discovered

THE HZDR RESEARCH MAGAZINE

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1 | 2021

XXL

RESEARCHING IN EXTREME LABS

Extreme states underground
Ultrastrong lasers, highest magnetic fields and exorbitant pressures facilitate completely novel experiments

When materials research meets cancer medicine
How electronic nanosensors trace the seat of diseases

Same method! Same result?
Global comparative test produces surprising finding

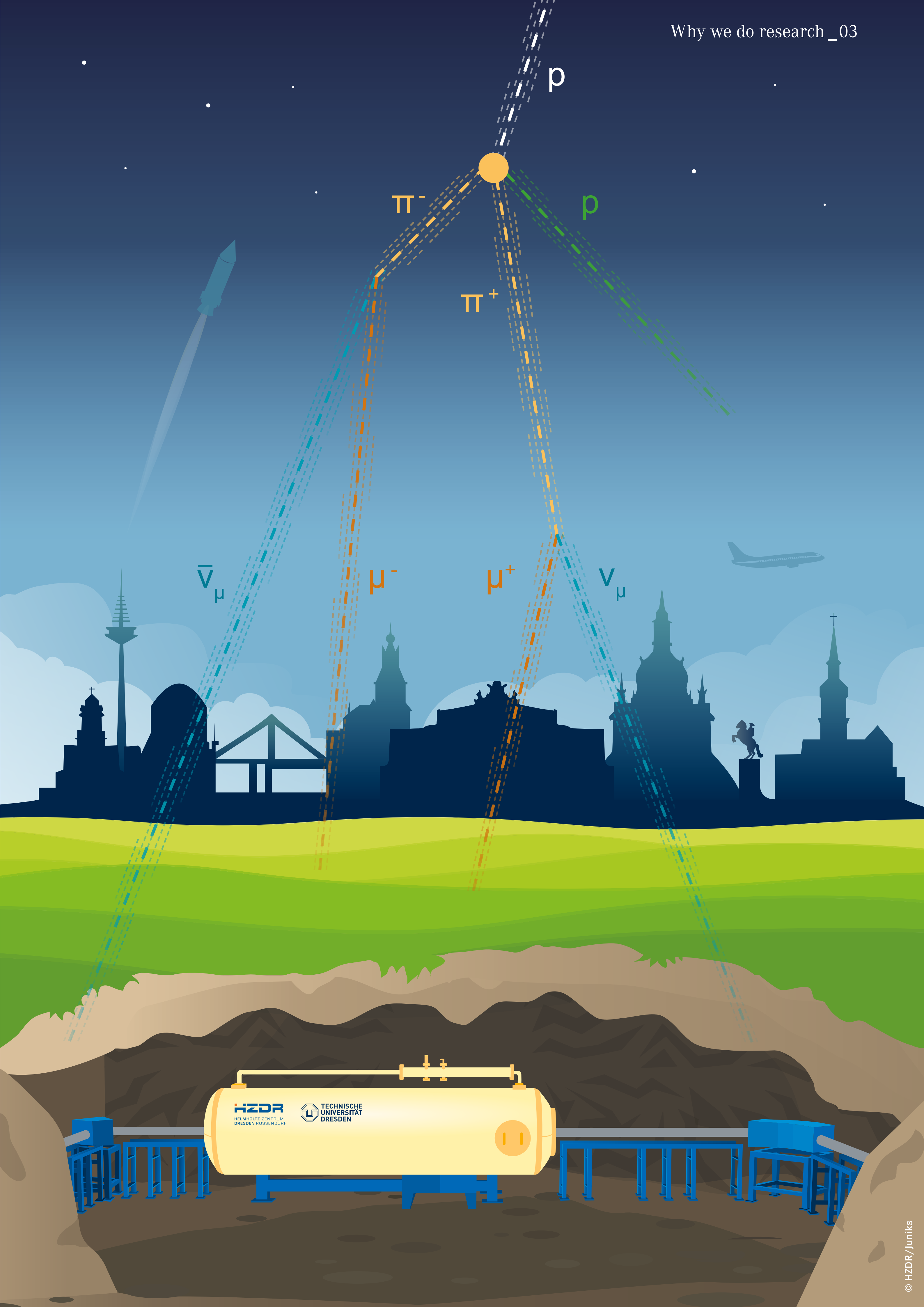
HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Big infrastructures for the tiniest particles

Into the white desert of the Antarctic, into the endless expanse of space, deep into the Earth's core: in order to focus on research, humanity has ventured to many remote places that seem inhospitable and impenetrable – always with the aim of generating new knowledge und insights. But the effort and expense involved in building and operating such stations and facilities is usually beyond the financial and personnel means of individual countries and institutions. Modern scientific research is thus largely a joint activity involving numerous countries and minds. To construct similar large-scale research facilities in every country would be economically and scientifically unfeasible.

As a member of the Helmholtz Association, HZDR offers a unique infrastructure that is open to researchers from all over the world – some of it in remote places like the Dresden "Felsenkeller" (rock cellar). Admittedly, researchers are not required to undertake a dangerous journey to get to the particle accelerator that the Rossendorf research center and TU Dresden have built there. Nonetheless, they should be immune to claustrophobia because above the lab are roughly 45 meters of massive rock – and for a good reason: the rock overburden protects the sensitive experiments in the tunnel from the particles of cosmic radiation that rain down on the Earth every single day.

This enables the physicists to investigate nuclear fusion reactions and decode in detail how our sun and other stars – like huge power stations – fuse atomic nuclei in their interiors and generate heavy elements. Experiments of this kind can only be conducted at two other places around the globe. The entire nuclear astrophysics community thus benefits from the accelerator lab in the rock cellar. Because, of course, just as at HZDR's other large-scale facilities, scientists can apply to do experiments below ground at any time – thus transporting new knowledge into the whole world.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Dear readers,

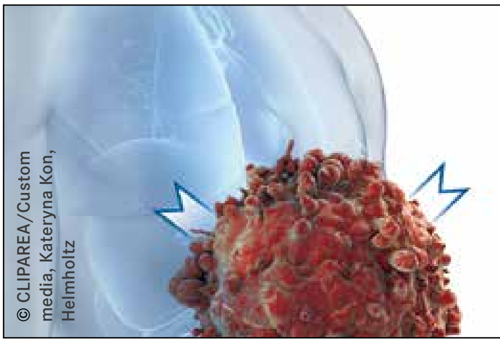
For more than a year now, a putative tiny virus has forced us to accept restrictions many of us would hardly have thought possible in a globalized world. In the first days of the pandemic, research, which thrives on scientific exchange, also experienced a moment of shock when it appeared to stop dead in the face of the global challenge, only to bounce back even stronger afterwards. In record time, scientists sequenced the virus's genome, discovered its spread pathways and, above all, developed vaccines that rob it of its horror.

Large-scale research facilities, where scientists from different countries and disciplines pool their expertise, have played an important role in these developments. With our High Magnetic Field Laboratory, the Ion Beam Center and the Center for High-Power Radiation Sources ELBE, HZDR operates three such facilities which attract researchers to Dresden from all over the world. At other facilities and in other countries our experts' knowledge is also in demand – for example for the construction of the Helmholtz International Beamline for Extreme Fields at the world's strongest X-ray laser XFEL or for the Rossendorf Beamline that we have been operating at the European Synchrotron Radiation Facility in Grenoble for many years.

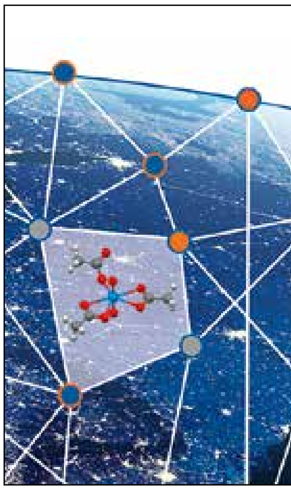
In this edition, we would like to give you a few examples, which research, thus, becomes possible. I look forward to your comments and suggestions and wish you a most enjoyable read.

Simon Schmitt
Department of Communications
and Media Relations at HZDR

Content



Portrait



Research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Cover picture: Experiments in high magnetic fields offer unique opportunities for acquiring fundamental knowledge about the matter around us. Magnetic fields enable scientists to influence material properties in a targeted and, above all, controlled fashion. This is why high magnetic fields are utilized in investigating many newly discovered materials: to understand their properties better and, ultimately, to optimize them. The capacitor bank in HZDR's High Magnetic Field Laboratory stores the energy required for generating the pulsed magnetic fields. Source: HZDR/A. Wirsig

Title

XXL Researching in extreme labs

Panorama

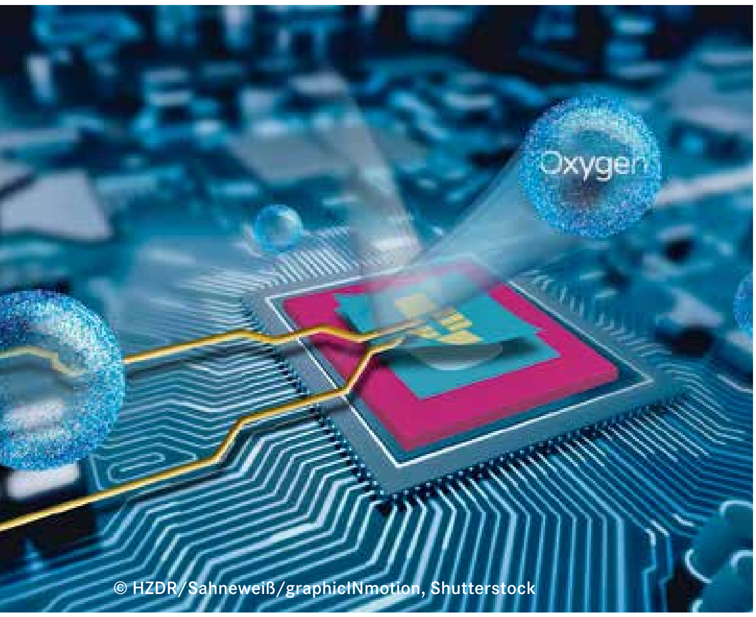
Highlights from our research

NANOELECTRONICS

Airtight packaging for semiconductors

A new technique for protecting electronic components made of sensitive materials from contact with the air or chemicals has been developed by researchers at the Institute of Ion Beam Physics and Materials Research. It involves embedding two-dimensional indium and gallium selenide semiconductors in hexagonal boron nitride. Although they exhibit excellent properties for manufacturing extremely small electronics, these semiconductors have hardly been used so far. The standard processes corrode the vulnerable substances during production, seriously reducing their performance capacity. As the Dresden physicists' experiments have shown, this problem is solved by completely encapsulating them in two layers of boron nitride. To this end, the researchers first of all etched the required electrode pattern in the upper platelet and filled in the holes with palladium and gold. They then laminated this film onto the wafer-thin semiconductor to make electrical contact.

