these spots is still not wholly direct, however, because the size of the spots depends on imaging parameters, as well as where the spots' fuzzy outlines are taken to be.



J LACAYO-PINEDA

Figure 1
The reconstructed surface of freshly sliced tyre rubber, as visualised by radiometric spectroscopy.

Stereo vision

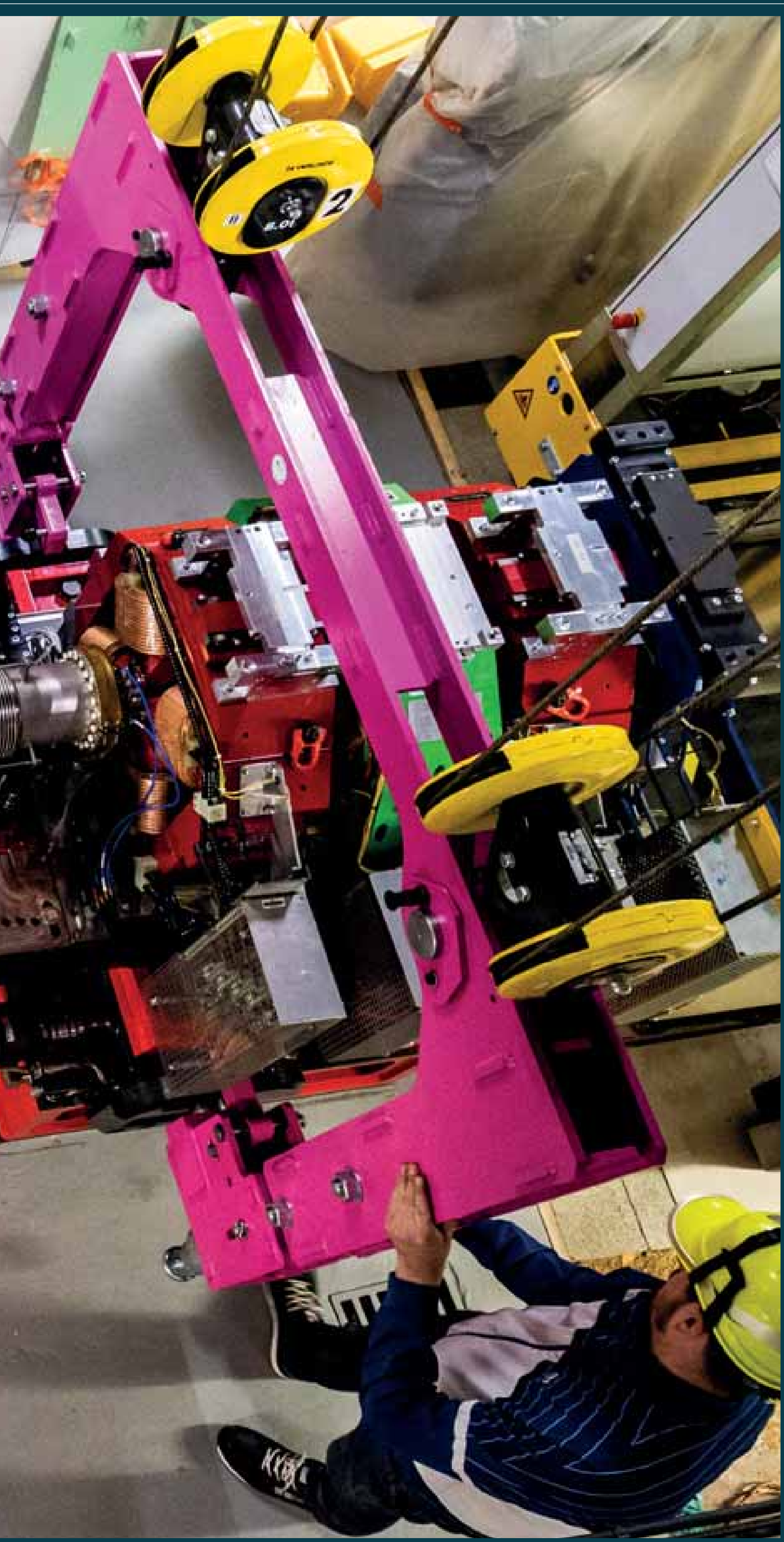
Joachim Ohser and Dascha Dobrovolskij of the University of Applied Sciences in Darmstadt, Germany, together with Jorge Lacayo-Pineda of Continental, and Matthew Putman of the imaging company Nanotronics in New York, US, wanted to determine whether a new imaging platform developed by Nanotronics, nSPEC 3D, could offer an alternative, foolproof method of estimating the size distribution. Based on radiometric stereo microscopy, the method involves illuminating a sample with six LEDs around the microscope's objective, pointing inwards at 45°. The six resultant 2D images are combined by a Nanotronics algorithm to produce a 3D, stereoscopic image of the sample's surface (see fig. 1).

