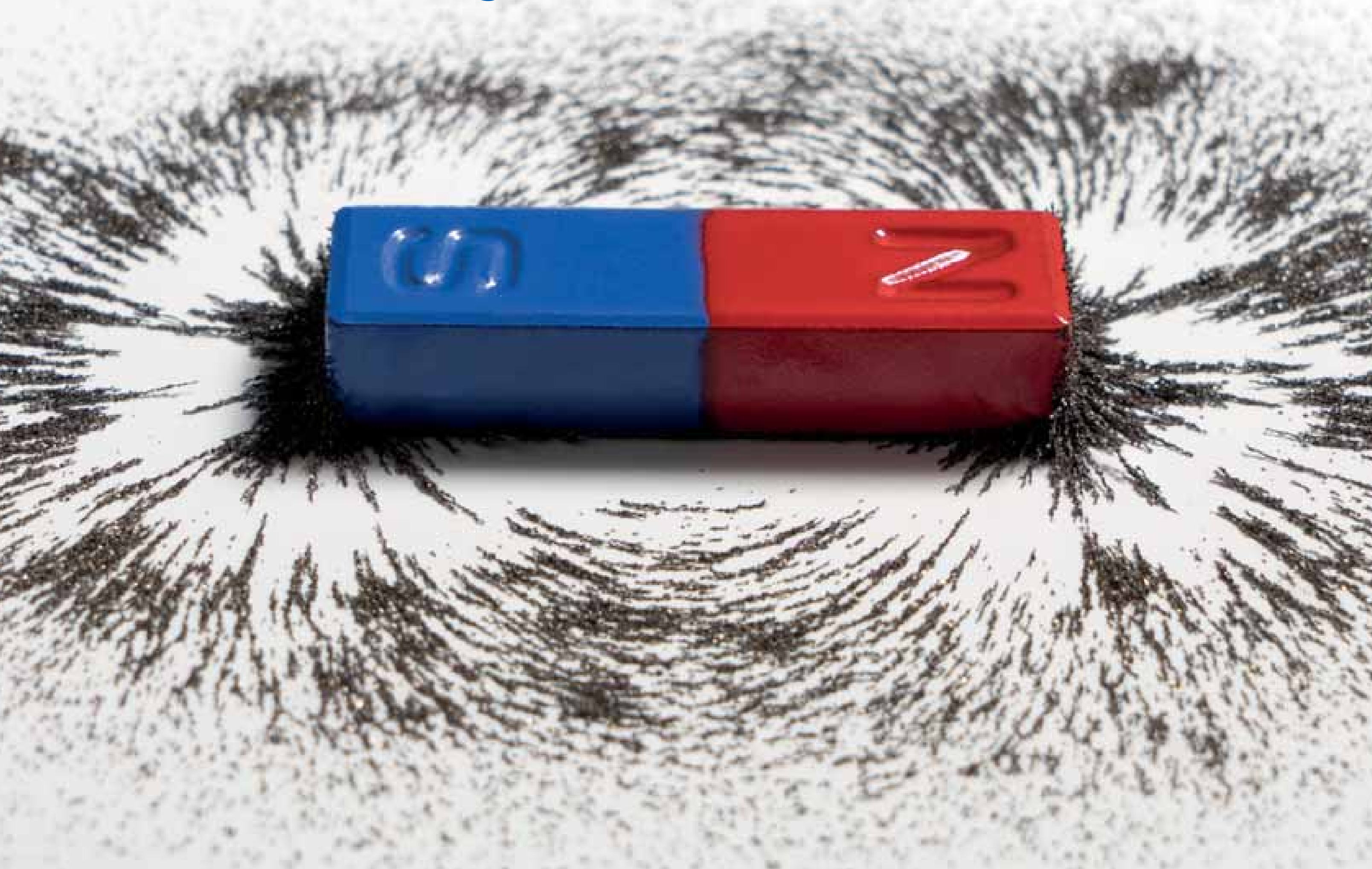
A LIGHT FOR SCIENCE

ESRF news

Number 78 March 2018

MAGNETISM

Testing the rules of attraction



Humans of the ESRF

User Meeting report

Russians boost EBS assembly

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X-RAY SPECTROSCOPY

SDD detectors for beam-line applications

Improved Resolution & Count Rates

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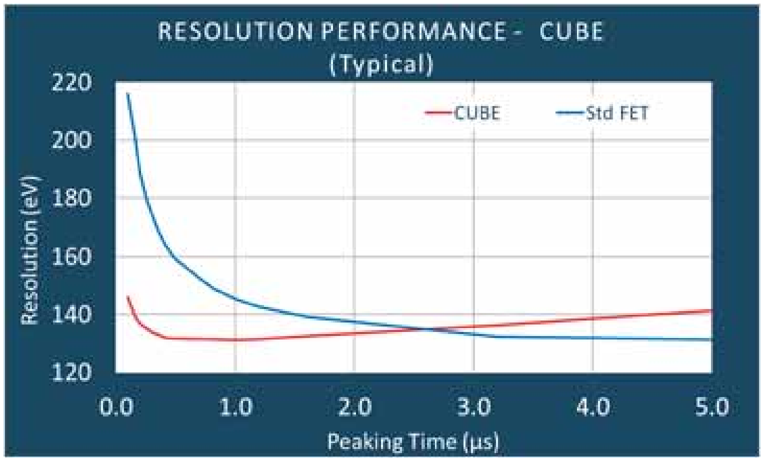

CUBE detectors offer improved resolution at shorter peaking times

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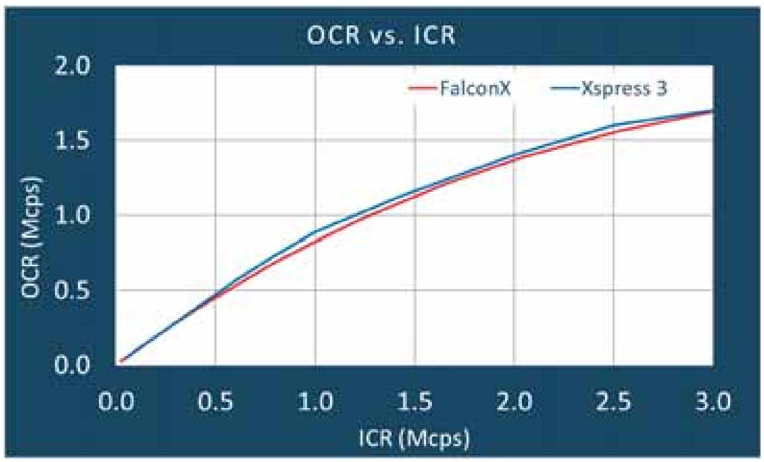

RaySpec SDD detectors - compatible with the latest Digital Pulse Processors from XIA and Quantum Detectors with input count rates >3Mcps

Single and Multi-Sensor SDD Detectors

Example of single sensor design

Example of multi-sensor design with UHV compatibility

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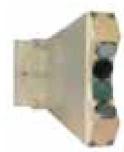
- High solid angle
- Slide options: manual / adapted for translation tables
- Gate valve and bellows available for UHV compatibility

Examples of Customised Designs

7 Sensor Circular Focused Array SDD



4 Sensor Vertical Focused Array SDD

4 Sensor 'Beam Through' Detector Circular Focused Array SDD

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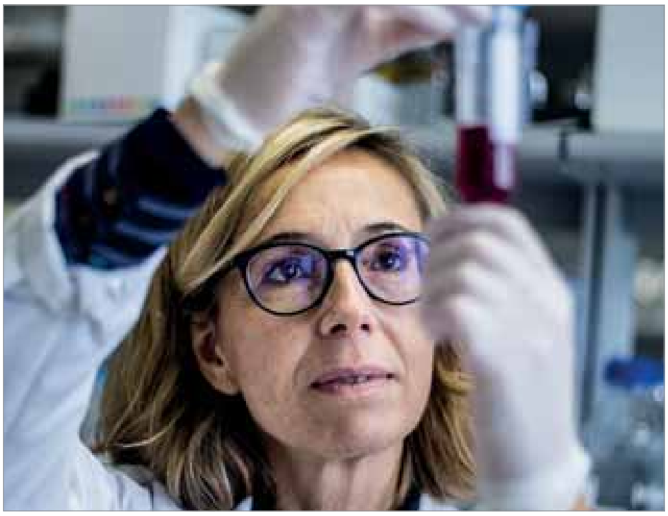
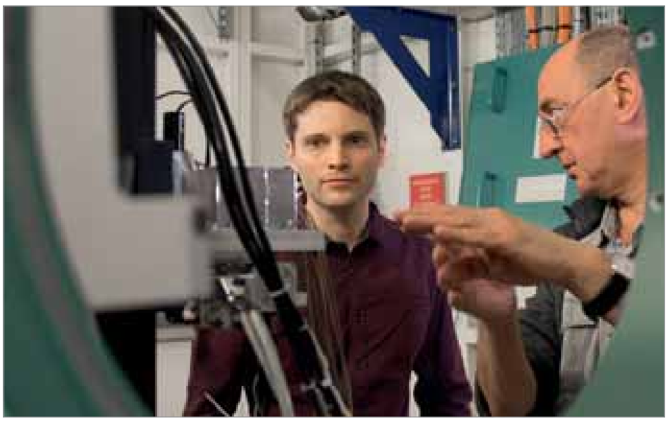
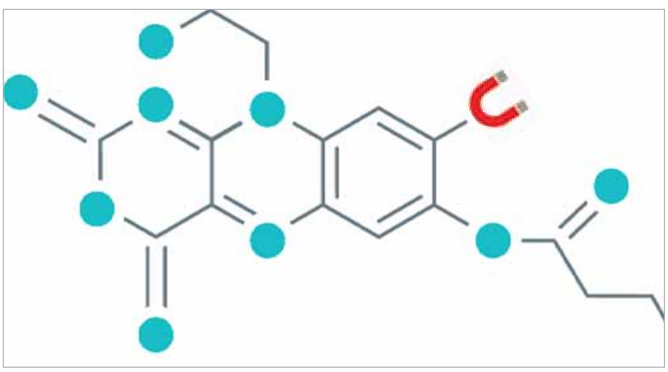
The European Synchrotron



Blog celebrates people of the ESRF, p11.



2018 Young Scientist revealed, p13.



Developing single-molecule magnets, p21.

On the cover:
Magnetism at the ESRF

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ESRFnews

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

Editorial committee
Gary Admans
Nick Brookes
Delphine Chenevier
Andy Fitch
Axel Kaprolat
Michael Krisch
Gordon Leonard
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Edward Mitchell
Pantaleo Raimondi
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Contributor
Anya Joly

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Managing editor
Susan Curtis
Art director
Andrew Giaquinto
Production
Alison Gardiner
Technical illustrator
Alison Tovey
Display-advertisement manager
Edward Jost
Advertisement production
Mark Trimnell
Marketing and circulation
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A new record

As we enter the fourth year of the ESRF's Extremely Brilliant Source (EBS) project, it is clear that 2018 will mark a turning point. By the end of the year, the procurement and assembly phases will be complete, and on 10 December, the current ESRF's last beam will fade away. That will signal the end of an era for users, but the beginning of an intense phase of dismantling and installation for the EBS project team.

Although 2018 will be crucial, in a project such as this every year matters. Behind the scenes, the last three years have seen a lot of groundwork: the conceptual design, and the engineering and procurement of thousands of individual, state-of-the-art components that make up the new storage ring. Today, the massive delivery of magnets, the mushrooming of buildings on-site and the first fully assembled EBS girders are all a visual testimony to the progress being made. This is generating excitement and pride both for the project team and for the wider ESRF community.