Publication: H. Arora et al., in ACS Applied Materials & Interfaces, 2019 (DOI: 10.1021/acsami.9b13442)

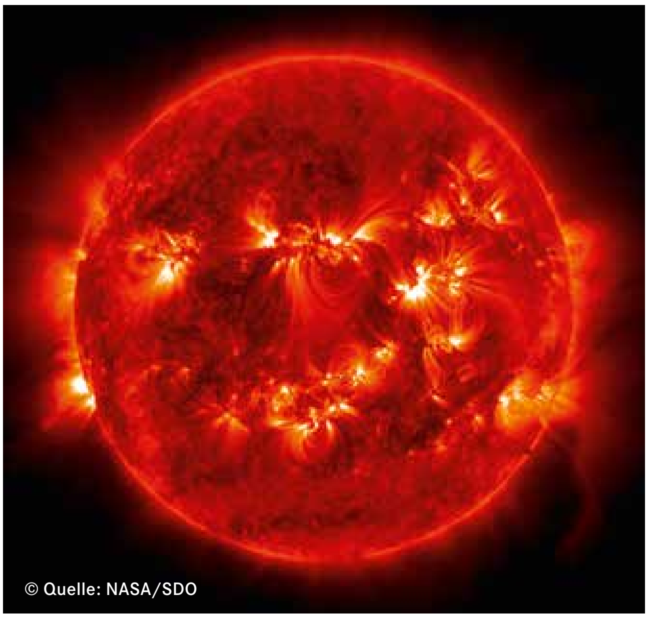


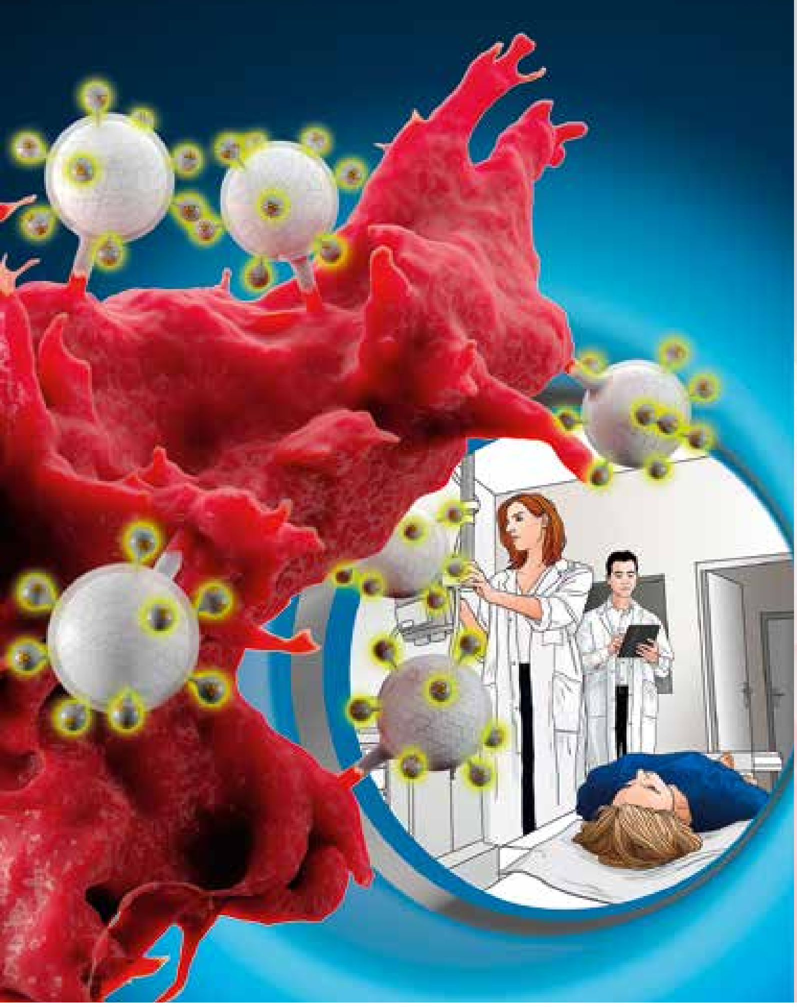
ASTROPHYSICS

Stable or unstable?

In the sun's rotating plasma a previously unnoticed magnetic instability is at work. Together with researchers at the University of Leeds and the Leibniz Institute for Astrophysics Potsdam, researchers in HZDR's Institute of Fluid Dynamics discovered this special case of so-called magnetorotational instability. The mechanism destabilizes rotating, electrically conductive fluids and gases in a magnetic field. This is the only explanation for the formation of stars and planets from large, rotating disks of dust and gas. Unlike in these disks, however, the inner layers near the solar equator rotate more slowly than the outer ones, which was previously considered to form an extremely stable flow profile. Now, the international team has demonstrated that when the magnetic field is helical, the magnetic instability sets in as soon as the velocity between the rotating plasma layers increases only slightly – exactly the condition that predominates in the regions of the sun near its equator.

Publication: G. Mamatsashvili et al., in Physical Review Fluids, 2019 (DOI: 10.1103/PhysRevFluids.4.103905)





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RADIOPHARMACY

Trained to hunt tumors

An interdisciplinary team from HZDR's Institute of Radiopharmaceutical Cancer Research and FU Berlin has developed biocompatible nanoparticles that make excellent carrier molecules for tracking down certain cancer cells. For this purpose, the researchers equipped tiny particles of dendritic polyglycerols with an antibody fragment that specifically binds to the antigen EGFR (epidermal growth factor receptor). Various types of cancer produce this protein in excess which means that high concentrations can be found on the surface of diseased cells. During their experiments, the scientists managed to demonstrate that their modified nanoparticles particularly accumulate on the tumor. By additionally combining them with the radionuclide copper-64 and a dye molecule, the cancer cells became visible both using positron emission tomography (PET) and near infrared fluorescence imaging. After a short period, the body eliminates the nanoparticles via the kidneys.

Publication: K. Pant et al., in Small, 2019 (DOI: 10.1002/smll.201905013)

MATERIALS RESEARCH

Headstrong magnetic moments

When examining special uranium crystals in high magnetic fields, researchers at the Helmholtz-Zentrum Berlin and HZDR's High Magnetic Field Laboratory observed an unusual physical phenomenon. Normally, the tiny magnetic moments in a solid align themselves to an external magnetic field. If it is strong enough, all materials usually become ferromagnetic. But the uranium compound U_2Pd_2In exhibited much more complex behaviour. Above 25.8 tesla, the magnetic moments no longer align themselves to the magnetic field but form a kind of crystal superstructure that replicates itself in a certain rhythm. The physicists believe one of the reasons for this are the different, strong interactions that work against each other in the crystal lattice. Their relative strengths shift in parallel with the magnetic field. These results offer insights into the interactions between the so-called 5f electrons, the outermost electrons that carry the magnetic moments.

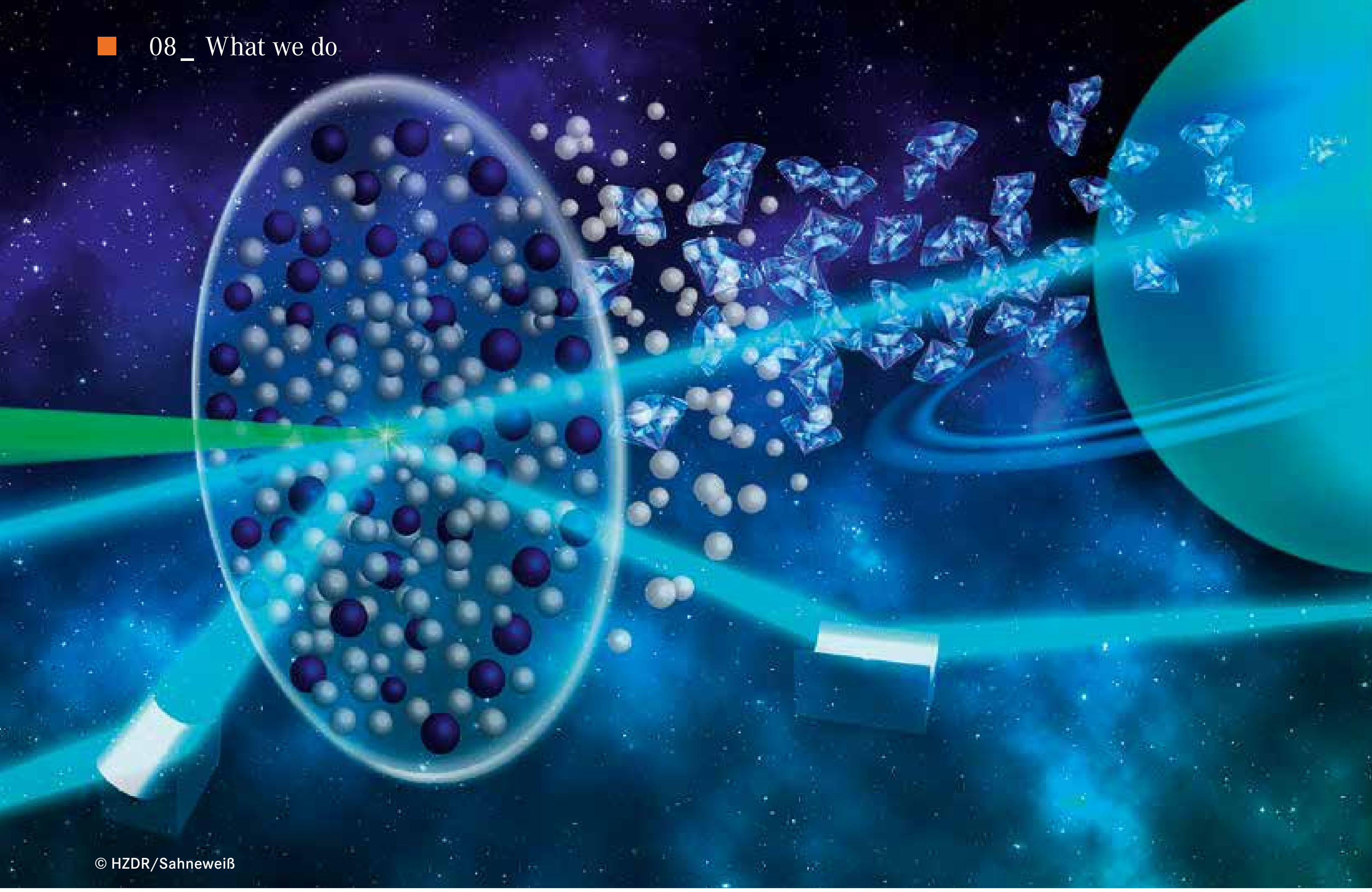
Publication: K. Prokeš et al., in Physical Review Research, 2020 (DOI: 10.1103/PhysRevResearch.2.013137