At the ESRF beamline ID19, Ohser could compare the size distribution of filler particles in rubber samples given by nSPEC 3D with that given by the "gold standard" of 3D tomography, synchrotron microtomography. "The application of coherent illumination combined with phase-retrieval techniques [at ID19] allowed 3D image acquisition of rubber samples with high contrast between the black-carbon filler particles and the rubber matrix, the segmentation of the filler particles, and finally the accurate estimation of the filler size-distribution," says Ohser.

Working with Alexander Rack of ID19, Ohser found that the new nSPEC 3D method delivered almost exactly the same estimation of size distribution as that given by synchrotron microtomography, as well as by computer simulations (*J. Microsc.* **274** 32). Continental's Lacayo-Pineda believes this bodes well for the new method's use in industry. "Radiometric stereoscopy is an efficient way of obtaining 3D information of the macrodispersion of fillers in rubber, which is indicative of both mixing efficiency and tyre performance," he says. ■

Jon Cartwright

STEF CANDÉ/ESRF



Full circle

A gantry lowers the last of 129 girders of the Extremely Brilliant Source (EBS) into the storage-ring tunnel – an important milestone in ESRF's upgrade to the world's first high-energy fourth-generation synchrotron.

Like the preceding phase, in which the original storage ring was dismantled and removed, the girder installation has been a logistical challenge. There are just three entry zones into the 844-metre circumference tunnel and little room for manoeuvring inside, meaning that the five-metre long, 12-tonne girders have had to be installed in a specific order. Since March, the gantry has been lifting the girders along with their 10,000 state-of-the-art components over the tunnel wall, while a specially designed transport module has been rolling them to within a centimetre of their final positions.

Although EBS teams are now celebrating the end of the girder installation, further installation work will continue until November, with engineers precisely aligning and connecting the girders, installing front-ends, and piping and cabling each component to the technical zone on the inside of the ring. Some 50,000 individual connections will have to be made and tested before commissioning, so that the powerful new research instrument can be opened to scientists in August next year. ■

Anya Joly

Training the next generation

A new team of young alignment engineers and technicians earn their stripes on the Extremely Brilliant Source (EBS).

Joining the ESRF's survey and alignment team marked a career turning point for Cristina Gonzalez Torres, who was previously a survey manager for renewable-energy plants. "Working as a metrology engineer at a synchrotron is new to me," she says now, having been in the job for three months. "But the EBS is a globally unique project – of course I wanted a chance to work on it."

The sentiment is echoed by her colleague Juliette Autin, who joined the ESRF in March last year from the world of civil engineering, and who now takes care of planning and organisation as well as the alignment of the girders, front ends and beamlines. "It's rare to get to work on such a large project," she says. "Even in the world of accelerators, the chance to be involved in the construction of a new machine is a once-in-a-lifetime experience."

Gonzalez Torres and Autin are part of the team that ensures that each of the 10,000 components in the EBS upgrade is precision-aligned. The work is both physically and intellectually demanding, and there is a lot riding on it, as the successful operation of the new source ultimately depends on the accurate alignment of each element to within 50 μm over a distance of almost one kilometre. But the dynamic team, which includes several new young recruits, brings a good-natured energy to the challenge.

STEF CANDÉ

Precision is everything

"The EBS brings together all the aspects that I sought when I entered the field of metrology: plenty of field work, being part of a team and a wide scope of tasks," says Marie Spitoni (pictured opposite, front), who arrived less than a year ago following a PhD in fluvial geomorphology. Spitoni's work includes anticipating future deformations of the storage ring linked to the geological environment of the ESRF. "I also like having to work with the constraint of extremely low tolerances on our measurements," she adds. "At the ESRF, everything is very precision-sensitive."

Her colleague Guillaume Chamblas agrees. "In other fields of survey and alignment we rarely need to push the equipment to its limits, but here we're exploiting top-standard instruments to their full potential – and that's exciting." Chamblas is a metrology engineer who arrived in November 2017 from the European particle-physics lab CERN to work on the complex alignment calculations.

As well as being exciting, the challenge is a worthwhile experience. "We are learning to understand how each component behaves, which is very useful in the long-term," says survey and alignment technician Emmanuel Alcouffe, who joined the group in October 2016. The team also appreciate the constructive, problem-solving atmosphere, and the chance to draw on the experience of their longer-serving colleagues, some of whom have worked at the ESRF for nearly 30 years.