An endeavour of this magnitude, with its vast challenges both human and technological, inevitably faces occasional frustrations, teething problems or temporary setbacks. However, success is not the absence of failure; it is the ability to confront it and find solutions. That is an enriching experience in itself. I am consistently impressed by the innovation and teamwork demonstrated every day by those involved with the project, and the way they tackle the highs and lows with professionalism, dedication and motivation. For me personally, after many years spent developing the hybrid multi-bend achromat (HMBA) lattice – the composition of magnets driving the electrons in the EBS storage ring – it is a privilege to see the passion and enthusiasm of everyone to make this shared vision a reality.

"We are on track to deliver a source worthy of the ESRF's world-leading role"

One of the main challenges that we face today is the scale of the EBS project. We have the necessary expertise, built up from improving our machine for nearly 30 years, but we have never attempted work of this extent in such a short amount of time. The stakes are high and the pressure is on, but I am confident that we are on track to deliver a source worthy of the ESRF's world-leading role in the field of accelerator science.

Our goal in the Accelerator and Source Division has always been to deliver the best X-ray beam possible so that, together with the planned flagship EBSL beamlines and the ambitious enabling technology, the ESRF can continue to provide the most innovative tools to expand the frontiers of science. In December, the ESRF will celebrate its 30th year of shining light on the great challenges of humanity. It is fitting that we are able to leave this legacy to inspire the next generation of scientists – for the next 30 years, and beyond.

Pantaleo Raimondi, *ESRF Accelerator and Source director and EBS project leader*

GIACOMO GHIRINGHELLI

From left: Giacomo Ghiringhelli, Lucio Braicovich and Nick Brookes in front of the RIXS spectrometer of the ID32 beamline.

RIXS pioneers bag EPS prize

ESRF users Giacomo Ghiringhelli and Lucio Braicovich of the Politecnico di Milano, Italy, have been awarded the 2018 European Physical Society (EPS) Condensed Matter Division Europhysics Prize. One of the most prestigious awards in condensed-matter physics, the prize recognises the pair's groundbreaking work in high-resolution resonant inelastic X-ray scattering (RIXS).

Francesco Sette, the director-general of the ESRF, offered "vivid congratulations" on behalf of the facility. "We're particularly pleased as Lucio and Giacomo were the key drivers for developing soft RIXS at the ESRF," he said, adding that Nick Brookes, the scientist in charge of the ID32 beamline, and his team had done a "wonderful job" in supporting them.

Ghiringhelli and Braicovich pioneered the use of RIXS at the ID12B and ID08 beamlines in the 1990s, before helping to develop today's flagship station at ID32. RIXS has since established itself as a prime tool for studies of highly correlated materials and high-temperature superconductors (see p25), with stations following Ghiringhelli and Braicovich's design being constructed at other large synchrotrons.

Ghiringhelli said that the award recognises Braicovich's "foresight" when considering the opportunities of third-generation synchrotrons such as the ESRF. "It took several years of technical and scientific effort before the count rate and energy resolution were good enough. On the personal side, working with Lucio for more than 20 years has been a daily pleasure."

The Milan pair are not the first ESRF users to win the award. In 2000, it went to the then-head of the ESRF theory group, Paolo Carra, and his colleagues Gerrit van der Laan and Gisela Shütz-Gmeineder, for establishing the field of X-ray circular magnetic dichroism. Ghiringhelli and Braicovich will be presented with their prize on 13 March 2018 at the 27th General Conference of the EPS Condensed Matter Division, in Berlin.

Oxygen erupts

Where did the Earth's oxygen come from? Many scientists believe that it was produced by the biosphere during the early evolution of life, but now a team of researchers in France have proposed an alternative origin: below ground. The team – which includes members from the Université Clermont Auvergne, the Université de Montpellier, the extreme-conditions lab CEMHTI in Orléans and several ESRF scientists – performed X-ray absorption spectroscopy at ID24 and Mössbauer spectroscopy at ID18 on synthesised deep-mantle material, and found a relatively high proportion of ferric iron, which could have stored an excess of oxygen for a long time. This suggests that a lot of oxygen was trapped in the deep mantle in the past, but could have escaped during the first subduction of tectonic plates 2.5 billion years ago (*Geochem. Persp. Let.* **6** 5).

Semi-aquatic dinosaur discovered

Therapods such as *Tyrannosaurus* dominated the land for some 160 million years of the Mesozoic Era, yet never conquered aquatic environments. Now, however, tomography data taken at the ESRF's ID19 and BM05 beamlines suggests the existence of a new species and genus of therapod with a semi-aquatic lifestyle. With a swan-like neck, and forelimbs like flippers, *Halszkaraptor escuilliei* lived 75 million years ago and probably looked like a large waterbird, walking on two legs on land but able to manoeuvre in water, like a penguin (*Nature* **552** 395). "The first time I examined the specimen, I even questioned whether it was a genuine fossil," says team-member Andrea Cau of the Geological Museum Capellini in Bologna.

P TAFFOREAU/ESRF

LUKAS PANZARIN

Left: Tomography scan of the *Halszkaraptor escuilliei* fossil.
Right: Artist's impression of the living creature.

Brittle stars hold secret to tough glass

Some materials need a boost in strength. Take glass, which must be tempered for more stressful applications such as car windscreens and cookware. Tempering involves rapidly heating and cooling a material – but according to ESRF users based in Israel, that's missing a trick.

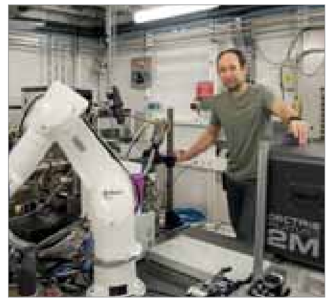
For three years, Boaz Pokroy and others from the Technion-Israel Institute of Technology have been visiting ESRF beamlines ID22, ID13 and ID16B, among other labs, to understand how spiny lenses on the arms of *Ophiocoma wendtii* – a starfish relative known as a brittlestar – can exhibit strength like tempered glass, despite growing in ambient conditions. Using powder diffraction, nano computed-tomography and other techniques, Pokroy and colleagues managed to uncover the change in crystalline structure that delivers this strength.

Together with scientists from the University of Wisconsin and the Natural History Museum of Los Angeles county in the US, the University of Trento in Italy and the Charité Hospital in Berlin, Germany, the team discovered that, during the transition from an amorphous to crystalline phase, magnesium-rich calcite nanoparticles separate from the rest of the material in a brittlestar's lens. These nanoparticles press on the inner part of the lens to "temper" it, until it becomes clear and tough (*Science* **358** 1294).

The researchers believe that this more efficient tempering process, without heating and quenching, could one day be applied by industry to various ceramic materials. "When we first came to the ESRF, we didn't expect our research to deliver these results," says Pokroy.

KENT MILLER (MODIFIED)

Ophiocoma wendtii **could inspire new ways to toughen materials.**



Max Nanao in the new experimental hutch.

ID23–EH2 is now open

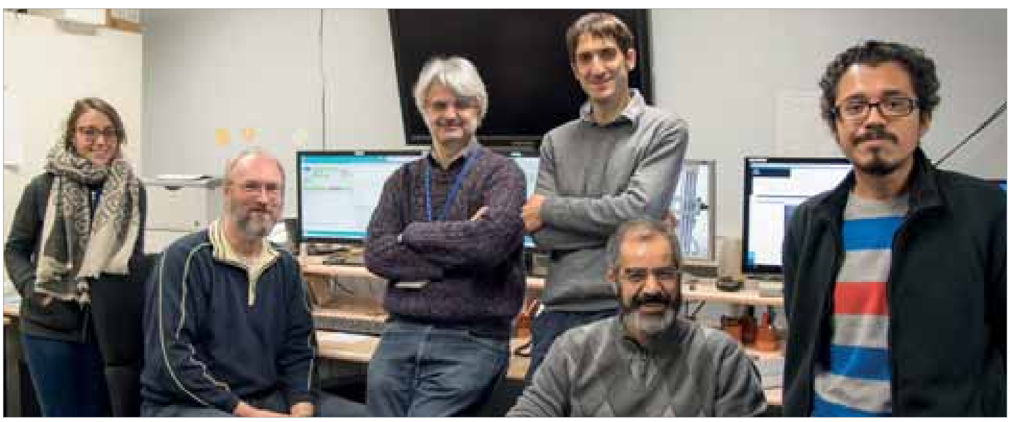
A new microfocus beamline at the ESRF is up and running. With a dedicated beam for macromolecular crystallography of less than 10 μm in diameter, ID23–EH2 is particularly suited to experiments on very small protein crystals and serial crystallography. It also has a state-of-the-art diffractometer, which can scan through samples very quickly and with significant automation. "We don't want users to have to depend on a micro-crystallography specialist 24/7 on the beamline," says Max Nanao, the beamline responsible. "The idea is that they can do it themselves, and in a largely automated manner." The beamline was designed and built in collaboration with the EMBL.

ESRF welcomes LAAMP teams

Four student-scientist teams visited the ESRF between October and December, as part of the Lightsources for Africa, the Americas and Middle East Project (LAAMP). The visitors, who came from Mexico, Senegal and Cyprus, were awardees of last year's first call for LAAMP, which aims to enhance advanced light sources and crystallographic sciences in those regions.

One of the visitors was Ibrahim Serroukh, a professor at the University of Queretaro in Mexico and a board member of the Mexican synchrotron project. Together with his PhD student Marco Garduño Ramón and the ESRF's Alberto Bravin, he worked at the ID17 beamline to investigate the diagnosis and therapy of breast cancer using phase-contrast imaging. "I'm very impressed by the very high level of science and technology and also by the organisation of the ESRF," he said. "It's amazing to see how the ESRF has made it easy for people from all over the world to work together, despite the diversity of their cultures and backgrounds."

The other visitors were Diouma Kobor and Ndeye Coumba Yandè Fall of University Assane Seck of Ziguinchor in Senegal, who worked with ESRF scientists Manfred Burghammer and Fabrice Wilhelm at ID13 and ID12; Kirsi Lorentz and Grigoria Ioannou of the Cyprus Institute, who worked with Marine Cotte and Wout de Nolf at ID21; and Erika Salas Muñoz, Maria Elena Fuentes and Julio César Lerma Hernández of the University of Chihuahua in Mexico, who worked with Hiram Castillo-Michel at ID21.



C ARGOUD/ESRF

From left: Master's student Caterina Amendola, the ESRF's Herwig Requardt, Alberto Bravin and Alberto Mittone, and Ibrahim Serroukh and Marco Garduño Ramón of the University of Queretaro at ID17.


ESRF/CHANTAL ARGOUD

The EBS assembly team from BINP, Russia, led by Sergei Gurov (far right).

Russian boost to assembly

The EBS girder assembly team has been bolstered by the arrival of 12 specialists from the Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia. The team of six magnet and six vacuum experts will work alongside ESRF staff to keep to the ambitious assembly schedule, which started in November last year and will run until the end of 2018.

By that time 128 girders of the new storage ring must be assembled with state-of-the-art magnets, vacuum chambers and the associated instrumentation. "The girder assembly process is very labour intensive and our engineers also have to maintain the excellent operating standards of the current machine, so we are very happy to have our colleagues from BINP on board," says assembly leader Jean-Claude Biasci.

Founded in 1958, BINP specialises in high-energy, plasma and accelerator physics, including the research, design and production of accelerators around the world. Its EBS team, headed by Sergei Gurov, brings knowledge and expertise gained from helping the development, assembly and commissioning of several leading light sources. "We have worked on machines including MAX-IV in Sweden, ALBA in Spain, NSLS-II in the USA, and BESSY-II and XFEL in Germany, so we are very excited to be able to work on the ESRF–EBS," says Gurov. ''It's also a great opportunity for us to get acquainted with the culture and traditions of France, establish professional contacts and meet friends."

The team already feels at home in the dedicated assembly building ESRF 01, where three assembly lines have been set up, each one fixed on a specific task: installing and aligning the magnets, placing the vacuum chambers inside the magnets, and finally closing the magnets for precise alignment. Each process takes around a week, with up to 80 individual components installed on each girder.