RAW MATERIALS RESEARCH

Valuable wastewater

Even small quantities of the important metal gallium can be recycled from industrial wastewater occurring during wafer production – as demonstrated by researchers at the Helmholtz Institute Freiberg for Resource Technology and the Institute of Resource Ecology. Until now, the standard separation methods failed in the face of the high concentrations of other substances in comparison with gallium. HZDR chemists therefore initially mixed the wastewater with so-called siderophores – a special group of substances that strongly bind iron. With the help of desferrioxamine B and E they were able to form stable gallium complexes and thus separate them from unwanted contaminants in the water, such as arsenic and calcium. To finally divide the gallium from the compounds, the researchers used chemical complexing agents. This allowed them to reclaim more than 90 percent both of the valuable raw material and the siderophores. Gallium is an important resource because industry needs the metal for many high-tech products.

Publication: R. Jain et al., in Water Research, 2019 (DOI: 10.1016/j.watres.2019.04.005)



PLASMA PHYSICS

Diamonds are a physicist's best friend

Thanks to a new measuring method a team headed by HZDR has reinforced the supposition that it rains diamonds in Neptune and Uranus, the ice giants in our solar system. Due to the extremely high pressure in their interiors, hydrocarbon separates into its two components. In turn, the released carbon atoms combine to form diamond structures that then sink into the planets because they are heavier than the material surrounding them. The researchers managed to use the new method to refine the experimental proof they had delivered some years previously. They showed that there is no fluid transitional form during separation: the carbon turns almost completely into diamonds. To conduct their experiments the scientists used a high-energy laser, which heats up the samples to high temperatures and causes shock waves inside them, and an X-ray laser. As a result of the scattering of the X-ray light they were able to draw inferences about the structure of the material.

Publication: S. Frydrych et al., in Nature Communications, 2020 (DOI: 10.1038/s41467-020-16426-y)

CANCER RESEARCH

Resistance is (hopefully) futile

Particularly radiation-resistant tumors in the head and neck area could be combatted by a combination of radiation therapy and immune therapy based on the technology known as UniCAR. These are the findings of laboratory experiments and an animal model carried out by scientists from HZDR's Institute of Radiopharmaceutical Cancer Research and colleagues at the National Center for Tumor Diseases Dresden (NCT/UCC). For this purpose, they developed a new molecular connection that specifically couples with the surface marker CD98. This structure is particularly prevalent on the cells of squamous cell carcinoma – the type of cancer associated with most of the malignant tumors in the head and neck area. Via a similar coupling with the white blood cells in the immune system, the so-called T cells, the connection channels these natural bodily defence mechanisms to the diseased cells and kills them. This may prove to be a way of destroying cancer cells that are extremely resistant to radiation therapy and often lead to renewed tumor growth.

Publication: C. Arndt et al., in OncoImmunology, 2020 (DOI: 10.1080/2162402X.2020.1743036)

MATERIALS RESEARCH

Sodium instead of lithium

Between the double layers of wafer-thin carbon graphene far more sodium atoms can accumulate than in the chemically comparable graphite. This is the conclusion drawn by a German-Russian group of researchers from HZDR's Institute of Ion Beam Physics and Materials Research, having re-enacted the processes using sophisticated computer simulations. They were able to demonstrate that sodium does not only accumulate in one layer but in several layers one above the other between the graphene wafers. These theoretical results could pave the way for batteries based on alkali metal. Previous prototypes have failed, in particular, because sodium is very unwilling to inhabit the graphite anodes. The combination with graphene could solve this problem and lead to significantly more inexpensive batteries – because unlike lithium that has mainly been used so far, sodium occurs much more frequently on Earth.

Publication: I. Chepkasov et al., in Nano Energy, 2020 (DOI: 10.1016/j.nanoen.2020.104927)

ASTROPHYSICS

Cosmic crash barriers

Strong magnetic fields could force the shock wave that occurs during a supernova – that is, the last major flash of a star at the end of its existence – in a certain direction. This has been demonstrated by researchers from the Institute of Radiation Physics together with an international team led by the French École Polytechnique Paris. To this end, they imitated the stellar event at the Intense Laser Lab (LULI) with the aid of a pulsed high-performance laser and a Helmholtz coil, developed in collaboration with researchers at HZDR's High Magnetic Field Laboratory Dresden. Against predictions, the energy and thus the remnants of exploded stars do not spread out spherically symmetric under the influence of the magnetic field like normal detonations but along a vertical axis. Building on this, the team now wants to use data on various supernova remnants to determine the strength and direction of magnetic fields in the entire universe.

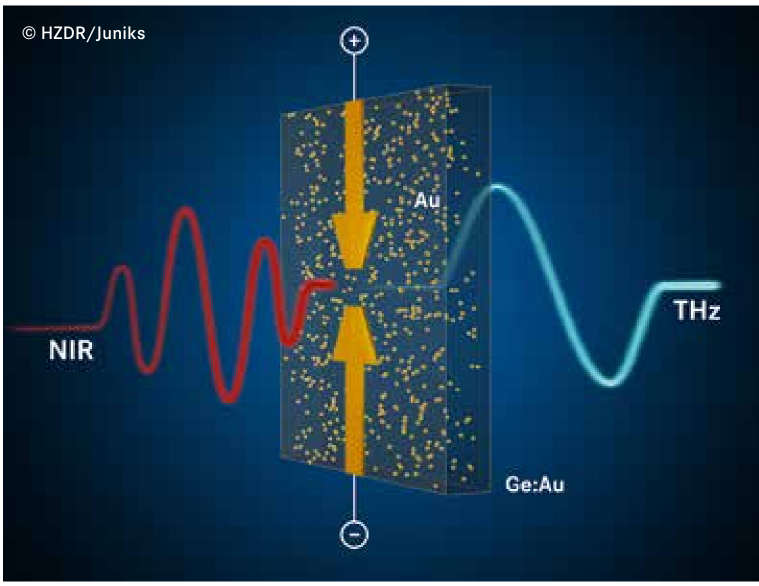
Publication: P. Mabey et al., in Astrophysical Journal, 2020 (DOI: 10.3847/1538-4357/ab92a4)

NANOELECTRONICS

Precious transmitters

Germanium spiked with gold could form the basis for developing transmitters for broadband terahertz waves. As a team of researchers at HZDR's Institute of Ion Beam Physics and Materials Research has shown, the refined metalloid could extend the bandwidth from 7 to 70 terahertz in comparison with the established technology based on gallium arsenide crystals. The physicists managed to solve the crucial problem that had so far hampered the use of the semiconductor germanium by incorporating the gold atoms. When a short laser pulse is shot at pure germanium – the point of departure for terahertz waves – the electric charge remains in the material for several microseconds. However, today's lasers can shoot their pulses at a rate of nanoseconds. The gold acts, in turn, as a trap which catches and neutralizes the charge. The researchers were thus able to reduce the time the electric carriers spend in the germanium to almost two nanoseconds.

Publication: A. Singh et al., in Light: Science & Applications, 2020 (DOI: 10.1038/s41377-020-0265-4)



Sharper X-ray vision for radiating elements

In the tunnel, the magnets are lined up one behind the other, more than a thousand of them, all counted. Since spring 2020, they have been deflecting fast electrons very precisely, thus generating the strongest X-ray beams at a synchrotron light source anywhere in the world. The magnets are brand new and form the core element of the huge upgrade of the European Synchrotron Radiation Facility (ESRF) within the Extremely Brilliant Source Project (EBS). This also benefits the beamline known as ROBL, that HZDR has been operating in Grenoble for more than 20 years. Labelled now ROBL-II, it opens up new possibilities to scientists.

_ **Text** . Frank Grotelüschen

How do actinides and other radioactive elements behave in potential repositories? How do they interact with the host rock and the technical barriers? Do they perhaps couple with microorganisms and thus get into the biosphere? Andreas Scheinost and his team have been addressing these kinds of questions on the Rossendorf beamline ROBL for many years.

So far, the group has acquired many valuable insights, for instance into the chemical behavior of selenium, technetium and plutonium – important fundamental data for future radioactive waste repositories. The ESRF upgrade – and, in parallel, that of the ROBL station – now allows researchers to experiment much more precisely. "We have fundamentally ramped up our experimental stations at ROBL-II," Scheinost explains. "Now, we can conduct completely new experiments and do the old ones faster and with detection limits one to two orders of magnitude better."