"This is a once-in-a-lifetime experience"

As this team neatly demonstrates, if the EBS is possible thanks to the skill and dedication of its established experts, it also provides an important opportunity to pass on valuable experience and knowledge to the next generation of brilliant scientists, engineers and technicians, ensuring that the ESRF remains in expert hands for decades to come. ■

Anya Joly

Pink beams galore

Why be monochrome when you could be pink? The Extremely Brilliant Source (EBS) pink beams will generate more possibilities for high-flux X-ray science.

What is a pink beam?
A synchrotron light source emits X-rays at a whole range of energies, potentially up to hundreds of kiloelectronvolts. In comparison with visible light – when all the colours of the rainbow are mixed together – this broad, raw output can be thought of as a white beam. Naturally, most light-source users find it easier to interpret the data generated by a single colour – that is, monochromatic – X-ray beam. Yet there is a middle ground: a so-called pink beam, characterised by a small but finite spread of energies.

Why would you want that?
In creating monochromatic beams, most of the photons leaving the storage ring – those outside an almost infinitesimally small energy range – are inevitably discarded. By including photons of slightly different energies, pink beams retain much more of the light source's potential flux, and for some applications this can be highly beneficial. Often these applications are where the precise incident X-ray energy is not that important. In fluorescence microscopy, for instance, the greater flux can enable the identification of dilute components that would otherwise be overlooked, while in disordered materials, it can help to generate structural information when the intrinsic scattering power is low. At the ID19 beamline, in order to obtain ever-clearer 3D images, the use of pink beams for microtomography has become practically routine.

What about when the energy resolution is very important?
Pink beams can still have benefits. In structural biology, complete datasets of protein crystals are usually obtained by rotating a crystal and taking multiple exposures, but for the smallest crystals this is not always feasible. However, the different photon energies within a pink beam in effect provide different viewing angles on a protein crystal, so that a complete diffraction dataset is possible even when actual crystal rotation isn't. Such diffraction datasets can be rather fuzzy and hard to interpret if the energy spread of the pink beam is too broad, but the new EBS source will make that interpretation far easier.

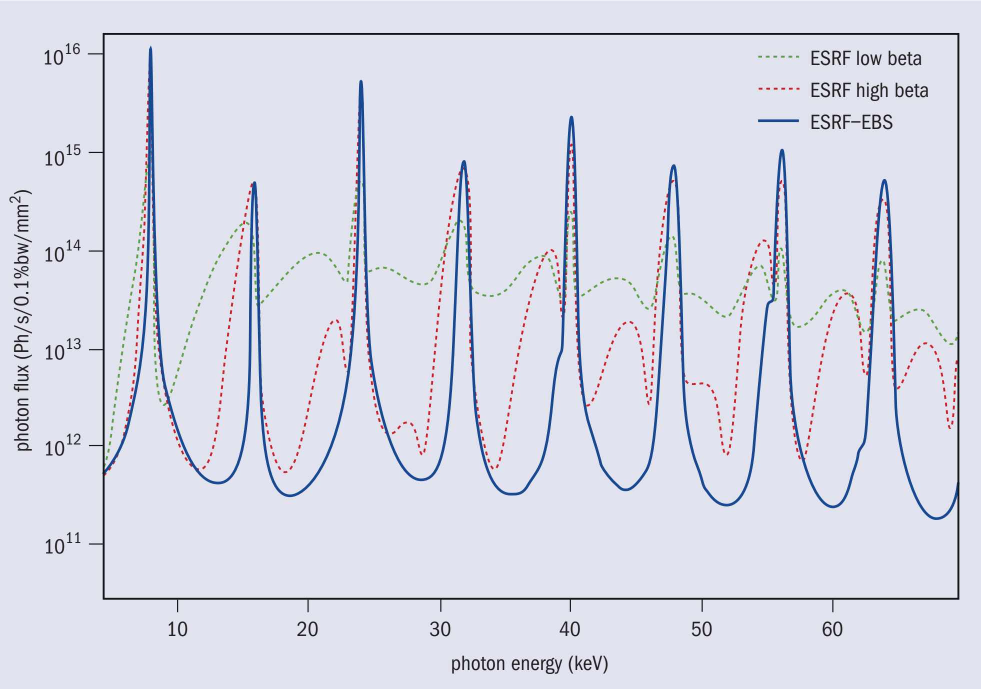


Figure 1 A pink beam is a selected harmonic from the photon flux of a beamline undulator. The EBS harmonics are narrower and more symmetric than those of the original ESRF (both its narrow, "low beta" beams, and its wider "high beta" beams), and so generate clearer data.