At the time of press, the team had already assembled the first nine girders, which could then be transported via crane and lorry to their temporary storage location in the Chartreuse Hall. The wintry Grenoble rain during this process did not bother them. "Back in Russia it's –38 °C so we are quite comfortable here in France!" laughs Gurov.

Insight: The injector complex

What is the injector complex?
The injection system includes the source and linear accelerator, where electrons are produced; the booster, where particles are accelerated to their operating energy of 6 GeV; and the transfer line, which extracts electrons from the booster and injects them into the storage ring, where they join the stored bunches at a rate of four times per second. In "top up" – one of several possible filling modes – this process takes place every 20 minutes and lasts around 30 seconds.

How will it change for the EBS?
One of the biggest changes will be physically rather small: a reduction of the booster circumference by 105 mm, which is necessary to preserve its size ratio with the new, slightly shorter storage ring. The booster's operation will also be changed, to reduce the so-called equilibrium emittance (how tightly the electrons are confined) and improve injection efficiency. A side-effect of a lower-emittance, brighter beam, however, is a lower lifetime – and this means more frequent injections.

Is that a problem?
For good-quality data, the electron beam has to be as stable as possible, but injections tend to disturb it. Over the past two years, engineering improvements have greatly reduced this disturbance, but the EBS team wants to go further. Changes include replacing one of the electromagnetic "septa" magnets in the transfer line with a permanent magnet, the field of which is more consistent, and providing other magnets with better power supplies and feedback systems. The long-term goal is a fully transparent injection process, with which beam stability – and data quality – wouldn't be affected at all.

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News from the User Office and User Organisation

The User Office would like to note that the next Beam Time Allocation Panel meeting to review proposals submitted for the 1 March 2018 deadline (last call before the EBS shutdown) will be 26 and 27 April.

The User Organisation would like to thank all the users who participated in the 2018 User Meeting and contributed to a dynamic atmosphere (see pp12–13). This year, the number of attendees was at its highest level for 10 years. There was increased participation in all the different sessions – the tutorials, the plenary session and the microsymposia – and a record number of posters was presented.

The User Organisation is pleased to see that this format of the meeting is so appreciated by the user community and that it attracts many students and young scientists. We would like to acknowledge the unique organisation work put in place by the ESRF User Office, the experimental division secretaries, and the Travel Office and the Communication Unit of the ESRF. In particular, we thank the Communication Unit that was set up to organise the production of the promotional video about the Young Scientist Award winner.

We would like to remind all users who have questions, comments or ideas for the next meetings, that they are welcome to contact the User Organisation directly at any time via e-mail. Representatives of each user scientific community can be found at www.esrf.eu/UsersAndScience/users_org.

Joanne McCarthy, Head of the User Office, and Paola Coan, chair of the UOC

News from the beamlines

● The pulsed laser of the **Structure of Materials group** (Brilliant B by Quantel, 850 mJ at 1064 nm, 20 ns pulse width) was refurbished and equipped with frequency-doubling modules, as well as optical focusing elements, and is available for user experiments.

● This summer, **ROBL (BM20)** will convert the former Materials Research Hutch into a second Radiochemistry Hutch (RCH-2). Access to this hutch and all diffraction experiments will stop in July 2018 and experiments in RCH-1 (bulk EXAFS and HR-XANES, XES and RIXS experiments on the single-crystal spectrometer) will resume in October until December 2018. Due to the limited beam time available, no new proposals were accepted for the call in March 2018. Both hutches will resume operation in summer 2020. RCH-2 will then host (single-Xtal-, high-resolution-powder- and surface-) diffraction experiments with priority for actinide samples. A new 5-crystal spectrometer will be available in this hutch for HR-XANES, XES and RIXS experiments of actinide materials.

● Beamline **ID17** has extended its broad biomedical imaging capabilities with a new setup for high-resolution microtomography in the first experimental station, located ~40 m from the source. The system is compatible with polychromatic illumination so can work even with the direct beam from the ID17 wiggler source. The new setup includes a 10x/5x or a 10x/2x pink-beam compatible optics (Optique Peter, France), providing 0.7/1.4 or 0.7/3.5 µm pixel size when combined with a pco.edge sCMOS-based camera. Different combinations of filters and of insertion device gap settings allow the wiggler spectrum to be shaped in the range 25-45 keV, or higher upon request. This new system is particularly suited for fast multiscale imaging in propagation-based phase-contrast imaging mode.

GUILLAUME GOTTHARD/SB GROUP

The new offline microspectrophotometer at the ID29S-Cryobench. Three LEDs (blue, green and red) have been used to visualise the intersection of the focal volumes of the three optical objectives.

● The **ID21** refurbishment is ongoing with major modifications of the optics hutches and the implementation of state-of-the-art optics, in particular a new pair of mirrors for harmonic rejection and the prototype of the new double crystal monochromator, designed for spectroscopy. Beamline operation should resume in April 2018 and beam time will then be shared between commissioning and user operation over the rest of the year.

● In the context of the ESRF EBS project, **XMaS (BM28)** is planning timely upgrades to its infrastructure, the replacement of critical components and the commissioning of new control equipment ensuring full operational capabilities for user operation at the restart of the new storage ring in 2020. After 20 years of operation and assuming further funding, the XMaS upgrade will start in May 2018 with the extension of the experimental hutch to take into account the new source position in the upgraded storage ring. The construction work will continue until September 2018 followed by reduced user operation until the December 2018 shutdown.

● On **ID29S-Cryobench** the new offline microspectrophotometry setup is now available in user mode for UV-visible absorption and Raman spectroscopies (see image, above). All four optical objectives are fully motorised and integrated into a minidiffractometer MD2M, which greatly facilitates crystal centring and spectroscopic data quality optimisation.

● The energy-tuneable MX beamline **ID30B** has been equipped with a fast REX nozzle exchanging device that allows rapid and automatic changing of the sample environment between a cryogenic gas stream and a dehumidifier. The beamline also offers a regular crystallisation plate screening service every second Wednesday from 09.00–17.00, upon demand. Finally, ID30B now offers the possibility to automatically collect diffraction data using the MXPress workflows, as used on the hands-off beam line MASSIF-1 (ID30A-1).

● MXCuBE3, a new interface for experiment control, is being progressively deployed on all the **Structural Biology group MX beamlines**. Developed in close collaboration with MAX-IV and the other partners of the MXCuBE collaboration (EMBL, DESY, HZB, SOLEIL, ALBA, MAX-lab and Global Phasing) MXCuBE3 provides a completely new user interface for MX experiments while at the same time maintaining the strengths and features of its predecessor, MXCuBE2. As a web application, which further simplifies the data-collection sequence via the implementation of a more interactive and focused interface, MXCuBE3 can be started virtually on any computer or mobile device without the need for the installation of any software apart from a recent web browser. It therefore greatly facilitates remote access experiments and seamlessly integrates with the latest development of the ISPyB LIMS.

● The **3rd Annual Users Meeting of iNEXT** will take place on the EPN Science campus in Grenoble from 19–21 March. iNEXT is a consortium funded by the Horizon2020 program that is pioneering coordinated access to infrastructures for macromolecular crystallography, SAXS, NMR, electron microscopy, advanced light microscopy and biophysics. The meeting intends to bring together iNEXT users of the various facilities, and iNEXT partners to exchange on recent scientific advances made in the field of structural biology. It will be followed by a dedicated "**iNEXT meets Industry**" workshop (Translating Structural Biology into Biomedical Applications) from 21–23 March at the ESRF.

People power

A new blog pays tribute to ESRF staff and users.

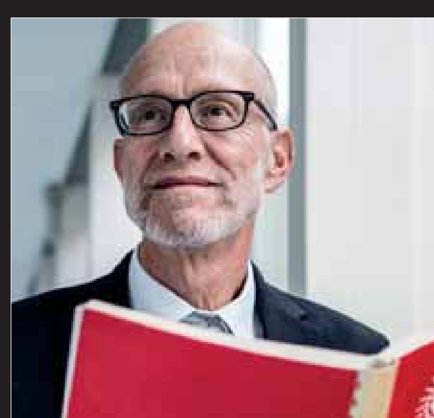
The ESRF has always been a beacon of cultural variety. Whether they are users, scientists, engineers, technicians or administrative staff, people from all walks of life and from all over the world work together at this unique, world-class facility for the advancement of science. Now in 2018, for its 30th anniversary, the ESRF is launching a blog, *Humans of the ESRF*, to pay homage to all these contributors.

The project is based loosely on the "Humans of New York" photographic project, which was born a decade ago to expose the eclectic mix of inhabitants of that vibrant US city. In the ESRF version, viewers can discover the driving force behind the success of the ESRF through its people and their stories, and celebrate 30 years of science, 30 years of innovation and 30 years of contributions to the great challenges of our time. The blog will be updated every Wednesday throughout the year.

● **https://humans.esrf.fr/**

ETIENNE BOUY

(Clockwise from top): Thierry Giraud, beamline technician; Montserrat Soler-Lopez, structural biologist; Jerry Hastings, ESRF science advisor; Joanne McCarthy, head of the User Office.



Virginie Chamard speaks on day two of the 2018 User Meeting.

Pearls of wisdom

The art of studying biomineralisation in molluscs was one of many topics discussed at this year's ESRF User Meeting.

From the outside, the pearl oyster could be mistaken for a lump of chalk. Crack it open, however, and it reveals a stunningly iridescent inner coating – mother of pearl, so prized it is often crafted into jewellery.

For ESRF users like Virginie Chamard of the CNRS Institut Fresnel at the Université Aix-Marseille in France, the fascination of the pearl oyster goes beyond sheer beauty. Remarkably, all of the shell is made of the same mineral – calcium carbonate. The exterior is calcium carbonate in the form of calcite, whereas the interior is in the form of aragonite, platelets of which are packed together to deliver that unique appearance of mother of pearl. Both calcite and aragonite can be formed geologically, at high pressures and high temperatures. Somehow, the pearl oyster manages to do the same in the benign conditions of the seabed. "It's quite amazing," says Chamard.

Speaking as one of the keynote lecturers at the ESRF's 28th User Meeting on 5–7 February, Chamard explained that the secret lies in biomineralisation: the growth of minerals with outstanding properties from less complex starting compounds. As it happens, said Chamard, there is a common structure to most biominerals, and this implies a common pathway for growth. Understanding that pathway requires studying the structure of the biominerals, and the most relevant aspects fall in the sub-micrometre range. Unfortunately, this scale falls awkwardly between that which can be accessed by electron microscopy and that which can be accessed with conventional optical microscopes and X-ray diffraction techniques.

The special one percent

To solve this problem, Chamard invented a new synchrotron imaging technique first demonstrated at the ESRF's ID01 beamline. The technique essentially involves selecting only the 1% of X-rays in the beamline that are coherent, and sending them towards a sample; the diffracted rays are then processed via an algorithm to reconstruct the sample's nanoscale structure. Coherent diffractive imaging, or X-ray Bragg ptychography as it is properly known, is sometimes also called "lensless" imaging because of the lack of X-ray optics – and in fact it is this lack of optics that allows the technique to pick up such tiny details without aberrations. Chamard and others applied it at ID01 in 2011, but she has since taken it to other synchrotron beamlines, such as the ESRF's ID13, and recently received a grant from the European Research Council. Given its micro focus capability, ID13 is "quite happy" with this very fine-scale work, she says, adding: "You have a wonderful beamline."

Last year, Chamard and her co-workers performed coherent diffractive imaging at ID13 on a sample of the exterior of a pearl oyster, and recorded an unprecedented 3D structure. At this scale, they could view single prisms within the calcite, as well as commonly ordered domains. Their results were evidence for particular models of biomineralisation involving the partial fusion of aligned nanoparticles with liquid-droplet precursors involving either the partial fusion of aligned nanocrystals or crystallisation from liquid-droplet precursors (*Nat. Mat.* **16** 946).