ESRF is a synchrotron generating ultrastrong X-ray radiation. The principle is that magnets in a storage ring with a circumference of nearly 850 meters maintain an electron beam on a circuit at nearly the speed of light whereby strong radio waves ensure the particles remain in motion. At all the points at which the magnetic fields deflect the electrons they emit high-intensity X-ray radiation – a valuable tool for many scientific disciplines which can study their very different samples in minute detail.

The storage ring started operating in the 1990s. In 1997, what was then known as the Research Center Rossendorf grasped the opportunity to install its own measurement station – the Rossendorf Beamline or ROBL, for short. "Back then, after the German reunification, the most important thing was to analyze the environmental damage caused by Wismut uranium mining in the GDR," ROBL head Scheinost recalls. "But today, we are mostly concerned with radioactive repository and fundamental research."

Using the high-intensity X-ray beam even the tiniest traces of radioactive elements like plutonium and americium in samples can be individually traced. Moreover, experts can deduce which chemical compounds these materials have formed – a core question. If, for example, plutonium is found in a soluble compound, it could be washed out of the repository at some stage and find its way into the groundwater. If the compound is insoluble on the other hand, the chances are considerably greater that it will remain in the repository for the required period of up to one million years.

Globally unique

However, experiments involving plutonium & Co. are a particular challenge: "Dealing with radioactive samples requires special safety precautions," Scheinost explains. "There are only two other beamlines that have equivalent safety precautions and not with the same spectrum of methods – which is what makes ROBL globally unique."

Scheinost sets off for the start of the beamline that consists of several hutches one behind the other. All in all, the beamline is approximately 100 meters long. He enters the first hutch through a massive metal door and points to the walls. "They contain significant amounts of lead to shield us from the intensive X-ray radiation." When the system is in operation, no-one is allowed in. If someone does open the door anyway, the emergency shutdown kicks in, and the entire storage ring comes to a halt.

Then Scheinost points to a small window at the end of the wall. "This is where the X-ray beam exits the accelerator." It passes through several evacuated metal boxes that form and bundle it and select a certain wavelength from its spectrum. Then the tailored beam passes into the first of two experimental hutches with a special protective container, a glove box. "You have to completely avoid contact with the radioactive samples. Inhaling them could be lethal," Andreas Scheinost explains. "That is why they have to be extremely well packaged, and we can only work with them in the glove box." On top of this, the specialists have to wear protective clothing. A radiation monitor checks for potential contamination.

Inside the glove box, a little robot positions the samples so that the X-ray beam from the accelerator can strike them. A detector registers the fluorescence radiation provoked by the interaction of the synchrotron beam and the sample, which allows the specialists to draw conclusions about the chemical behavior of the radioactive matter. This method has already enabled HZDR researchers to gain interesting

Impressive: ESRF's circular building in the Science and Technology Park at Grenoble, France. Source: ESRF insights: "We have been able to show that radionuclides like selenium and technetium, which were previously considered to be extremely mobile, change so much under repository conditions that they are not nearly as mobile as we thought." Which is reassuring because up to now, the experts had feared that radioactive selenium could seep out of the repository after about 10,000 years. Given the ROBL findings, that is very unlikely.

Added X-ray power thanks to a finer beam

After the upgrade, Andreas Scheinost and his team can study their samples in even greater detail. Among other things, yet lower concentrations of the radionuclides can be traced. The reason is that the ESRF storage ring now delivers X-ray radiation that is much better bundled and thus more concentrated than it was before. "Up to now, the beam could be bundled on a spot about 300 by 300 micrometers," Scheinost explains. "Now it’s 30 by 30 micrometers."

To achieve this, those responsible at ESRF had to go to some trouble. "Extremely Brilliant Source" is the name of the 150 million euro upgrade program under which the old storage ring has effectively been completely replaced by a new one. The upgrade took more than a year and in order to demonstrate the result, ESRF specialist Benoit Joly turns down a twisty concrete corridor. "We call it a chicane," he explains. "The walls are made of meter-thick concrete so that no unwanted radiation can escape to the outside."

A few more steps and he is standing in the accelerator tunnel, pointing to its core components: the electrons, moving at almost the speed of light, circulate in a flat, evacuated vacuum tube completely surrounded by massive magnets painted in different colors. The red ones keep the particles on track, the blue ones act as magnetic lenses and ensure that the packages in which the electrons are bundled are always kept as small as possible.

All these magnets are new: before the upgrade some of them were electromagnets, now they have been replaced by permanent magnets made of samarium-cobalt – which reduces their energy consumption by 20 percent. "The new magnets are smaller, but we have more of them," says Joly. "Altogether, we have assembled more than a thousand, roughly twice as many as before." The advantage of the new design is that the magnets are considerably closer to the electron beam and can therefore focus the packages much more precisely. Now these little electron packages can emit much finer and thus more concentrated X-ray beams – an inestimable advantage for many experiments at ESRF’s 44 beamlines.

However, the experts did have to face some technical challenges: "It wasn’t easy to manufacture the permanent magnets," Benoit Joly recalls. "They are composed of five modules each and every module had to have a different field strength." This required high-precision production technology – once complete, the magnetic field strength could not be altered. All in all, the experts had to install more than 10,000 individual components in the narrow tunnel, many of them had to be positioned to precisely 50 micrometers.

"Including the planning and preparation, we can look back on five years of concentrated work," Joly explains. "Of course, we were on tenterhooks whether the machine would work as it was supposed to." Now, the electrons travel reliably through the ring again. Since September 2020, the first experiments using the highly-concentrated X-ray radiation have been possible.

Plutonium surprise

This was something Andreas Scheinost and his ROBL team had also factored into their planning. In order to exploit the new potential to the full, the research group totally rebuilt their second measurement hutch. Now there are three different experimental set-ups, each with its own different scientific focus. Scheinost's colleague Kristina Kvashnina points to a spectrometer with which the samples can be investigated in greater detail under the influence of the intensive X-ray beam: five special crystals are precisely maneuvered by 40 engines. This is the only way they can collect the fluorescence radiation emitted by the sample and direct it to one of the highly sensitive detectors.

But the researchers need different silicon or germanium crystals to cover the whole energy range required. "Altogether, we have some 225 of them. They are bent in a special process and cost up to 10,000 euro each," Kvashnina explains. "Using this spectrometer, we can increase the resolution of our spectra and thereby find chemical forms of radioactive elements that we had missed so far."

Everything under control: Andreas Scheinost investigates the structure of surfaces using the 6-circle goniometer. Source: HZDR/D. Morel

She has achieved remarkable results with this method. "We ascertained that, under certain conditions, where we had expected plutonium to be soluble, it actually forms a solid mineral," the scientist reports. "That was something the community hadn't expected. Even after decades of research, these elements often behave in very surprising ways." Insights like this create the basis for the models that can predict the long-term behavior of radionuclides in nuclear waste repositories.

One of the things Kristina Kvashnina is currently investigating is the behavior of nanoparticles that contain radioactive elements. What makes this exciting is that, depending on size, the chemical behavior can change considerably. "Not so much is known about the mechanisms behind this," she says. "We want to discover new details."

Ceramics instead of glass

Another item being newly set up at the ROBL measurement station is a so-called diffractometer. "With the help of synchrotron radiation, you can use it to discover details about how a crystal is structured," says HZDR researcher Christoph Hennig. "We can elucidate the precise structure of radioactive compounds. And that is very helpful if you want to estimate how these compounds will behave in a repository in the long run." In the future, using the much finer beam from the ESRF storage ring, experts will be able to study far smaller crystals than ever before – which is important because some materials cannot be made into big crystals when preparing samples. But Hennig and his group also want to put proteins under the precision X-ray magnifier. What happens, for example, when radionuclides penetrate an organism – do they enter the cells and oust the iron in the hemoglobin? "There's still a lot we don't know," Hennig emphasizes. "It's also interesting to discover to what extent bacteria that live deep in the ground can ingest these materials."

Finally, the HZDR team also conducts research into new materials for repositories. In Germany, for example, radioactive waste from reprocessing plants has traditionally been stored inside glass. As part of a new project, the ROBL team is investigating whether the radionuclides could also be encased in special ceramics which have a considerably longer life expectancy than glass. "We can even assume that the entire waste will have decayed completely before these ceramics break up," Christoph Hennig explains. "And with our methods we can provide information on how to manufacture these ceramics so that they survive in a repository for as long as possible."

Publications:

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The path to ROBL

There are two ways of getting beamtime at the Rossendorf Beamline: Most of it – known as HZDR beamtime – is managed by the ROBL team directly. At least eight weeks before the planned experiments you must submit a formal application which is then assessed by a Review Committee on its scientific relevance. The rest of the time is allocated by an ESRF advisory board – also based on the scientific merit of the proposal submitted. In both cases, ROBL researchers recommend to contact them in advance to check whether the desired measurements are technically viable.