How?
A single pink beam is one of many selectable harmonics in the white X-ray spectrum generated by a synchrotron undulator on an insertion-device (ID) beamline. (Wigglers, which are also found on ID beamlines, generate a flat, mostly white energy spectrum, so are not as suitable for pink beams.) The ESRF's original undulators generated asymmetric harmonics with individual energy spreads of about 5%; however, the new EBS undulators will generate harmonics with narrow energy spreads of about 2% and – crucially – a symmetric profile (see fig. 1). The result is more flux and more easily interpretable X-ray data – so long as the detectors can stand the photon onslaught.

"The result is more easily interpretable X-ray data"

Might we need new detectors, then?
Yes – if the applications plan to make full use of the pink beam's flux. Many of the ESRF's current detectors, which work by counting individual photons, could easily be saturated by pink beams. In such cases, these detectors will have to be replaced by integrating detectors, such as the Jungfrau detector developed by the Paul Scherrer Institute in Switzerland. By absorbing photons over a fixed time window, and calculating their total effect, integrating detectors can withstand high flux. It is for this reason that they are already used by X-ray Free Electron Laser (XFEL) sources. Naturally, XFELs generate even higher flux than synchrotrons, but the EBS source has the potential to generate more stable beams, making the two types of light source highly complementary. ■

Jon Cartwright

Spot the di

The periodic table is split into blocks of similar properties. But at the bottom, as one ESRF user shows, that's not so easy.

WITH elements, as with people, it can be hard to find things in common. One of the earliest attempts to find similarities in the fundamental constituents of matter grouped them into four categories: metals, non-metals, gases and "earths". Later, it was proposed that the elements naturally fit into groups of three, known as triads. Only in 1869 did the periodic table as we know it come into being, when the Russian chemist Dmitri Mendeleev discovered that commonalities naturally emerge once the elements are ordered in rows according to their atomic weight.

A century and a half later, chemists still rely on Mendeleev's system of organisation, albeit using atomic number rather than weight. It is so influential that the United Nations Educational, Scientific and Cultural Organization has named 2019 the International Year of the Periodic Table. Indeed, the periodic table is instantly recognisable to anyone, even if not everyone knows what it means. There is the tall, narrow block on the left – these are soft, highly reactive metals that form ionic compounds. On the right, there is a wider block of elements that are more tempted to bond covalently. In the middle, there is that very broad block, the transition metals, which form coloured compounds, and can often be employed as catalysts.

And then there is the bottom. School textbooks often forget about the lanthanides and the actinides – those two rows of metals separated from the rest of the periodic table, and characterised by outer electrons in f-orbitals – perhaps because comparatively little is known about them. Physically at least, they share some common properties, such as being soft and silvery. But Kristina Kvashnina of the Helmholtz-Zentrum Dresden Rossendorf (HZDR) in Dresden, Germany, claims that the closer you look, the more individual the elements at the bottom appear – more so than any other block in the periodic table. "I always thought that if I studied one of these elements, another might behave the same," she says. "But the ones I've studied so far all behave differently – you can't generalise knowledge about them."

Because the actinides are radioactive, very few synchrotrons offer the ability to compare and contrast both rows

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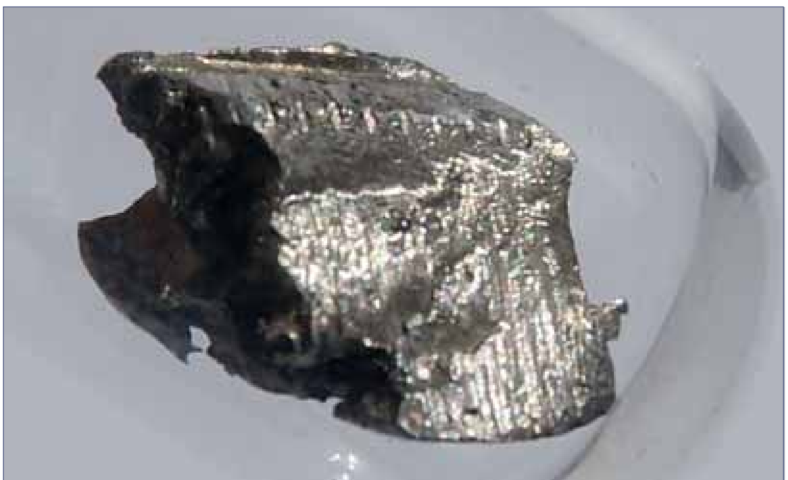
at the bottom of the periodic table. At the ESRF's BM20 "ROBL" beamline, which is owned and operated by the HZDR, two experimental hutches have airtight walls, as well as a dedicated ventilation system to filter out radionuclides in case of a spillage. Whenever Kvashnina enters or leaves, she must place her hands and feet on monitors to check that her radiation levels have not significantly changed. Most of her experiments are conducted inside a transparent, radiation-proof box, which has built-in gloves so that samples can be manipulated.