Chamard's talk on Tuesday 6 February was followed by another keynote lecture by physicist Hugh Simons of the Technical University of Denmark on imaging material dynamics at multiple scales in three dimensions; later that day, environmental scientist Jérôme Rose of the Université Aix-Marseille III in France gave the third and final

C ARGOUD/ESRF

Kilian Peter Heeg with Alexander Chumakov on ID18.

Young Scientist 2018: Kilian Heeg

The 2018 Young Scientist Award has been presented to Kilian Peter Heeg, a regular user of the ESRF's nuclear resonance beamline ID18, in recognition of his pioneering work on light-matter interactions that enhance the brilliance of X-ray pulses. The award, which was announced during this year's User Meeting on Tuesday 6 February, is presented annually to a single ESRF user to recognise outstanding work carried out at the ESRF.

Heeg, 31, is a physicist and postdoctoral researcher at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. His award-winning work was published last year in the journal *Science*, in which he described how the precisely controlled motion of a resonant target allows an X-ray spectrum to be tailored, such that specific X-ray pulses can be amplified. The work has opened up new paths in X-ray science, such as exciting nuclear resonances more efficiently. In other research, he has explored the concept of "slow light" – the exploitation of quantum-optical effects to reduce the group velocity of an X-ray pulse by several orders of magnitude.

"I wanted to be a mathematician when I was a child and I was always fascinated by natural sciences," he says. "However, in my final years in school I fell in love with physics and very quickly became fascinated by quantum mechanics and especially quantum optics. I feel very honoured and pleased to have been chosen as the winner of this year's ESRF Young Scientist Award."

Kilian first began using ID18 in 2013. "Kilian Heeg is a rising name in the field of nuclear resonance scattering and, despite his young age, he has several papers to his name, each of them averaging around 20 citations," says Alexander Chumakov, ESRF scientist on ID18. "We're always happy to see him come back to ID18 to conduct experiments and bring new ideas."

Kirstin Colvin

keynote lecture on assessing the risks of nanotechnologies during their entire product cycle. The Tuesday also saw a progress update on the Extremely Brilliant Source (EBS) upgrade, the 2018 Young Scientist Award (see above) and the poster session.

Spider prize

The prize for best poster went to Silja Flenner, a first-year PhD student at the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research in Germany, whose work explores the structure and function of the small hairs found on spiders' feet. Using scanning X-ray nanobeam diffraction and small-angle scattering at the ESRF beamline ID13, she has begun to understand how the hairs allow spiders to crawl upside-down, on rough and smooth surfaces, while still being able to carry more than the spiders' own body weight. "What I really appreciate is that the meeting is well scaled to allow you to see all the posters on show, and have time to discuss with ESRF staff and other users," she says. "Thanks to the organisers for such a great event."

As usual, the User Meeting was a hive of activity, seeing the arrival of more than 380 participants from 28 countries. While the Tuesday was devoted to plenary sessions, Monday gave users the opportunity to choose from 12 different tutorials, with topics ranging from how to analyse particular types of X-ray data, to how to communicate results to the media. Wednesday's timetable offered three user-dedicated microsymposia: high-pressure science, metallurgy and minerals processing, and synchrotron approaches to neurological diseases.

The 28th User Meeting came at the end of a successful year for the ESRF, with record numbers of experimental proposals and users coming on site. But the meeting was special for another reason, as it will have been the final one to take place while the ESRF still has its original storage ring, which has operated for 25 years. Paola Coan, chair of the ESRF User Organisation Committee, paid tribute to this history at Tuesday's opening address. "2018 marks the end of an era for the original storage ring, as well as the beginning of a new era with the realisation of the EBS, the first of a new generation of storage rings," she said.

Jon Cartwright and Kirstin Colvin

In earshot: why I came to UM2018

"Because it's so cool and I have an experiment coming soon!"

"To visit a symposium and find out which beamline I could use for my science"

"For meeting friends, visiting beamlines"

"To contribute to a discussion on the future of structural biology"

"To talk science and do networking!"

"To hear the plans to further develop this great machine"

Shining a light on magnetism

The ESRF prises apart a difficult subject.

The Aurora Borealis is a vivid example of magnetism in the natural world, as the Earth's magnetosphere is buffeted by the solar wind. Meanwhile, the automotive and various other industries are increasingly reliant on high-performance magnets.

It almost goes without saying that magnetism is a necessary part of our lives. In fact, life itself could not have evolved were it not for the Earth's magnetic field, which deflects the solar wind and protects us from harmful cosmic rays; birds, flies, bacteria and various other creatures even appear to use it to navigate. We use magnetism to generate electricity, to drive motion, to record data, to play music, to study our bodies via nuclear magnetic resonance. The latest hybrid cars contain thousands of magnets. Lest we forget, the ESRF and all other particle accelerators would not work without magnetism.

That is not to say we fully grasp magnetism in all its guises. "Only few subjects in science are more difficult to understand than magnetism": so claimed the *Encyclopædia Britannica*, as recently as its 15th edition in 1989. That was perhaps overly pessimistic – our understanding of the phenomenon has come a long way since the Greek philosopher Thales of Miletus proposed that lodestone attracts iron because it has a soul. Since the development of quantum mechanics early last century, we have known about the atomic origin of magnetism, in electron spins. Nevertheless, many questions remain today – and the ESRF is well-placed to answer them.

One of those questions is how to best exploit magnetism at the atomic scale in computing. Conventional computers process data by exploiting electronic charge, but there is only so much smaller and faster charge-based processors can be made without running into problems of overheating. By exploiting electron spin instead of charge, as in the promising field of spintronics, this limit could be circumvented. At ESRF beamlines such as ID12, X-ray magnetic circular dichroism (XMCD) provides an ideal way to study a key phenomenon involved in spintronics – the magnetic proximity effect, in which a magnetic state in one layer influences the magnetic properties of an adjacent layer (p19).

An XMCD spectrum is the difference in absorption of left- and right-circularly polarised photons within a sample, whose magnetism is kept either parallel or antiparallel to the propagation direction of the incident X-ray beam. Because of its elemental and orbital specificity, and its ability to probe extremely small volumes, the technique offers unique possibilities when studying the magnetism of complex samples. As well as the elements of spintronic technology, such samples could be molecular magnets, which could one day form the basis for super-high density data storage (p21).

> "Many questions remain. The ESRF is well-placed to answer them."

Attractive options

The ESRF offers many other ways to study magnetism. Also at ID12, users are taking advantage of X-ray absorption to get to the bottom of the so-called magnetocaloric effect, a phenomenon that could save the vast energy expended worldwide on refrigeration (p23). Meanwhile, users are coming to ID18 for access to world-leading Mössbauer spectroscopy facilities, in the hope of better understanding how magnetism bears up in extreme conditions (p16). Finally, resonant inelastic X-ray scattering at the ID32 beamline is revealing that magnetism could even hold the secret to high-temperature superconductivity, the potential route to lossless energy transport (p25).

Few scientists would naturally associate superconductivity with magnetism, but then as this Focus section shows, magnetism is full of surprises. In years to come, in part thanks to the ESRF, maybe a few other magnetic applications will be considered a necessary part of our lives.

Jon Cartwright

Extreme magnetism

Mössbauer spectroscopy at the ESRF gives an unprecedented view of magnetism at high pressures and temperatures.

Any physics student can tell you why something is magnetic. The reason is the presence of free electrons, which "spin" in a certain direction, each creating a tiny magnetic field of its own. In some materials, these spins like to align, and then all the tiny magnetic fields add up, creating one big magnetic field.

So far, so good. But the physics of magnetism is rarely so straightforward, and the scientific question is usually more subtle: why are some things magnetic, but not others? As it turns out, the alignment of electron spins depends on a number of interacting factors, not least atomic structure. To understand why only some materials are magnetic, and to know how to make others, requires complex theoretical models.

Extremes of pressure or temperature are a good way to put these theoretical models to the test. They also hold the possibility of turning otherwise ineffective materials into those with desirable magnetic properties. But magnetism under extreme experimental conditions hasn't always been easily accessible, particularly as the samples inside diamond anvil cells (DACs) – the tools used to generate high pressures – are mere microns in size. This is where the recent development of high-pressure, high-temperature Mössbauer spectroscopy at the ESRF comes in. "It's been a breakthrough," says Rudolf Rüffer, former scientist in charge (now emeritus) of the nuclear resonance beamline ID18.

> **"We needed a highly focussed and intense beam. The ESRF's Mössbauer source was our choice."**

Mössbauer spectroscopy is not the only way to study magnetism at high pressure. For instance, X-ray Magnetic Circular Dichroism (XMCD) stands out for its elemental and orbital selectivity, and has been used to investigate magnetism at extremes at the ID24 and, more recently, ID12 beamlines. Despite these advantages, however, XMCD at very high pressures has a drawback: the opacity of diamonds to soft X-rays makes it impossible to directly access the crucial "3d" electron states involved in magnetism in metals such as iron, cobalt and nickel. As a result, magnetism must be probed indirectly through the "4p" states, the signals of which are less intense and harder to interpret. "We spent a lot of effort to understand how to interpret the data," says ESRF physicist Raffaella Torchio. "It's been very challenging."

By contrast, Mössbauer spectroscopy can directly probe magnetism at extreme conditions. Based on the phenomenon discovered by the German physicist Rudolf

Mössbauer in 1957, the technique involves exciting atomic nuclei with high-energy radiation, and recording their subsequent decay. If the nuclei experience a magnetic field from within or outside the material, their nuclear states split into several others, and by analysing the subsequent interference of decays, it is possible to determine the strength and direction of the field, and whether the material is ferromagnetic, antiferromagnetic, paramagnetic, and so on. Historically, the initial radiation was provided by radioactive sources in the lab, but with little ability to focus, experiments with high-pressure DACs have been limited.

Highly focussed

In the past 10 years, the ESRF has changed that. Since Rüffer helped pioneer synchrotron Mössbauer spectroscopy at the ESRF in the early 1990s, the focussing has improved down to 5 by 10 μm. What's more, the introduction of a nuclear monochromator with high energy resolution means that it is now possible to scan a sample at incremental steps of energy, delivering a spectrum not in the time but in the energy domain. "In principle, you get the same information," Rüffer explains. "But evaluation of the data for untrained people is much easier." Coupled with a facility for homogeneous laser heating, ID18 has become one of only two places in the world (the other being Japan's SPring-8 light source) where nuclear-monochromator Mössbauer studies of magnetism at extreme conditions are possible.

In 2015, Vasily Potapkin at the University of Münster in Germany and others exploited ID18 to seek the collapse of antiferromagnetism in nickel oxide (NiO). The transition would confirm the prediction of the British Nobel laureate Nevill Mott, who supposed that the unusual non-conductivity of NiO and other transition metal oxides arises from free electrons being held in place by strong correlations, generating magnetism in the process. Destroy the magnetism, Mott said, and NiO will become a conductor – probably at pressures of several gigapascals. At ID18, however, Potapkin and colleagues found that NiO's magnetism remains at pressures up to 280 GPa (*Phys. Rev. B* **93** 201110). The result was doubly surprising, because it suggests that magnetism in NiO is as resilient as the atomic structure itself. "This is a fairly unusual concept for physicist, as we tend to look to these two things separately," says Potapkin.

Extreme conditions also hold the gateway to new materials. Multiferroics – materials exhibiting both magnetic and electric polarisation – have potential for spintronics (see p19), but so far do not work well at ambient temperatures. In 2016, Igor Lyubutin at the Russian Academy of Sciences in Moscow and others showed at ID18 that a pressure of 30 GPa could boost the magnetic and ferroelectric transition temperatures of a new multiferroic member of the langasite family, $Ba_3TaFe_3Si2O_{14}$, from 27 to 130 K (*JETP Letters* **105** 26). "We needed a highly focused and intense synchrotron radiation beam to record the Mössbauer spectra from the very small samples in our DAC," says Lyubutin. "The ESRF's Mössbauer source was the technique of choice."