http://esrf.eu/UsersAndScience/UserGuide/Applying

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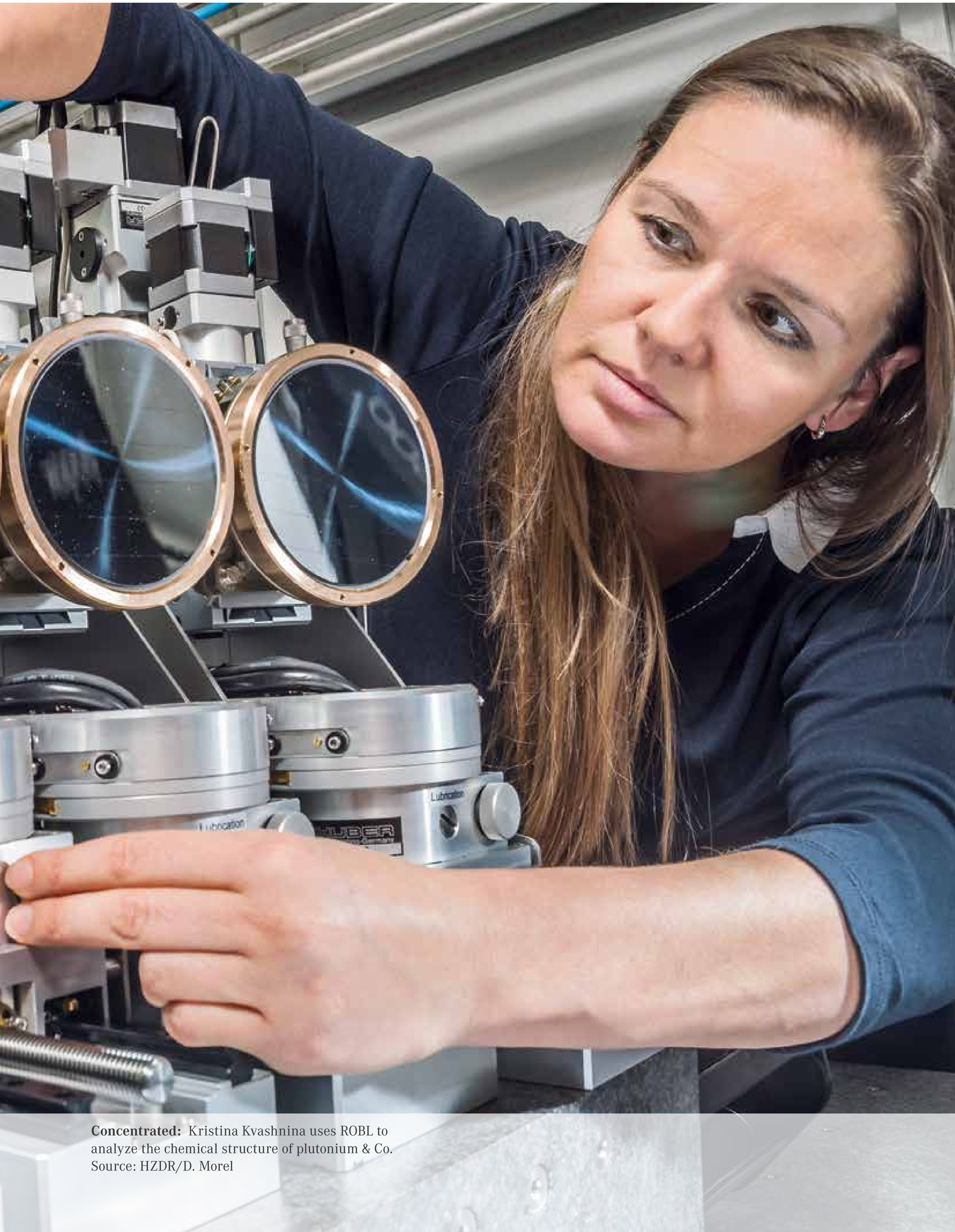


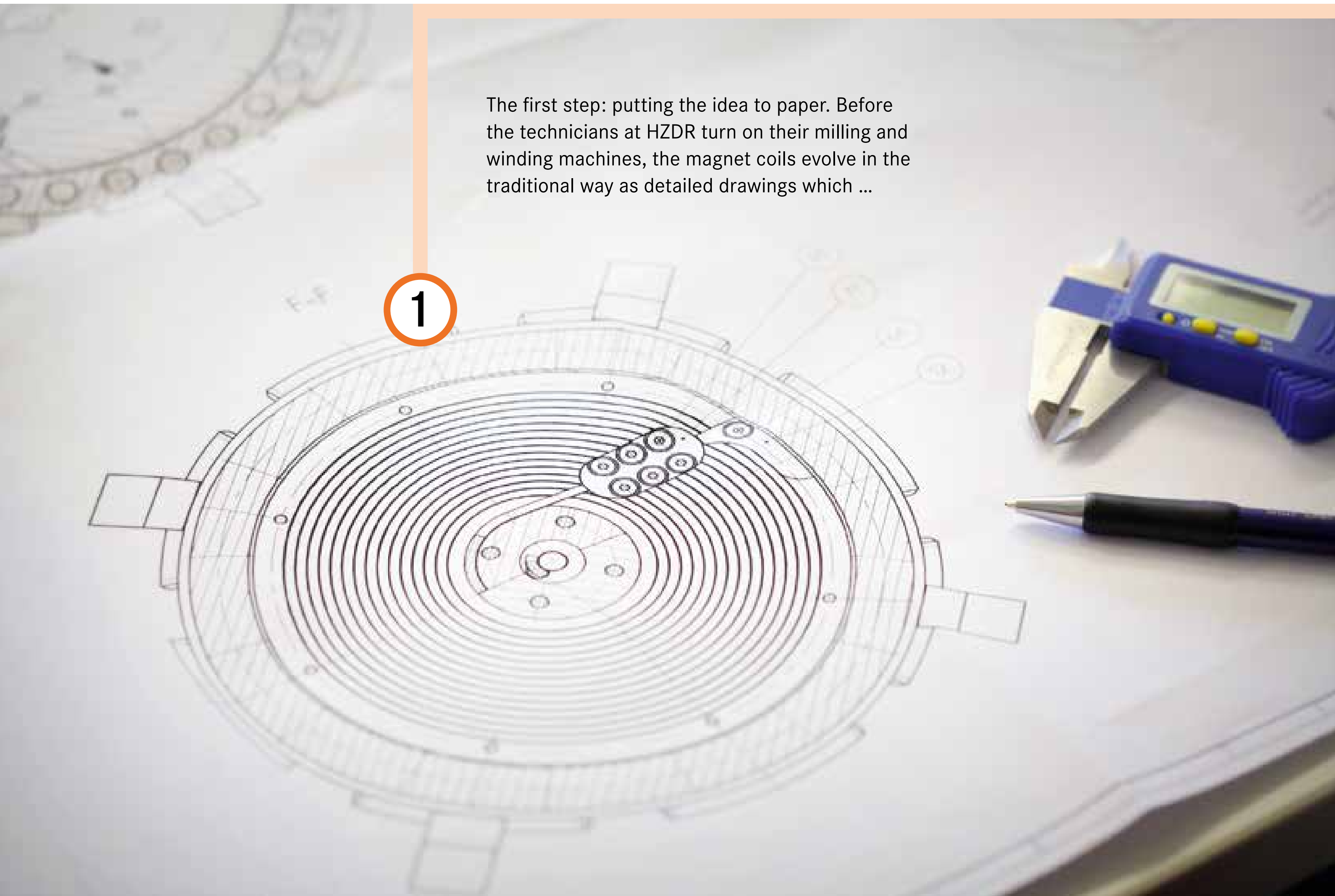
Concentrated: Kristina Kvashnina uses ROBL to analyze the chemical structure of plutonium & Co.
Source: HZDR/D. Morel

Thimble-sized research lab

At the Dresden High Magnetic Field Laboratory (HLD), physicists drive strong electric pulses through selected material samples in order to enable the development of novel nanomaterials and modern superconductors. During the experiments, the most powerful capacitor bank for pulsed magnets in the world releases energies for a fraction of a second that a diesel locomotive needs to accelerate from zero to 150 kilometers per hour. To withstand the incredible loads, engineers and scientists at HZDR have jointly developed magnets that survive the magnetic-field pulse protecting the samples inside. *discovered* shows how these sophisticated "research labs" are created.

_ **Text** . Simon Schmitt

_ **Images** . Amac Garbe



The first step: putting the idea to paper. Before the technicians at HZDR turn on their milling and winding machines, the magnet coils evolve in the traditional way as detailed drawings which ...

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... development engineer Stefan Findeisen (left) and experimental physicist Sergei Zherlitsyn elaborate on the computer. The experienced team not only designs and manufactures coils for the Dresden High Magnetic Field Laboratory but also, for example, for the Helmholtz International Beamline for Extreme Fields (HIBEF), which HZDR is constructing at the European XFEL in Schenefeld, near Hamburg.

In the workshop of the HLD, Franz Sedlak at the braiding machine spins a reinforcement around the wire out of which the technicians wind the coil. Through the machine – custom-made for the HZDR – he braids a mixture of a glass fiber and the synthetic Zylon fiber around a copper-alloy wire.

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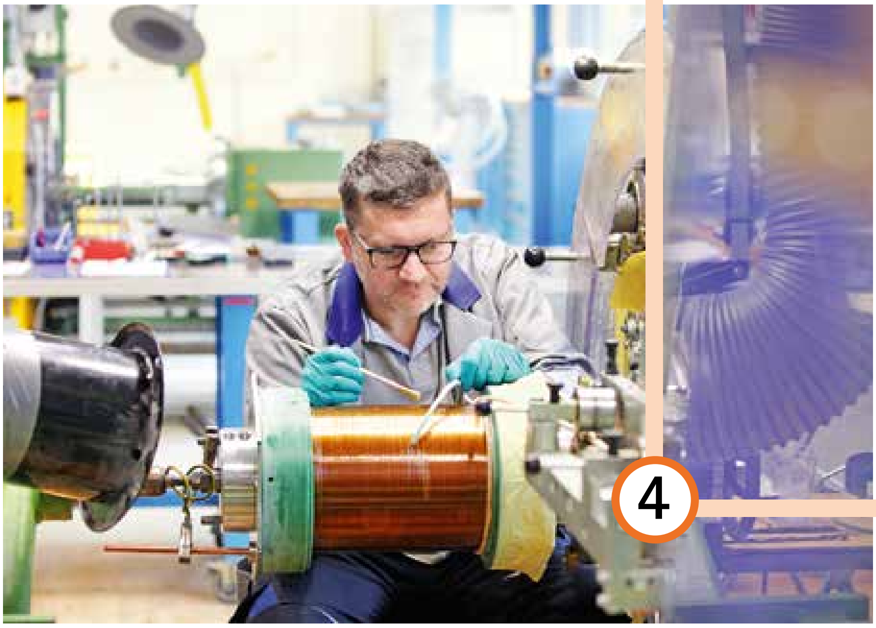


4

While the braiding machine slowly wraps the copper-alloy wire, Mirko Krause uses a paintbrush to apply epoxy resin to further reinforce the winding. HLD technicians produce about five to six such coils every year. For the magnetic coils – each one is unique and custom-made – they need up to two months.