Kvashnina has been coming to the ESRF beamlines BM26, ID26 and ROBL for more than a decade, but she received a boost two years ago in the form of a starting grant from the European Research Council (ERC), for the maximum possible amount of €1.5 m. The grant has enabled her to lead a team of five researchers, to clarify our understanding of the bottom of the periodic table with techniques such as high-resolution X-ray absorption spectroscopy, X-ray fluorescence detection, X-ray emission spectroscopy and resonant inelastic X-ray scattering. "From my experience, much of our recent breakthrough knowledge about the lanthanides and actinides has come from synchrotron facilities, where you can study elements at the atomic level," she explains. "I think that's maybe why I got the ERC grant."

The potential applications of lanthanides and actinides is a big driver for funding (see tinted boxes). The actinides plutonium and uranium are perhaps most famous for their use in atomic energy; less well-known examples are the lanthanides cerium, which senses air-exhaust ratios in catalytic converters, and europium, which provides the fluorescence of euro bank notes and the plastic stars that adorn children's ceilings. Kvashnina's group has also been studying thorium, an actinide used in nuclear reactors and solar cells, and praseodymium, a lanthanide used for strengthening alloys.

One of Kvashnina's first hints about the individuality of the bottom elements came with her studies of plutonium and uranium. With two fewer electrons in its 5f orbital, she says, uranium ought to be the simpler and more predictable of the pair. Yet in a series of experiments, she and her colleagues have found evidence for uranium in a +5 oxidation state, which theoretical studies had predicted to be unstable (*Phys. Rev. Lett.* **111** 253002; *Chem. Commun.* **53** 115). Conversely, she has found plutonium to exhibit surprisingly straightforward behaviour. In a recent unpublished study, her group experimented with synthesising plutonium-oxide nanoparticles in water from a variety of plutonium oxidation states and in a variety of conditions: every time, the nanoparticles generated were crystalline rather than amorphous, two nanometres in diameter, and insoluble.

"That's an example that impressed me so much," she says. "Even if you think that plutonium is very complicated, and its chemistry is complicated, now we have an

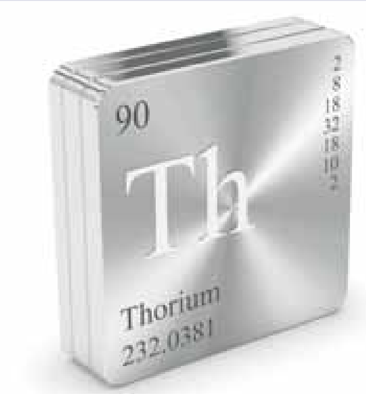


CERIUM: EASING BONE IMPLANTS

When biomaterials are implanted into the human body to replace damaged tissues, there is a high risk of the generation of surplus reactive oxidative species, such as hydrogen peroxide, which prolong inflammation and recovery. Cerium oxide is an effective antioxidant, particularly in the case of bioactive glass for bone implants, but too much actually hampers the formation of bone tissue. Using fluorescence data taken from X-ray absorption near-edge spectroscopy at the ID26 beamline, however, Paola Luches at the Institute for Nanoscience in Modena, Italy, and colleagues discovered that a bigger effect can be achieved from less cerium oxide if the cerium is in a +5 oxidation state, and if the surrounding glass is oxygen deficient. The results improve the prospects for bioactive-glass bone grafting (*PCCP* **20** 23507).

THORIUM: THE MODEL ACTINIDE?

Thorium is unlike other actinides in that its 5f and 6d orbitals have been shown to hybridise with orbitals from neighbouring atoms. That is another example of the individuality of actinides (see main text), but in this case, for scientists, the individuality actually makes life easier. Uniquely, thorium's electronic f states are all more energetic than the d states; moreover, the element only has a single-known oxidation state. As a result, scientists coming to the ESRF can study the effect that thorium's electronic structure has on its macroscopic behaviour without worrying about any changes in chemistry. "With thorium it's easier – you don't have these complications," says Sergei Butorin of Uppsala University in Sweden.



idea that that's not the case. It might actually be more predictable than uranium – and we found that out only by using synchrotron radiation."