Last year, William Clark of the University of Stuttgart in Germany as well as Ulrich Schwarz at the Max Planck Institute for Chemical Physics of Solids and others used ID18 to study a material with widespread importance: iron nitride (Fe_2N). A possible component of Earth's core, iron nitrides are of great interest to geoscientists, but they are also used throughout industry as protective coatings. Clark and colleagues found that when they heated Fe_2N to temperatures of 1300 K and subjected it to pressures above 10 GPa, it reacted with the elemental nitrogen in the DAC to produce FeN, and took on a structure like that of nickel arsenide. It also became magnetic – surprisingly, for the general trend in iron nitrides is for magnetism to diminish with increasing nitrogen content (*Angew. Chem. Int. Ed.* **56** 7302).

According to Rainer Niewa of the University of Stuttgart, such a dramatic change might prove to deliver other beneficial properties – greater hardness, for example. "The most advantageous aspects of using the ESRF's Mössbauer spectroscopy was the laser heating possibilities for high-pressure equipment, allowing us to reach very high temperatures that we could measure *in situ*," he says.

When it comes to Mössbauer spectroscopy at the ESRF, there is a lot more to be discovered at extreme conditions – even conditions so extreme they are not found on Earth (see "Meteoritic impact", below). But now that Niewa and others have made headway, the pressure is on.

Jon Cartwright

Meteoritic impact

For the most extreme conditions, you don't need lasers and diamond anvil cells – you just need the tumult of the early solar system, before the Earth was formed. That is true for a group led by Richard Harrison at the University of Cambridge in the UK, who study meteorites containing iron-nickel alloys to better understand the magnetic history of those meteorites and our planet – a field of research known as palaeomagnetism.

The magnetism of meteorites isn't a wholly reliable record: like computer hard drives, they can corrupt over time. For that reason, at the ESRF's ID18 beamline last year, the scientists uncovered the composition of metals in a potentially hardy section of their meteorites known as the "cloudy zone" (*Meteorit. Planet. Sci.* **52** 925). It was the first application of synchrotron Mössbauer spectroscopy to meteorite samples, and could help to piece together the meteorites' – and the Earth's – magnetic past.

Rudolf Rüffer pioneered synchrotron Mössbauer spectroscopy, and set up the ESRF's ID18 beamline. He is succeeded at ID18 by Alexandr Chumakov.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Instruments That Advance The Art

The spin doctors

The future is spintronics, and to develop it scientists need XMCD.

The discovery of giant magnetoresistance (GMR) in 1988 marked a turning point for information technology. The effect, which exploits the concept of electron spin to detect tiny magnetic fields via huge changes in resistance, allowed the capacities of hard-disc drives to balloon from megabytes to terabytes. It was a vital breakthrough for making user-friendly desktops, iPods and even the internet possible.

Thirty years is a long time in this field. Today, our smartphones, tablets and laptops are more likely to feature electrically driven "flash" memory than a GMR hard disc, even if the latter still takes the overall burden of data storage elsewhere. But basing technology on electron spin rather than charge – so-called spintronics – is still a major goal, whether it comes to further miniaturising magnetic bits or developing a truly universal memory, such as magnetoresistive random-access memory.

MILIND ALVARES/FLICKR

Spintronics has put music at our fingertips.

New properties

A key element of spintronics is the magnetic heterostructure, in which a coupling of a ferromagnet to another sort of material – a metal, a semiconductor or an insulator – generates entirely new functional properties, going far beyond a simple averaging of the two components. X-ray magnetic circular dichroism (XMCD) is ideally suited here, with its elemental and orbital selectivity, its ability to tease out an otherwise inaccessible magnetic response and – at third-generation synchrotrons such as the ESRF – a sensitivity to single atomic layers.

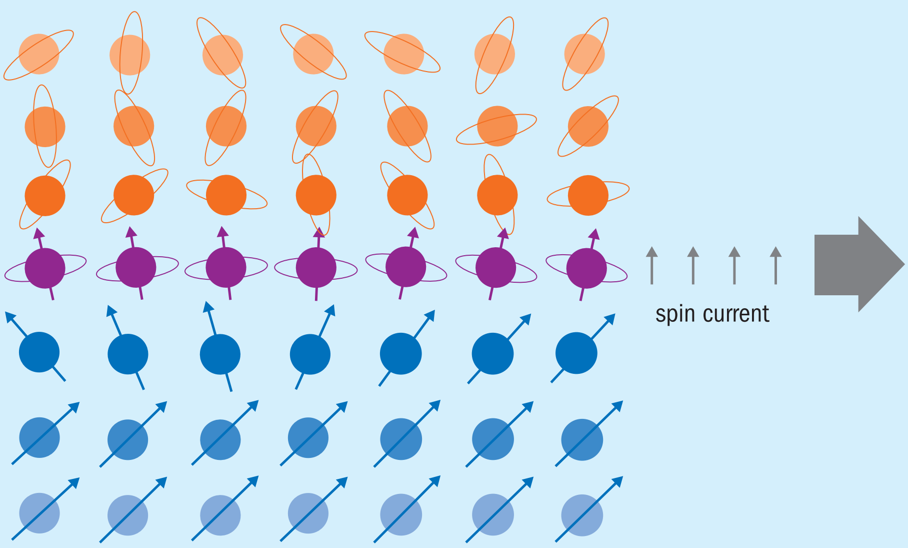
From the early days of operation of the ESRF's ID12 beamline, XMCD has elucidated an important aspect of magnetic heterostructures: the magnetic proximity effect, in which a magnetic state in one layer influences the magnetic properties of an adjacent layer. A ferromagnet can even induce magnetisation in an adjacent material in which there was previously none at all. In 2016, for instance, Michael Caminale at Fondation Nanosciences in Grenoble and colleagues demonstrated that this induced magnetism can be very large, especially for elements such as palladium and platinum that are on the verge of ferromagnetism (*Phys. Rev. B* **94** 014414). The fact that the magnetism is not limited to the interface and extends deeply into the nominally non-magnetic layer is important for further optimising today's spintronic devices, in which spins influence the electrical resistance.

But the most exciting future for spintronics could lie in the exploitation of pure spin currents, for either data storage or logic devices. This type of spintronics would avoid the problem currently associated with the miniaturisation of electronics – overheating – because electron spins do not suffer from heat-generating resistance to electronic charge, only magnetoresistance. Usually, spin currents are generated in bilayers of ferromagnets and non-magnets, where the non-magnets are metals with strong "spin–orbit" couplings, such as palladium and platinum. These combinations have been a remarkable playground to try out several different mechanisms for spin currents (see "Spin the bottle", below).

The correct interpretation of these results depends on the existence of any induced magnetism in the non-magnetic layers, as this would suggest that the observed magnetoresistance is not due to a pure spin current after all. XMCD at ID12 has allowed various groups to look into this. Last year, Martin Collet of Université Paris-Saclay in France and others unambiguously confirmed that magnetic proximity effects do not play an important role in spin current phenomena at the interface of platinum with various ferromagnetic insulators. In other words, there was indeed a pure spin current without an induced magnetic moment (*Appl. Phys. Lett.* **111** 202401).

Such studies bode well for spintronics. And who knows? Maybe in another 30 years time, computers using electronic charge will seem like dusty relics.

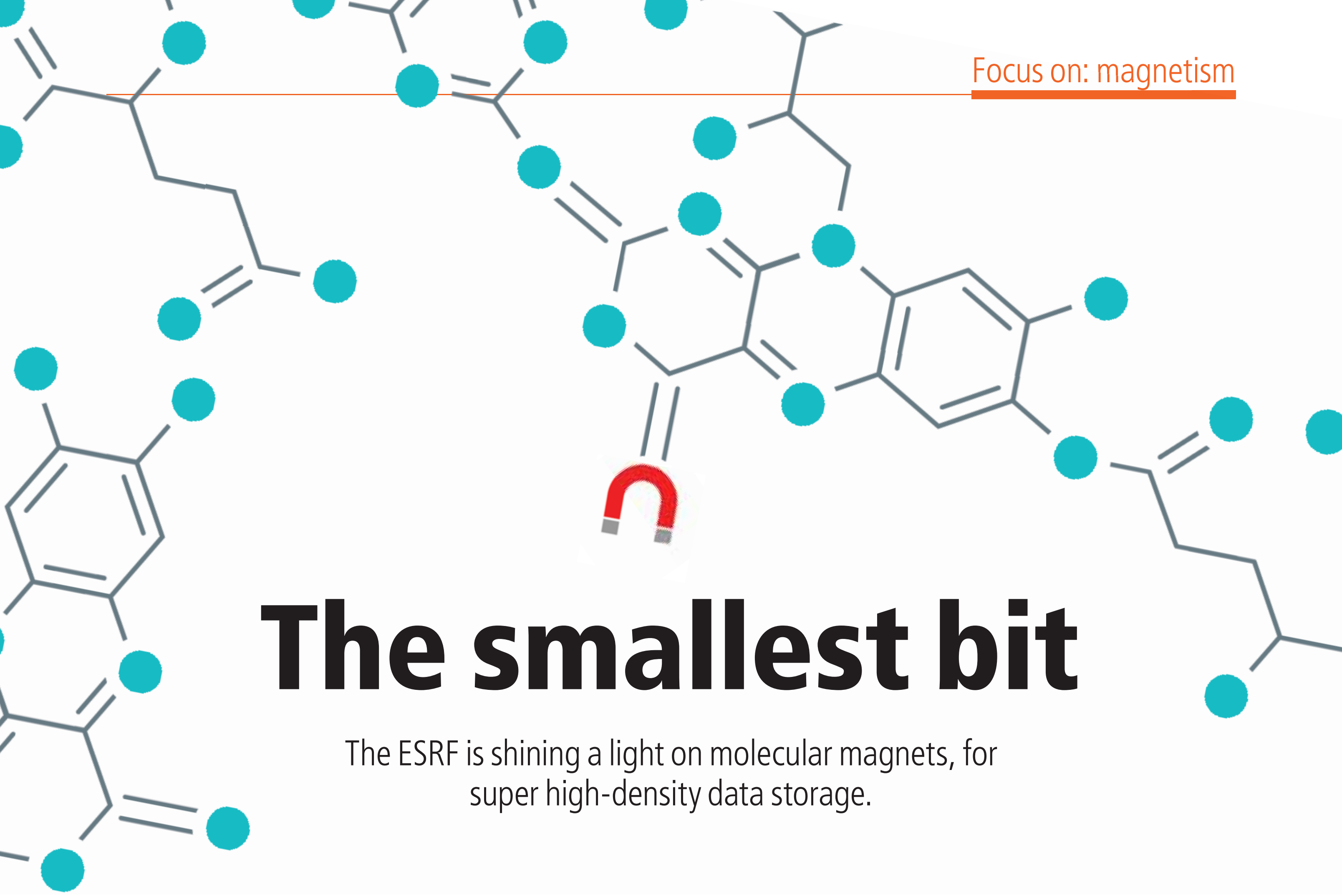
Jon Cartwright and Andrei Rogalev, ESRF



Spin the bottle

In recent years, several different mechanisms have emerged for the production of spin currents – though it isn't yet clear which one will ultimately succeed for commercial applications. Spin caloritronics involves controlling electron spins with a heat current. Magnonics, on the other hand, involves the use of quanta of spin waves, known as magnons, to generate spin currents. Finally, spinorbitronics exploits so-called spin-orbit interactions – the coupling of an electron's spin to its velocity – to generate and detect a spin current.

The target of all of these is the interface (purple atoms) between a ferromagnet (blue atoms with arrows) and a heavy metal with a strong spin–orbit coupling (orange atoms with circles).