5

In order to encase and insulate the coil, Mario Gulich at the milling machine cuts a composite material of glass fiber and hot-pressed epoxy resin into magnet flanges. These pieces ensure the coil is highly resistant to the extreme stress it is exposed to during the experiments.

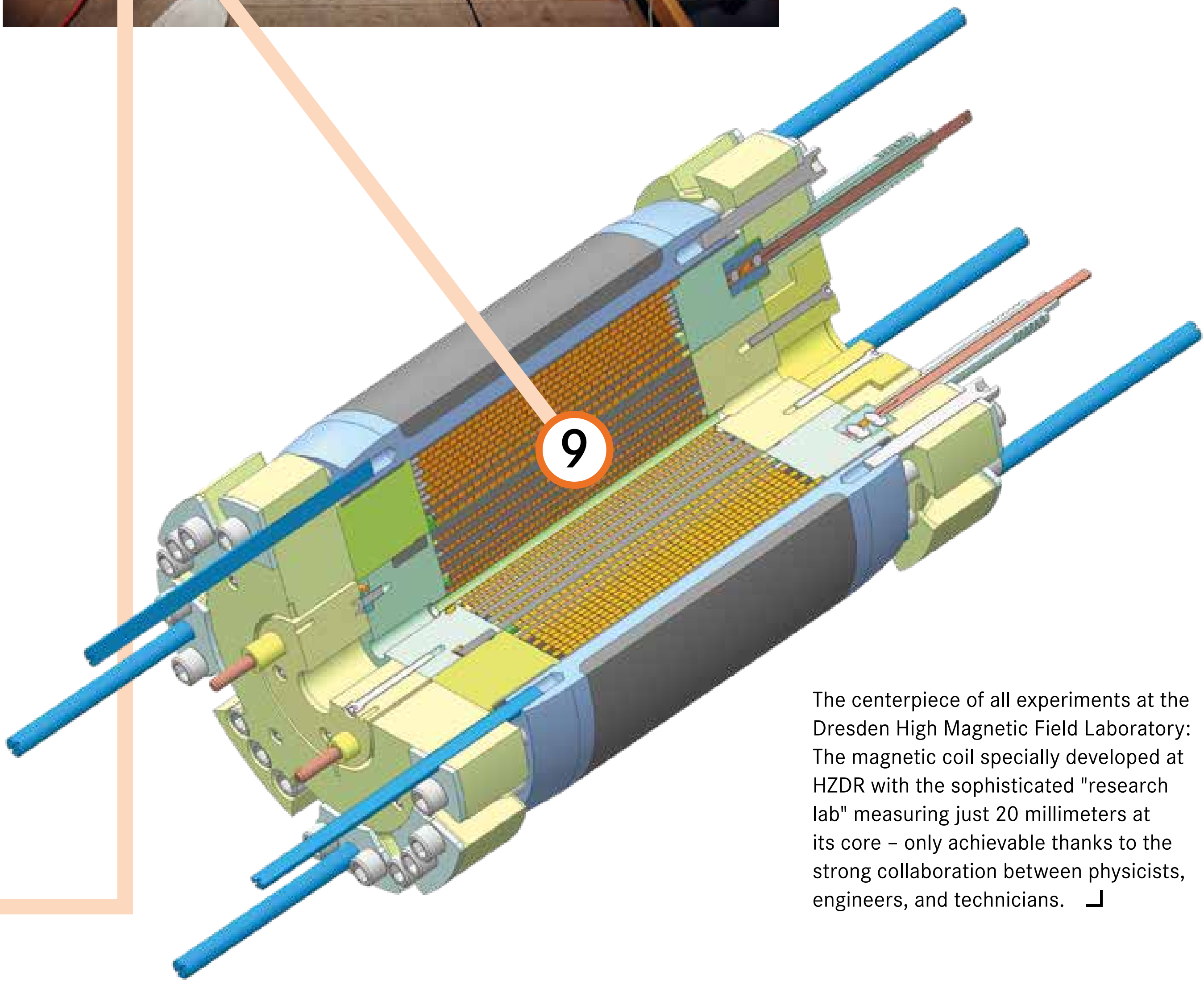
6

Before the magnet coil surrounded by a steel cylinder goes into operation, Oliver Kersten (left) and Sergei Zherlitsyn check that the central tube – the narrow place at which the samples are located during the experiments – has not been damaged during the winding.

7

At the High Magnetic Field Laboratory, electrical technician Karsten Schulz installs the Dresden engineers' masterpiece in the pit of what is known as the magnet cell. Scientists from all over the world ...

...such as Tatsuya Yanagisawa (right) from Hokkaido University in Japan enjoy unique opportunities for their experiments. To ensure that researchers receive the best possible support on site, so-called "local contacts", such as HLD postdoc Atsuhiko Miyata, are ready to assist at any time.



The centerpiece of all experiments at the Dresden High Magnetic Field Laboratory: The magnetic coil specially developed at HZDR with the sophisticated "research lab" measuring just 20 millimeters at its core – only achievable thanks to the strong collaboration between physicists, engineers, and technicians.

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Extreme states underground

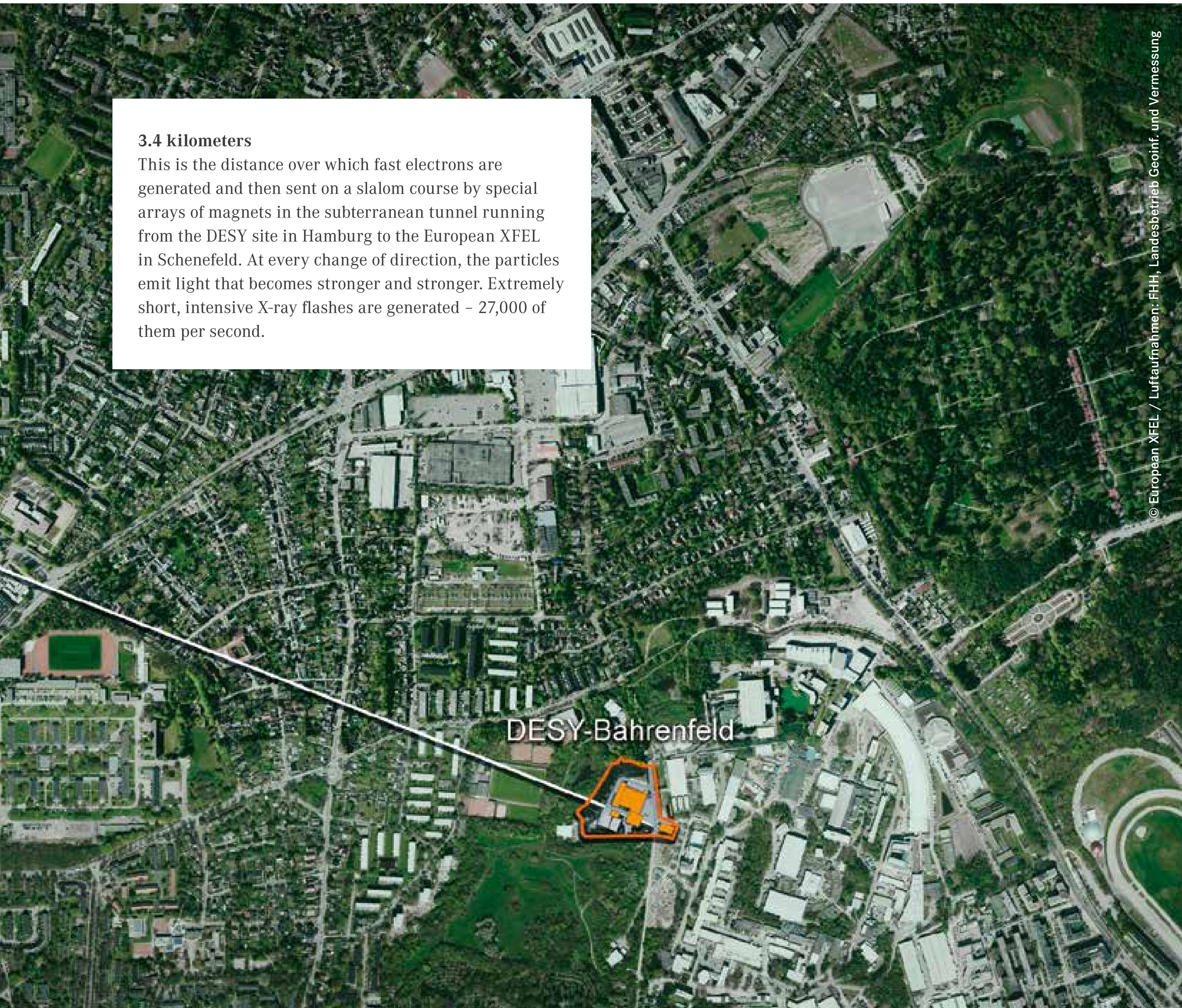
Ultrafast X-ray pulses, incredibly strong magnetic fields, high-intensity lasers and exorbitant pressures. The Helmholtz International Beamline for Extreme Fields (HIBEF) at the European XFEL's High Energy Density (HED) station in Schenefeld, near Hamburg – one of the most modern X-ray light sources anywhere – offers research groups from all over the world the very best instruments currently available. Their common goal is to acquire new insights into stars, planets, plasma clouds, quantum systems and versatile materials.

_Text . Jan Oliver Löfken

Wheat fields, meadows and pasture fences form the landscape just a few meters behind Hamburg's western city boundary. But the bucolic appearance is deceptive because it is here, in Schenefeld, Schleswig-Holstein, that up to 27,000 times every second the world's most intensive X-ray flashes are released. They are produced by the 3.4-kilometer X-ray laser, the European XFEL, by electrons – accelerated almost to the speed of light by a superconducting particle accelerator. At a depth of 15 meters, this globally unique X-ray light arrives in a chamber surrounded by massive concrete walls. Since 2019, it has housed six measurement stations which can be used concurrently.