Awkward transition

The lanthanides and actinides are sometimes termed the inner transition metals, because of the place they would occupy – between group two and the transition metals – if they were to be incorporated into the main body of the periodic table. A commonality within the actual transition metals is that one element can often be substituted easily for another – copper for iron in a catalyst, for example. Previously, scientists have believed that substitutions might be possible within the bottom elements as well – for example, between plutonium, cerium and thorium, which are superficially analagous. But here, too, Kvashnina and her colleagues have found more differences than similarities. Unlike plutonium, which can exist in +2 to +7 oxidation states, thorium exists only in the oxidation state +4 (*PNAS* **113** 8093), yet can form nanoparticles of various sizes. Meanwhile, cerium can also form variously sized nanoparticles; on the other hand, it can exist in at least two oxidation states, +3 and +4 (*J. Anal. At. Spectrom.* **26** 1265; *ACS Nano* **7** 10726).

Neil Hyatt, a nuclear chemist at the University of Sheffield, believes this lack of commonality poses a big challenge for the disposal of radioactive waste, as it shows the impossibility of extrapolating the behaviour of plutonium compounds from thorium or cerium counterparts. "We have to understand these differences at a fundamental level to develop predictive tools of plutonium behaviour in a repository, to assure the safety for 100,000 years," he says. "Kristina and her team are at the forefront of this research, which is writing a new chapter in our understanding of the transuranic elements with the help of synchrotron radiation at the ESRF."

Some of the irregularities of the lanthanides and actinides result from the nature of the 4f and 5f orbitals, which are held relatively close to the nucleus, and therefore do not influence chemistry as much as other orbitals containing valence electrons. For the same reason, some chemists often suspect that electrons in 4f and 5f orbitals prefer not to hybridise with orbitals from neighbouring atoms. In 2016, however, Kvashnina found evidence to the contrary – and yet another example of actinide eccentricity – in the hybridisation of thorium 5f and 6d orbitals with oxygen orbitals in thorium dioxide (*PNAS* **113** 8093).

One day, might Kvashnina begin to find trends that bring some cohesion to the bottom two rows of the periodic table? There is hope in the ESRF's upgrade, the Extremely Brilliant Source, which will boost energy resolutions and thus make such trends easier to spot. But it could be that she is fated to study each of the lanthanides and actinides individually – to explore what she calls the "chemical zoo" of their properties, one by one. "I try to see similarities, because similarities help with predictions," she says. "I wish they would be similar – but they are not!" ■

Jon Cartwright

URANIUM: A DREAM MAGNET

Although it is better known for its applications in nuclear power, uranium has also been touted as a ferromagnet for situations when its radioactivity does not pose a problem – in space, for example. That is because its magnetic properties can be easily tuned via the addition of other chemical species. Unfortunately, says Roman Gumeniuk of the Freiberg University of Mining and Technology in Germany, "you don't know in advance what those properties are going to be". One alloy Gumeniuk recently trialled at the ESRF, containing uranium, beryllium and germanium, lost its magnetism above 160 K – far off room temperature (*Phys. Rev. B* **97** 174405). Still, Gumeniuk is hopeful that uranium could one day usurp neodymium, whose alloys are currently considered the best all-round ferromagnets.

"Kristina's team is at the forefront of this research, which is writing a new chapter in our understanding of the transuranic elements with the help of the ESRF"

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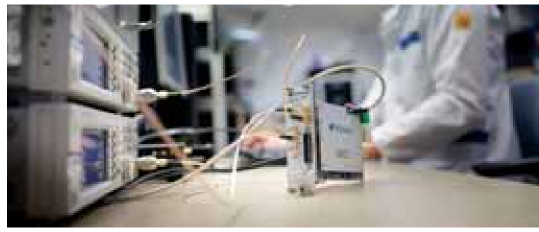
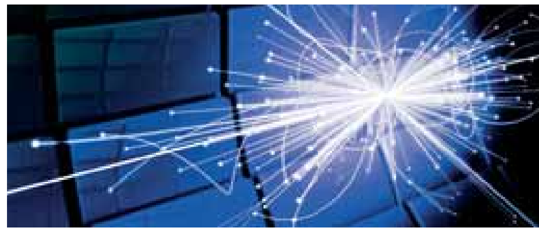
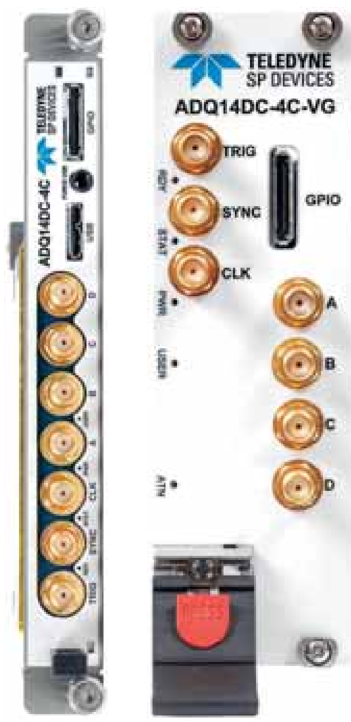