The smallest bit

The ESRF is shining a light on molecular magnets, for super high-density data storage.

Data storage has become more and more compact. Today, we can almost squeeze 1 terabit of data onto every square centimetre of a hard drive, which equates to around one magnetic bit per 1000 atoms. If that sounds impressive, imagine a storage medium in which every atom or molecule can act as an individual magnet to hold a bit of information. On something the size of a keyring, you could store some 25,000 gigabytes of data – that's about half a week's output from all the ESRF beamlines.

We may not have to imagine for much longer. Last year, a group based at the IBM Almaden Research Center in California, US, recorded data onto a single atom for the first time – a milestone in the development of single-atom memory. But the IBM group's system worked only at very low temperatures, less than 10K, and because the properties of isolated atoms can hardly be tuned, there is no obvious way to make the system work in ambient conditions. The properties of molecules, however, can be tuned. By designing the molecular chemistry surrounding a metal ion, it may be possible to make the magnetic moment of that ion stable at room temperature – the building block for practicable memory.

Such embedded metal ions are called single-molecule magnets, and X-ray magnetic circular dichroism (XMCD) at the ESRF's ID12 beamline is well placed to study them. A type of spectroscopy involving circularly polarised X-rays, XMCD is sensitive enough not only to access the magnetic states of such magnets, but also to determine the energy barrier required to flip them up and down (or in binary terms, from one to zero). What's more, unlike other techniques it can determine where the magnetism actually comes from: the electron's intrinsic spin, or from the orbit of the electron around its atomic nucleus. That is important, because it is only the electron-orbit contribution that scientists can potentially tailor to improve high-temperature operation.

"XMCD at ID12 is well placed to study single-molecule magnets."

Rare-earth metal ions have a strong orbital contribution. In past studies, single-molecule magnets based on these have operated up to 60K, which is still far off room temperature but which is accessible with liquid-nitrogen cooling. Nevertheless, rare earths interact rather weakly with their surrounding chemistry, and so attentions has recently also turned to the heavier transition metals, which interact more strongly.

Initial findings

In 2016, we used XMCD at ID12 to decouple the spin and orbital contributions to the total magnetic moment of a single ion of the heavier transition element iridium in a molecular entity (*Nat. Commun*. **7** 12195). Then last year, we performed a similar study of the heavier transition element osmium (*Chem. Eur. J* **23** 11244). In both of these studies, the orbital contributions were huge – potentially great news, if we want to tweak the chemistry to make the magnetic moments stable closer to room temperature.

We are still just at the beginning, and with more studies at ID12 and elsewhere the detailed link between the chemical structure of single molecules and their properties as magnets could be obtained. Other synchrotron techniques could help, too: in February this year, Alberto Cini of the University of Florence in Italy and colleagues demonstrated that the properties of surface-grafted molecules can also be accessed with Mössbauer spectroscopy at the ESRF's ID18 beamline (*Nat. Commun.* **9** 480). Once the molecules have been completely tamed, storing information in them seems within reach.

Kasper S Pedersen, Technical University of Denmark

Hard X-ray microscopy and quality assurance at the IMAGE beamline at KIT

Karlsruhe Institute of Technology (KIT), Germany, specified an instrument for hard X-ray microscopy and quality assurance (Microscopy and Quality Assurance – MiQA). The instrument has been conceptually designed in order to combine propagation-based parallel beam imaging, lens-based full-field microscopy and 3D laminography and tomography modes. It will also allow to easily characterize X-ray optical elements. As a dedicated industrial partner for Beamline Instrumentation, PI miCos designed and manufactured MiQA and installed the machine at the IMAGE beamline at KIT. The main applications enabled with MiQA are multiscale 2D and 3D imaging from several microns down to some 10 nm resolution. Scientists will use it as an experimental station for various material research and life-science studies, e.g. in situ characterization of functional materials, microsystem devices or batteries and small animal imaging down to cellular level.

Machine layout

The station is prepared to carry six X-ray optical elements in total and features 56 motorized axes for alignment and experimenting. For utmost flexibility, each optical element is placed on its own positioning module, which can travel independently from other modules on three massive parallel tracks along the beam path. The modules are driven by linear motors using air bearings. The central sample module is designed to carry the sample along the beam path over a travel range of 3500 mm, all other modules have a travel range of 2800 mm. To provide highest possible stability during an experiment, each granite module can be individually cut off from the air supply, so that the respective module solidly sits firmly on its granite track.

X-ray optics modules

For alignment purposes, each of the four optics modules features a hexapod that provides six degrees of freedom. Hence, the centre of rotation can be set arbitrarily by software commands to match the optical centre of the X-ray optical element. Goniometers with high-angular travel range allow for rotation of – for example – gratings around the beam path. Additionally, Piezo scanners are implemented to enable phase scanning of, for example, X-ray gratings in the nanometre range.

Instrument for hard X-ray microscopy and quality assurance (MiQA). PI miCos designed and manufactured MiQA and installed the machine at the IMAGE beamline at KIT.

Detector module

The detector gantry module positions the camera with the detector optics in the field of view in three degrees of freedom. The parallel kinematic machine provides two lateral degrees of freedom perpendicular with respect to the beam and one rotational degree of freedom around the beam axis. The centre of rotation can be easily and, due to the parallel kinematic design, arbitrarily set by software commands to adapt for the actual detector geometry.

Sample module

The heart of the system is the sample module, which allows for different experimental schemes. From bottom to top it stacks a hexapod, a goniometer for laminography mode, a rotational air-bearing stage for tomography and a high-resolution (< 10 nm) X/Y/Z PiezoWalk® drive stage assembly that enables ptychography, too. The heavy-duty hexapod underneath allows for alignment in six degrees of freedom with arbitrary centre of rotation. In order not to be influenced from changing loads, six redundant struts equipped with absolute encoders are implemented only for measuring the position of the top platform. A separate outer control loop compensates for the deformations of the driving struts based on the data collected from the measurement struts. In this way, a repeatability of less than 100 nm is achieved over the full travel range of the hexapod. The rotation stages' measured sphere of confusion at sample position 100 mm above the stages' surface is less than 85 nm to 130 nm in diameter, depending on the tilt angle of the goniometer underneath.

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Catching the cold

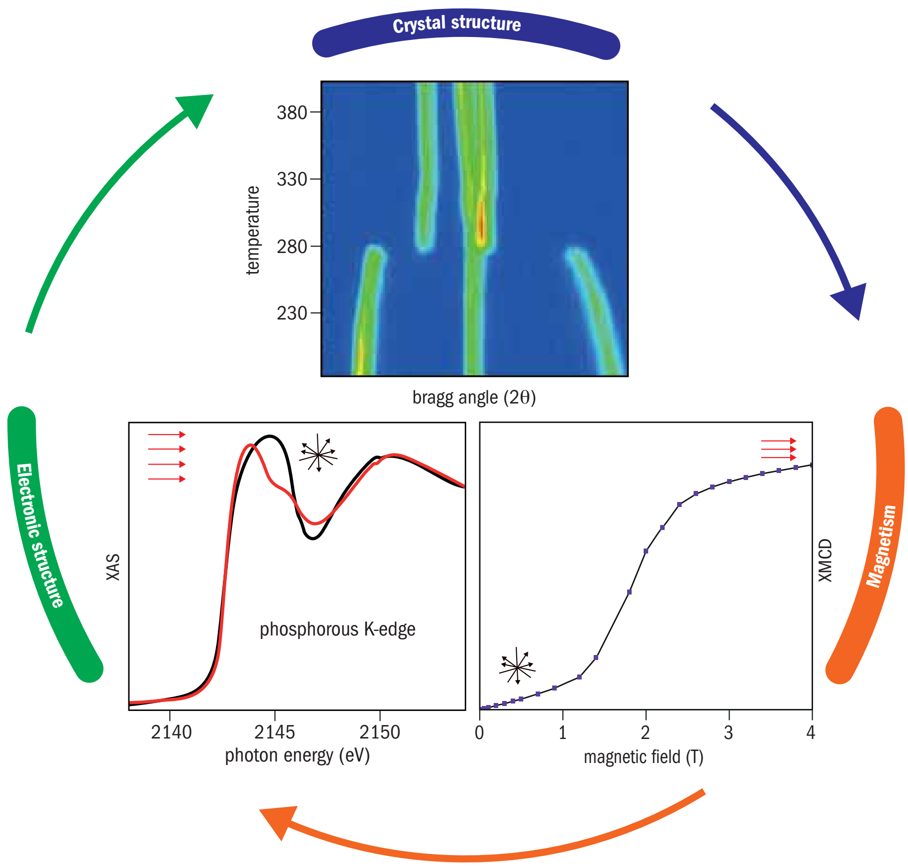
Magnetic refrigeration could cut energy consumption dramatically. The ESRF is hot on its tail.

Everyone likes an ice cream on a warm summer's day – but who spares a thought for the energy that keeps it cold? According to the US Energy Information Administration, air conditioning and refrigeration accounts for between 15 and 30% of the household electrical consumption in developed countries. Yet efficient alternatives to the conventional refrigeration method – vapour compression – are scarce.

The magnetocaloric effect (MCE) could be the answer. It involves magnetising a material with an external field, and then removing that field: the material reverts to a disordered state, in doing so absorbing thermal energy and cooling down. In principle, the MCE could be exploited not just for everyday refrigeration but also for specialist tasks such as temperature-activated drug delivery to specific points in the human body. But while magnetic refrigerators exist, they are costly and their performance remains limited due to an MCE of only a few degrees.

To improve matters, scientists need a better understanding of the MCE's origin. Near room temperature, a sizeable MCE is only given by a magnetic phase transition involving a big difference in net magnetisation – a ferromagnetic to paramagnetic transition, for example. But the MCE is particularly enhanced in transitions of the first order; that is, discontinuous ones in which latent heat is absorbed or released. Unfortunately, an overwhelming majority of magnetic transitions are continuous, second-order.

It is possible to improve the MCE of a material by tweaking its chemical composition, so that its original second-order magnetic transition is accompanied by a change in crystal structure. This makes the magnetic transition first order, turning the MCE into a giant effect – although there are drawbacks because the transition will often work in one direction but not the other, creating undesirable losses in a cycle. Therefore, the search is on for first-order magnetic transitions without breaking the crystal structure. These are rare indeed, and mostly confined to a handful of material families: iron-rhodium, lanthanum-iron-silicon and manganese-iron-pnictides. In these examples, the magnetic transitions originate from drastic electronic reconstructions made possible by the itinerant d-states of transition metals. These enhance the magnetic discontinuities and the MCE.



Data collected at the ESRF reveals a synergy between different discontinuities at the origin of the MCE. In the crystal structure, the break in the evolution of the powder X-ray diffraction patterns is the hallmark of a first-order magnetic transition. The same transition can be seen as a discontinuous rise in XMCD signal, as the magnetic field is varied. Finally, XAS shows the disruption in electronic structure when the magnetic field is switched from off (black) to on (red).

With the elemental and orbital specificity of its X-ray absorption techniques, not to mention end-stations covering large ranges in temperature, magnetic field and pressure, the ESRF is ideally placed to study the interplay between the crystal structure and the electronic and magnetic properties of transition-metal alloys (see figure). In 2016, for example, we exploited the ID12 beamline's unique ability to access the K-edge of phosphorous via X-ray absorption (XAS) at the ferromagnetic transition of MnFe(P,Si,B). Surprisingly, this K-edge betrayed an abrupt modification, hinting that the metalloid site could be a new lever for controlling electronic structure changes. What's more, although phosphorous atoms are considered non-magnetic by nature, magnetic circular dichroism (XMCD) data showed that they actually carry a finite magnetic moment in the ferromagnetic state, in accordance with our first-principles calculations.