Not enough that the European XFEL itself breaks many records: Toma Toncian and his colleagues from the Helmholtz-Zentrum Dresden-Rossendorf break even more. Together with the HED group led by Ulf Zastrau at the European XFEL's HED experimental station, the researchers integrate and jointly operate various set-ups that are provided by the Helmholtz International Beamline for Extreme Fields (HIBEF) user consortium. Under the leadership of HZDR, HIBEF pools the devices and expertise of various research institutions in order to make them available to HED users. Consequently, at this experimental station, miniscule material samples are exposed to extreme conditions and also analyzed at the same time using the European XFEL's unique X-ray light. Ultrashort, very intensive light pulses generated by a high-energy laser excite the samples within fractions of a second and create extreme environments, like in the sun's core.

These light flashes abruptly transform a sample into a plasma of electrons and charged ions. Exotic phase transitions and processes like those inside distant exoplanets could reveal themselves in this way. An anvil cell exerts extreme pressures of up to 4 million bars on samples, compressing them between two diamonds. Experiments of this kind allow researchers to gain new insights into geological processes in the mantle or core of our Earth. Finally, pulsed magnetic fields of up to 60 Tesla will help to answer the open questions of materials research, such as the origin of zero resistance in superconductors. >

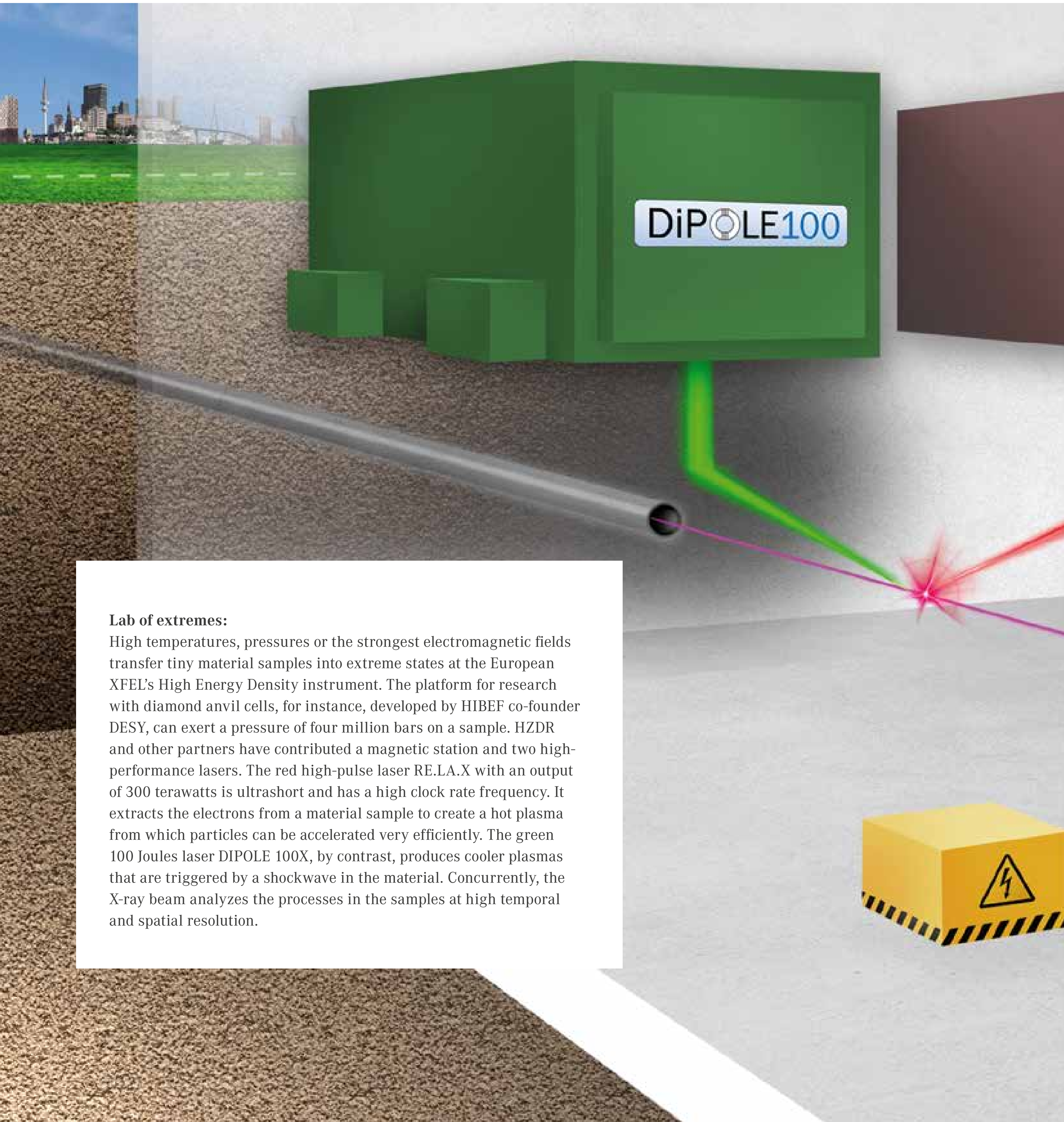


3.4 kilometers
This is the distance over which fast electrons are generated and then sent on a slalom course by special arrays of magnets in the subterranean tunnel running from the DESY site in Hamburg to the European XFEL in Schenefeld. At every change of direction, the particles emit light that becomes stronger and stronger. Extremely short, intensive X-ray flashes are generated – 27,000 of them per second.

Unique combination raises great expectations

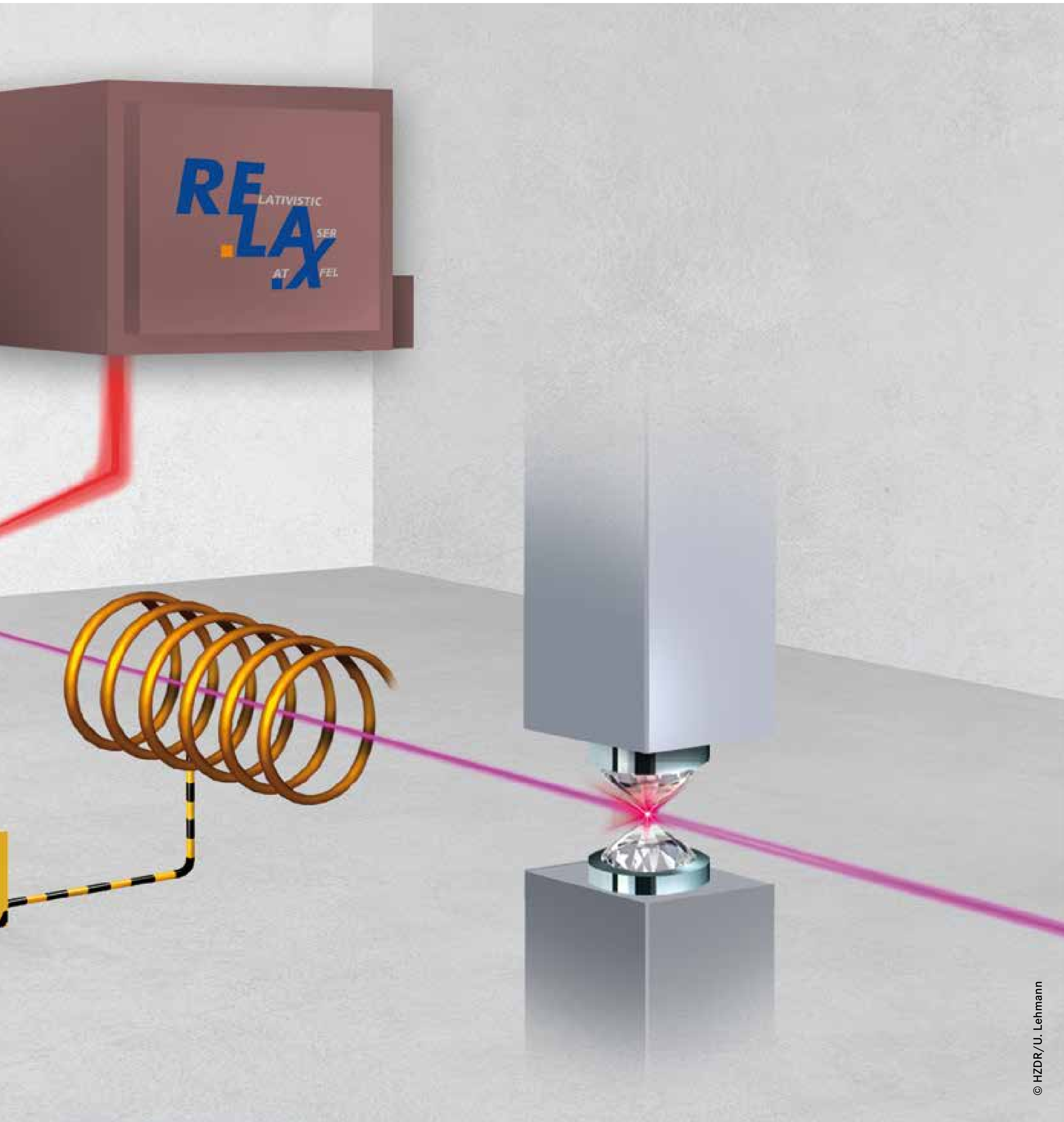
"Nowhere in the world is there anything to compare with this combination of extreme test conditions and the European XFEL's intensive X-ray pulses," Toncian believes. The expectations are concomitantly high among the over 80 research groups from some 60 institutes and 16 nations in Europe, America and Asia. The first user experiment with the high-intensity laser took place in May 2021.