When Compromise is Not an Option.

High-Performance Digitizers for Big Physics Applications



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Steering the system

As the new chair of the CNRS, **Antoine Petit** has to keep one of the world's largest scientific agencies on track for success.

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In a world of increasingly autonomous computer systems, software bugs are a bigger threat than ever before – a fact Antoine Petit knows better than most. For much of his career in research, he developed mathematical models that could, via reverse engineering, determine whether software is able to generate problematic outcomes – an autopilot crashing a plane, for instance – based on certain initial values. "The software's behaviour depends on those initial values, but they can be infinite in number," he says. "In [my line of research], we tried to construct finite mathematical models for infinite behaviour."

Over the past few decades, models like Petit's have helped manufacturers perform stringent "verification and validation" checks on products involving complex computer software. Today, as the new chair and CEO of the French National Centre for Scientific Research (CNRS), Petit is no longer directly involved in such research – yet he has not left the complexity behind him. As Europe's biggest agency for fundamental science, the CNRS has some 33,000 employees, a budget of €3.3 bn and a role in its nation's research infrastructure unlike anything else in the world. More than 1100 laboratories in France and elsewhere are in fact joint endeavours with the CNRS. "If you go outside France, then people know very few French universities," explains Petit, "but they know the CNRS."

Petit took up his new role in January last year, having progressed through other senior administrative roles in the CNRS, the French Ministry of Research and the French National Institute for Computer Science and Applied Mathematics (INRIA). He arrived at a significant time. This year, the CNRS celebrates its 80th anniversary, and for the past decade or so has been attempting to boost the international ranking of French universities, which have previously been hidden in the agency's shadow. "We've been trying to keep the scientific excellence of the CNRS, which is recognised worldwide, but somehow transfer part of it to universities," he says.

He believes that he was selected as chair partly thanks to his six objectives for a new CNRS: to admit that basic research is at the heart of all scientific progress; to boost links with industry; to forge links between research disciplines, including between the sciences, arts and humanities; to be more present at the European level; to strengthen the partnership with French universities; and to proselytise the value of science to society at large. Naturally, many of those objectives are shared with the ESRF, of which the CNRS is the French shareholder, together with the French Alternative Energies and Atomic Energy Commission.

"With the ESRF, we have one of the very best and most successful synchrotrons, created more than 30 years ago, and every year attracting several thousand users from all over the world," says Petit. "We are proud to have it in Grenoble, in France, but what is most important is that it is based in Europe. No country in Europe can imagine to have such infrastructure alone."

For a theorist, Petit has a surprising interest in the practical challenges of the world today. But actually, he says, his background makes it easier for him, politically, to assert the importance of tackling them. "No one can say, 'Ah, but this guy isn't able to be theoretical anyway'. On the contrary, theory was my world at the very beginning. But the relationship between science and society was not as important 30 years ago. Today, it is crucial not just for creating jobs, but also to help people to have a better understanding of [practical] issues, like climate change." ■

Jon Cartwright

BORN: 1960, Paris, France.
EDUCATION: Doctorate in Computer Science, University of Paris Diderot (1985).
CAREER: Assistant professor, University of Orleans (1984); lecturer, University of Paris South (1989); professor, École normale supérieure Cachan (1994); deputy director, French Ministry of Research (2001); scientific director, then inter-regional director for south-west France, CNRS Information and Communication Science and Technologies Department (2004); head, Paris-Rocquencourt research centre, INRIA (2006); chair and CEO, INRIA (2014); chair and CEO, CNRS (2018).