This is just one piece of a multifaceted puzzle. But by replacing phosphorous with neighbouring elements in the periodic table, it might be possible to boost the MCE effect in these alloys. In fact, our group and other ESRF users are trying this already, helped by complementary tools such as extended X-ray absorption fine structure spectroscopy on BM26A, X-ray diffraction on BM01A and XMCD in soft X-rays on ID32. With any luck, our ice creams will stay cold well into the future – even when energy is harder to come by.

Francois Guillou, TU Delft, the Netherlands and the ESRF

"This is one piece of a multifaceted puzzle."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Following the continued success of the class leading nEXT range of turbomolecular pumps, we're reaching even higher with the new nEXT85.
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INNOGY SE

Engineers lay the superconducting cable in the city of Essen, Germany.

A spin on superconductivity

Could high-temperature superconductivity arise from magnetism? The ESRF is helping to find out.

On 30 April 2014, German officials switched on a new power cable in the city of Essen. At about 1 km end to end, the cable was, and is, the longest superconducting cable ever laid in a power grid, designed to eliminate the energy lost in conventional cables. "What started to be a dream in the 1980s is now becoming reality," said Johannes Georg Bednorz, the German physicist who shared the 1987 Nobel Prize in Physics for the discovery of high-temperature (high-Tc) superconductivity.

The superconducting cable is "high temperature" in that it requires only the relatively modest cooling of liquid nitrogen, not liquid helium. Of course, the real dream for our energy networks is a superconductor that doesn't need cooling at all. That first means understanding how high-Tc superconductors work – but this, despite the Essen achievement, is still something of a mystery.

Perhaps, as research at the ESRF and elsewhere implies, the secret could lie in magnetism. High-Tc superconductors based on copper- oxides or "cuprates", such as the Essen cable, and upcoming iridates (see "New contender", right), are known to exhibit a strong exchange interaction – a force that keeps atomic spins aligned. In raw (undoped) cuprates, this manifests as an alternating, antiferromagnetic ordering of the copper-oxide planes. But cuprates must be doped to be made superconducting, and this complicates matters.

Developed over the past two decades by the ESRF and the Paul Scherrer Institute (PSI) in Switzerland, resonant inelastic X-ray scattering (RIXS) can probe spin waves, which characterise the exchange interaction. Early studies at the PSI and the ESRF showed that the spectrum of spin waves broadens when cuprates are doped and the long-range antiferromagnetic order gets destroyed, leading to a damping of spin waves. On the other hand, the studies also showed that doping affects rather less the energy and intensity of the spin waves, suggesting that the magnetic interaction remains strong at short range. This scenario has become clearer with our recent RIXS measurements at the ID32 beamline, which charted spin-wave damping as a function of doping, and observed the persistence of the short-range interaction. The results reinforce an idea that the pairing of electrons – the accepted basis of superconductivity – could indeed arise from damped magnetic excitations observed by RIXS.

If magnetic properties are key, does a difference in them explain the variation of superconducting transition-temperatures from one cuprate family to another? Last year, we performed a systematic RIXS study at ID32 of spin waves in undoped cuprates in which the number and distance of oxygen ions sitting above and below the magnetic copper sites varied. Although the magnetic interaction of copper atoms with their nearest neighbours changed little, the overall electronic wavefunctions became more localised when the oxygen atoms were closer to the copper-oxide planes (*Nat. Phys.* **13** 1201). Such localisation prevents electrons from hopping from one site to another over longer ranges.

This might sound like superconductivity could be improved by making cuprates with oxygen atoms farther from the planes. Unfortunately, it's not that simple: oxygen atoms work as bridges carrying the doping charges to the superconducting planes and cannot be totally removed. But in helping to understand the origin of high-Tc superconductivity, the results are heartening. RIXS could yet provide the insight that we've all been waiting for.

Giacomo Ghiringhelli, Politecnico di Milano, Italy

The RIXS spectrometer at the ID32 beamline.

New contender

Cuprates may be the best known high-Tc superconductors, but they are not the only materials with promise. Iridium oxides, or "iridates", are structurally similar to cuprates. They also share characteristics thought to be key to cuprates' superconductivity, such as a strong exchange interaction, as has been revealed in recent spin-wave studies of iridates at the ESRF's ID20 beamline and the Advanced Photon Source in Chicago, US. It remains to be seen whether iridates can be superconducting, but if not they may still shed light on their cuprate cousins.

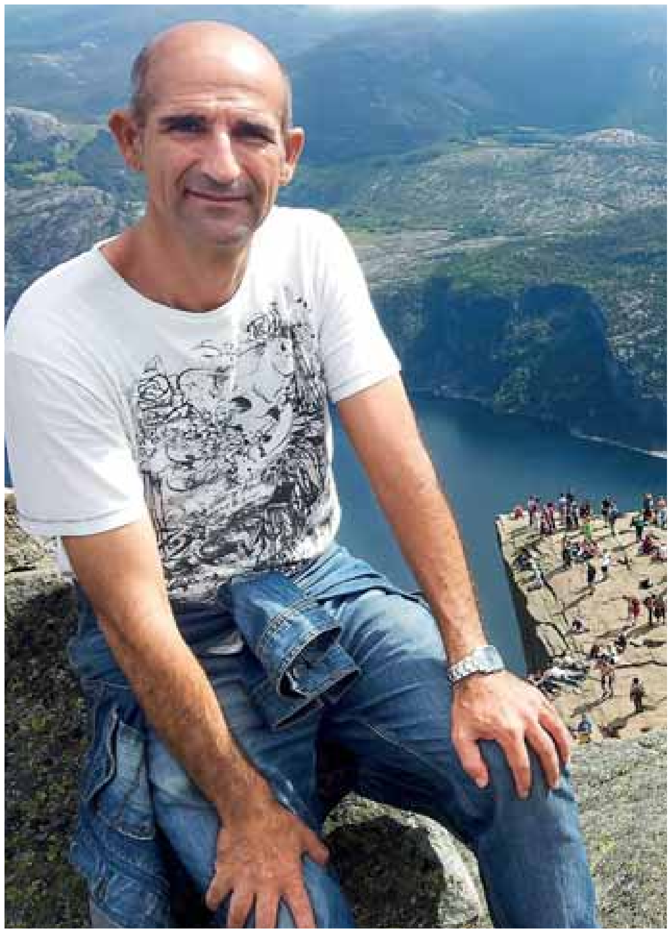
Jon Cartwright

Inspiration is key

Motivated users do better science, says **Miguel Ángel García Aranda**, the new chair of the ESRF Council.

Serendipity brought Miguel Ángel García Aranda to the ESRF. In 1988, he had just finished his chemistry degree at the University of Malaga in Spain, and saw an advert on the department noticeboard for a course on neutron and X-ray science, hosted by the ILL and the ESRF in Grenoble. That year the synchrotron had just formally come into existence, with the signing of its convention and statutes by 11 founding members; it was keen to inspire future users. "I wrote a letter, I was accepted, and I got on a 24-hour bus from Malaga to Grenoble," Aranda recalls. "Et voilà, I am doing synchrotron research."

Thirty years on, Aranda has been appointed as the new chair of the ESRF Council, a position that came into effect for him on 1 January this year and will last two years, until 31 December 2019. It marks the culmination of a career that – regarding either research or management – has always paid close attention to the needs of people and society. In particular, he has never forgotten his lucky entry into synchrotron science, and its lesson for nurturing users for the ESRF's major upgrade, the Extremely Brilliant Source (EBS). "It shows how all this outreach activity is very important," he says. "There is a lot of room here – we may need to approach broader communities."



Miguel Ángel García Aranda in brief

Born: 1966, Cártama, Malaga, Spain.

Education: BA chemistry (1988), PhD chemistry (1992), University of Malaga.

Career: PhD training, University of Oxford, UK (1989–1991); postdoc, University of Cambridge (1992–1993); assistant professor (1994–1999), associate professor (1999–2011) and professor (2011–), University of Malaga; scientific advisor for large facilities, Spanish Ministry (2004–); scientific director, ALBA (2013–); vice-chair (2014–2017), chair (2018–), ESRF Council.

"I need to see some kind of product, some output for society."

TV influence

Aranda himself was first inspired into science in early high school, when he eagerly anticipated every new episode of the renowned science television series *Cosmos*, by the US astrophysicist Carl Sagan and others. In the absence of physics degree courses on offer near Malaga, his home town, he jokes that he was forced to become a "frustrated" physicist instead, by reading chemistry. Although his PhD was on high-temperature superconductors, he soon moved on to electron-correlated materials, such as manganite and nickelate, and in 1996 he returned to Grenoble to perform his first experiment, powder diffraction, on the newly built ESRF. One experiment took three to four days; today, Aranda points out, it would probably take less than 24 hours.

It wasn't long before Aranda began to feel the limits of what he calls "curiosity-driven" research. "If I don't see a final product, for me it's not very motivating," he explains. "I need to see some kind of output for society." In the late 1990s he began to look around Andalusia for industries that might benefit from his expertise in crystallography and powder diffraction. He discovered cement, a product that, according to a 2002 report by the World Business Council for Sustainable Development, produces 5% of global emissions of carbon dioxide. Eco-cement was to become the focus of his research for the next 20 years.

The research itself, however, became a smaller and smaller part of his career as Aranda took on greater managerial roles, including in 2013 the scientific director of ALBA, the Spanish synchrotron. There he learned the need to motivate not just himself, but scientists under his direction. "Scientists are the key asset, not just at ALBA but in any research infrastructure," he says. "If our colleagues are not motivated, we cannot profit from the science. Motivation and creating the right environment is a core business." He also learned how to lobby for funding: despite tough economic times in Spain, ALBA has three new beamlines in construction and at least one more in planning, bringing its total to 12.

As a national synchrotron, ALBA helps to foster a light-source community on which an international facility like the ESRF can draw. The role of the ESRF-EBS will be forever world-leading, he says; nevertheless, there is the challenge of helping every user to best exploit its tools, especially given the potential for data-deluge. "We have to ensure that everybody is on board," he says.

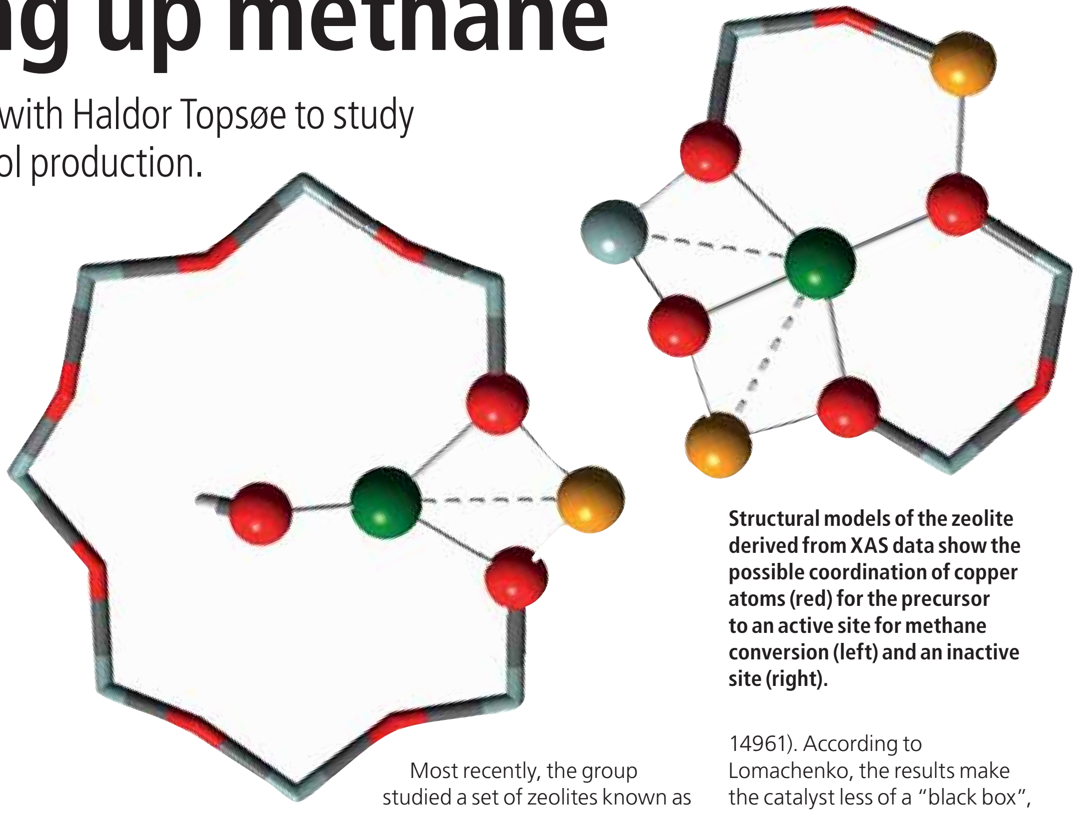
Jon Cartwright

Cleaning up methane

The ESRF is working with Haldor Topsøe to study catalysts for methanol production.