"We are proud to have the ESRF in France, but most important is that it is in Europe"

21st International Magnetic Measurement Workshop

24–28 June 2019

As this issue goes to press, there are just a few days left (until 7 June) to register for the the 21st International Magnetic Measurement Workshop (IMMW21), hosted this year by the ESRF. A week-long event, IMMW21 is a forum for presentations and discussions on the equipment and techniques used to measure, characterise, and fiducialise magnetic fields – typically those of accelerator magnets and insertion devices. Topics covered over the four days of talks include an overview of magnetic measurements; sensors; measurement reports; instruments; methods; and fiducialisation and alignment. More than 60 participants from a dozen countries have already registered for the workshop, which will be held at the Hôtel Mercure Président, 15 minutes from Grenoble city centre.

EBS workshop on energy materials and devices

23–25 September 2019

The heterogeneous devices that will play a role in the future green-energy economy – such as batteries, solar cells and super-capacitors – rely on complex interactions over many length scales. This workshop will focus on the application of established and emerging synchrotron techniques to understand problems from the energy sector, and investigate new opportunities following the EBS upgrade. Topics covered include: hydrogen storage and the hydrogen economy (fuel cells); gas separation and storage (porous materials); catalysis for energy-related processes; electrochemistry and battery research; fuel efficiency and consumption; solar energy; thermoelectrics; piezoelectrics; and super-capacitors. The speakers will be asked to highlight scientific trends in their areas of expertise. Meanwhile, participants will have the opportunity to learn about the anticipated performance gains following the EBS upgrade, and to identify new experiments that will become possible as a result. Registration for abstracts, 19 July 2019; final registration, 25 August 2019.

EBS workshop on X-ray emission spectroscopy

3–5 December 2019

Several beamlines at the ESRF have added X-ray emission spectroscopy (XES) to their portfolio and further installations are planned with the forthcoming EBS upgrade. The aim of this workshop is to give an overview of the new possibilities provided by XES, and to gather feedback from the user community about relevant applications for which further instrumental development will be required (for example, sample environment, and time and spatial resolution). More details will be provided in the next issue.

MOVERS & SHAKERS

Jean-Claude Biasci, the front-end group leader in the ESRF's accelerator and source division (ASD), and the assembly manager of the Extremely Brilliant Source (EBS) upgrade, has been appointed the new head of the ESRF's instrumentation services and development division (ISDD). Biasci takes over from Michael Krisch, who recently joined the complex systems and biomedical sciences group in the ESRF's experiments division as the ID17 beamline responsible.

Biasci joined the ESRF as a mechanical engineer in the early 1990s, having previously worked at the Linear Accelerator Laboratory in Orsay, France. At that time he was helping to construct the ESRF's original 844-m circumference storage ring – the world's first "third-generation" synchrotron light source. In more recent times, he has taken a leading role in the implementation of the EBS accelerator programme, and in particular the installation of the new storage ring in the tunnel – an incredibly complex task that involves the oversight of 10,000 individual components. "Twice in my life I've been able to live through exceptional engineering projects – first with the ESRF, and now with the EBS," he said in a recent interview. "But the EBS is the greatest challenge."

That challenge will continue within ISDD, in which Biasci will be responsible for the cutting-edge instrumentation required to make best use of the world's first high-energy "fourth-generation" synchrotron source. His new role takes effect from 1 September 2019 for a period of five years. "We all welcome Jean-Claude to his new role and responsibilities, and we look forward to working together," the ESRF management stated.

Sakura Pascarelli, the leader of the ESRF's matter at extremes group, and the scientist in charge of the ESRF's ID24 and BM23 beamlines, has been appointed the new scientific director of the European X-ray Free Electron Laser (XFEL). Pascarelli studied physics at Sapienza University of Rome before doing a PhD in Grenoble; she then joined the ESRF, where she has taken on increasing managerial responsibilities. Her research is dedicated to the technique of extended X-ray absorption fine-structure (EXAFS) spectroscopy, which has a thriving user base, with BM23 often oversubscribed by 400%. In addition to her ESRF roles, Pascarelli has served on several scientific advisory committees, for example at the Australian Synchrotron and at the Spanish Synchrotron ALBA.

In her new role, Pascarelli will be responsible for the four short-waved hard X-ray instruments at the European XFEL: FXE for studying extremely fast processes; SPB/SFX for investigating biomolecules and biological samples; HED for studying matter under extreme pressures and temperatures; and MID for investigating nanostructures or irregularly ordered materials such as glasses, liquids and biological substances. She will also be responsible for developing the scientific research programme for these experiment stations. "With her extensive knowledge and experience of management roles at a world-leading X-ray science facility, Sakura Pascarelli is a perfect fit for the role of scientific director at European XFEL," said Maria Faury, chair of the European XFEL Council. "I am sure she will bring fresh perspectives to our work."