To a non-chemist, methane and methanol might appear almost identical: both contain one carbon and four hydrogen atoms, the only difference being, in methanol's case, an added oxygen. But whereas methane is a highly potent greenhouse gas, and often an unwanted industrial by-product, methanol is a valuable chemical and liquid fuel. An efficient way to convert methane directly into methanol "is at the top of agenda of the chemical industry," says Kirill Lomachenko, the scientist in charge of chemistry and catalysis at the ESRF's ID24 beamline.

Zeolites – porous, aluminosilicate minerals – are one type of catalyst that could help the reaction proceed in mild, readily obtainable conditions. Zeolites containing copper have shown particular potential, but even those containing the same components can be assembled with different pore and channel sizes, and some work better than others. In recent years, researchers from Haldor Topsøe, a Danish catalysis company, as well as various universities in Norway, Italy and Russia, have paired up with Lomachenko and the ESRF to find out why. "At the ESRF we find exceptional conditions to perform a broad range of experiments, which allow us to obtain unique information about the geometric and electronic structure of our catalysts," says Pablo Beato, lead scientist of atomic-scale analysis at Haldor Topsøe.



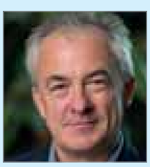
Structural models of the zeolite derived from XAS data show the possible coordination of copper atoms (red) for the precursor to an active site for methane conversion (left) and an inactive site (right).

Most recently, the group studied a set of zeolites known as Cu-SSZ-13 using X-ray absorption spectroscopy at the ESRF's BM23 and BM26A beamlines, in addition to lab techniques such as infrared spectroscopy. The study allowed them to identify the most favourable sites for methane conversion, and determine how the abundance of these sites scaled with different copper and aluminium content in the zeolite structure (*J. Am. Chem. Soc.* **139** 14961). According to Lomachenko, the results make the catalyst less of a "black box", and could help them to develop more promising candidates.

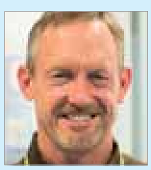
In the meantime, the researchers are looking into other zeolite catalysts, some of which show very high activity. "Dedicated experiments are already planned and will be conducted at the BM23 beamline of the ESRF in the first half of 2018," says Lomachenko.

Jon Cartwright

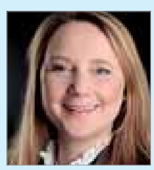
Movers and shakers



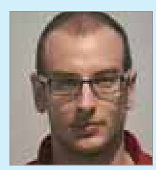
Mark Thomson of the University of Cambridge in the UK has been selected as the new executive chair of the Science and Technology Facilities Council, a UK public funding agency. Thomson has a background in experimental particle physics, and will take over from Brian Bowsher at the beginning of April when UK Research and Innovation (UKRI) – a new umbrella body for the distribution of research funds – comes into being. Thomson will also lead the development of a UKRI roadmap for innovation and infrastructure.



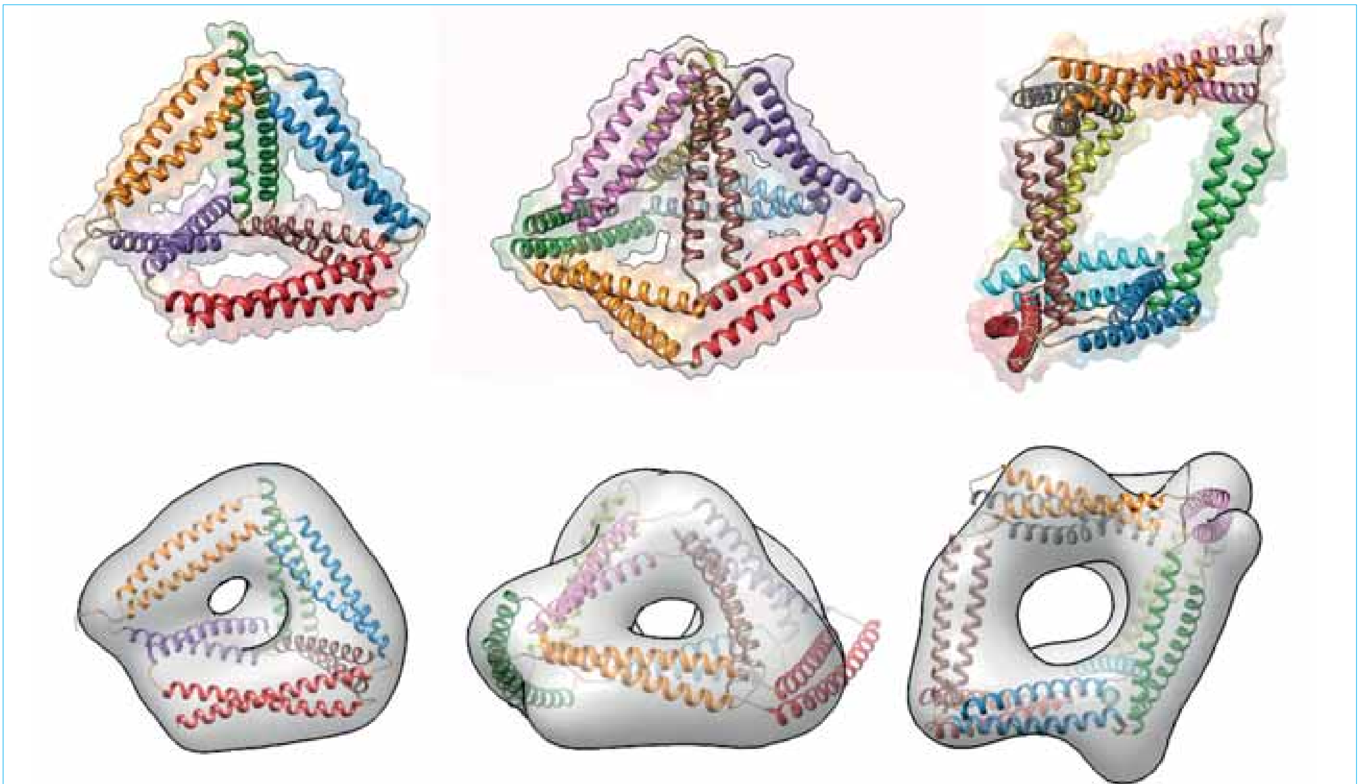
Ian McNulty is the new director of physical sciences at the MAX IV synchrotron in Lund, Sweden. Previously leader of the X-ray microscopy group at the Center for Nanoscale Materials at Argonne National Laboratory in Illinois, USA, McNulty has studied ordering in nanomagnetic materials, coherent diffractive imaging and orbital angular momentum states of light; in total, he has published 190 papers and holds two patents. He said he was "humbled" to have been chosen for the role, which will begin full-time later this year.



Nicole Elleuche has been named as the new administrative director of the European X-ray Free-Electron Laser (XFEL). A biologist by training, Elleuche is currently a member of the management board at the Heinrich Pette Institute, Leibniz Institute for Experimental Virology in Hamburg, where she has also been responsible for administration and technical services for nearly five years. Her new responsibilities at the European XFEL include human resources, procurement, finance and legal affairs.



Marco Moretti has left the ESRF to become an assistant professor at the Politecnico di Milano in Italy. At the ESRF he was beamline responsible for ID20, and used resonant inelastic X-ray scattering to study the electronic and magnetic excitations in iridates, with worldwide collaborators. His new role will see him in the group of Giacomo Ghiringhelli (see p6), although he hopes to return to the ESRF regularly. "I will be back as often as possible, because the ESRF is a very special place for me," he says.



R JERALA

Neat folds: Protein "origami" is an emerging technique that involves programming protein strands to fold themselves into a variety of shapes, for applications ranging from drug delivery to smart biomaterials. Similar to DNA origami, but potentially far more adaptable, protein origami was invented by Roman Jerala at the National Institute of Chemistry in Ljubljana, Slovenia, and co-workers back in 2013, but the structures had to be folded *in vitro*. Now, the same group has not only made more complex folds – including a pyramid and a triangular prism – but has also, by increasing the charge on building modules, made them self-assemble inside living organisms. The structure blueprints (top row) match very well with the structures determined by electron microscopy (bottom row) and small-angle scattering at the ESRF's BM29 beamline (*Nat. Biotechnol.* **35** 1094).

In the corridors

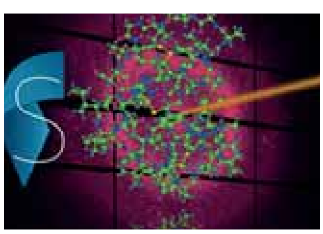
Clever bunch

To deliver bright, coherent X-rays, facilities such as the ESRF need tightly bunched electrons, but this fights natural electron repulsion. Now, Dao Xiang and others from Shanghai Jiao Tong University in China have shown that a single electron bunch can be made tighter, by bookending it with repulsive bunches sent before and after – potentially improving the spatial and temporal resolution of experiments (*Phys. Rev. Lett.* **120** 044801). Although the trick is best suited to the "single pass" of bunches in free-electron lasers, says Xiang, it "should stimulate more advanced ideas in controlling X-ray pulse width in synchrotrons".

Remote introduction

A nine week, massive open online course (MOOC) on synchrotrons and X-ray free-electron lasers (XFELs) will begin on 5 March. Provided by the École Polytechnique Fédérale de Lausanne, the course will cover introductory themes such as the production of synchrotron and XFEL radiation, the interaction of X-rays with matter, X-ray optics, beamlines and instrumentation. Each week's instalment will consist of two to three, 20-minute videos, plus optional problems. Enrolment is free, and a certificate can be purchased on completion of the course, if the pass grade is met.

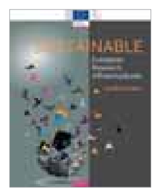
• See www.edx.org/course.



Pulsing to the stars

Like sailors turning to the heavens, spacecraft can turn to X-ray pulsars for navigation. That's according to NASA engineers, who have demonstrated autonomous X-ray navigation in space on an experiment called Station Explorer for X-ray Timing and Navigation Technology (SEXTANT). The system works because the timing of pulsar X-rays is very regular – almost as regular, in fact, as the atomic clocks employed in GPS. A spacecraft with the technology could navigate itself to the farthest reaches of the Solar System and beyond, says NASA. "It's a breakthrough for future deep-space exploration," said Jason Mitchell, SEXTANT Project Manager.

Sustainable science



The European Commission has published a document that aims to start a high-level debate among member states and other stakeholders about the future of large research infrastructures. Based on a previous consultation process, *Sustainable European Research Infrastructures: A Call for Action* discusses the problems of building and maintaining cutting-edge facilities given the limitations of national and European science budgets. According to the document, the debate needs "to discuss the related complex and multi-level sustainability challenges, to explore ways of combining funds of different sources more efficiently and ultimately [to define] Europe's goals for the next-generation Research Infrastructures".