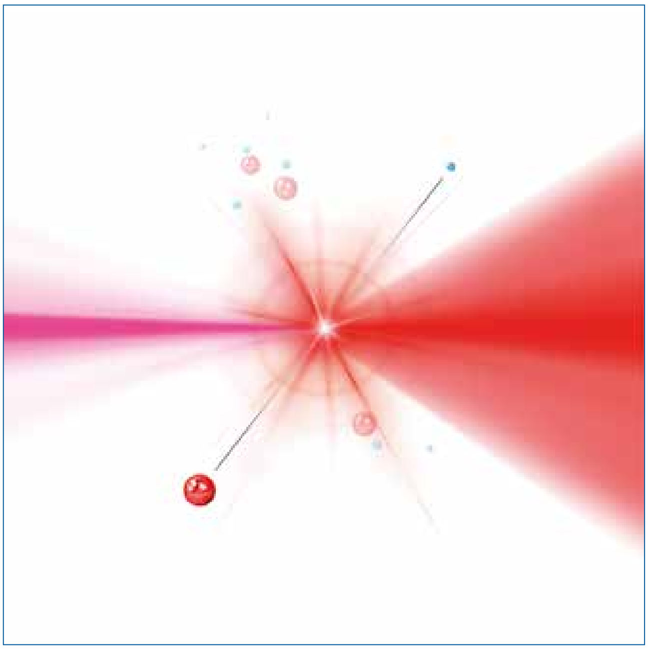
Toncian and his team are responsible for ensuring that the complex apparatus functions smoothly, which requires precision work down to the last detail. In the control room, the 41-year-old physicist studies his monitor where he can observe the focus and beam position of the intense laser. In parallel, his colleagues a level above him adjust little mirrors, lenses and other optical modules. The utmost dexterity is required because the laser punishes even the tiniest variance with lower-quality laser flashes.



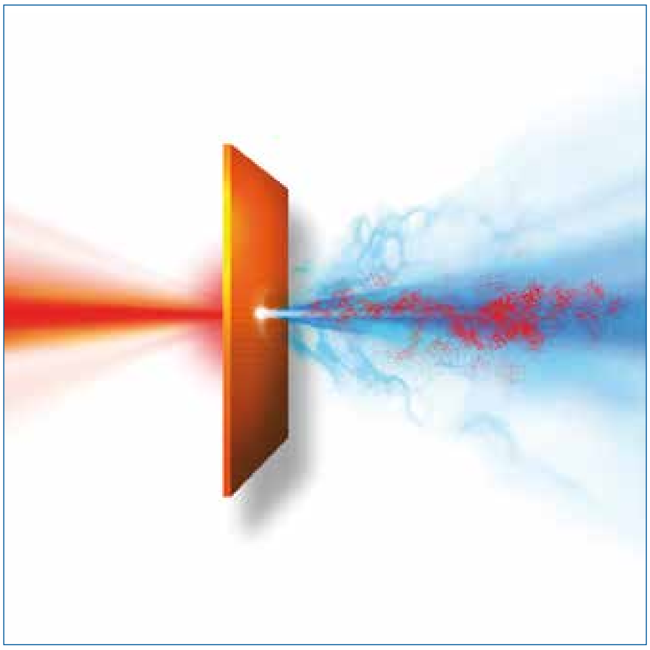
Lab of extremes:
High temperatures, pressures or the strongest electromagnetic fields transfer tiny material samples into extreme states at the European XFEL's High Energy Density instrument. The platform for research with diamond anvil cells, for instance, developed by HIBEF co-founder DESY, can exert a pressure of four million bars on a sample. HZDR and other partners have contributed a magnetic station and two high-performance lasers. The red high-pulse laser RE.LA.X with an output of 300 terawatts is ultrashort and has a high clock rate frequency. It extracts the electrons from a material sample to create a hot plasma from which particles can be accelerated very efficiently. The green 100 Joules laser DIPOLE 100X, by contrast, produces cooler plasmas that are triggered by a shockwave in the material. Concurrently, the X-ray beam analyzes the processes in the samples at high temporal and spatial resolution.

In order to not disturb the path taken by the light flashes from laser to sample, cleanliness is paramount. Therefore, Toncian and his colleagues only enter the laser room, which is kept as dust free as possible, via an airlock. Wearing a lab coat and mob cap, the researchers avoid contaminating the air. Safety glasses with dark lenses protect their eyes from the laser flashes which could take the wrong light path if any unintended reflections occurred. Given the enormous output of the special titanium sapphire laser with all of 300 terawatts, this is absolutely essential. By comparison: 300 terawatts are equivalent to more than the thousand fold output of all the power plants in Germany. At the HIBEF high intensity laser, however, this gigantic output is only reached for an extremely short time: 25 quadrillionths of a second, known as a femtosecond. >



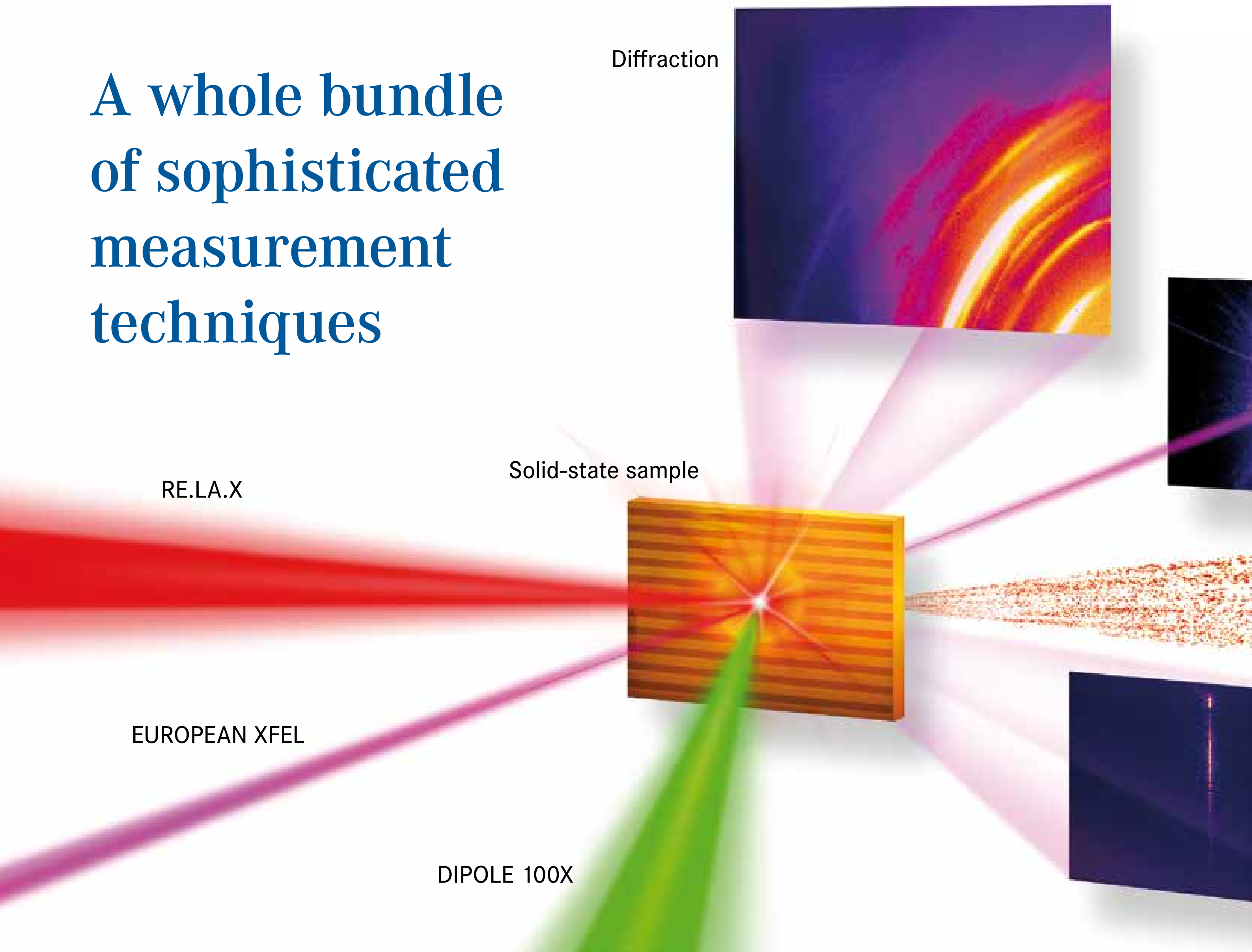


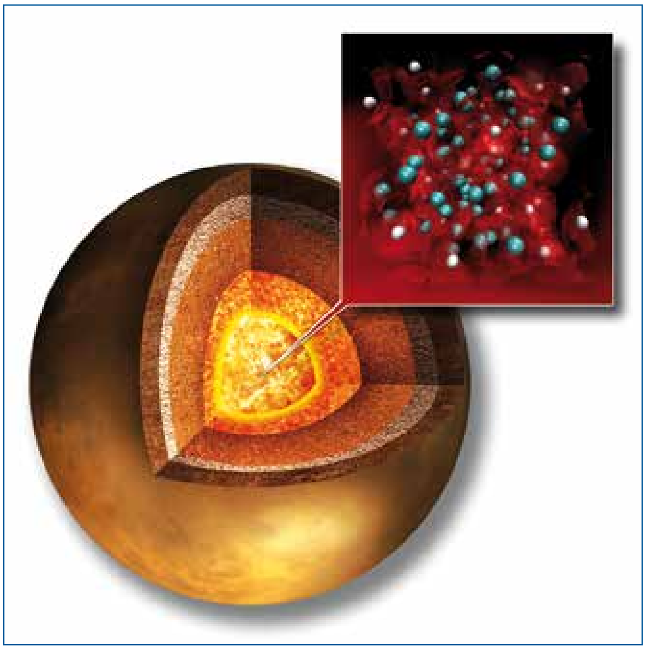
Interaction: The combination of RE.LA.X (red) with the X-ray laser (lilac) allows scientists to observe the interaction between virtual particles in a vacuum for the first time.



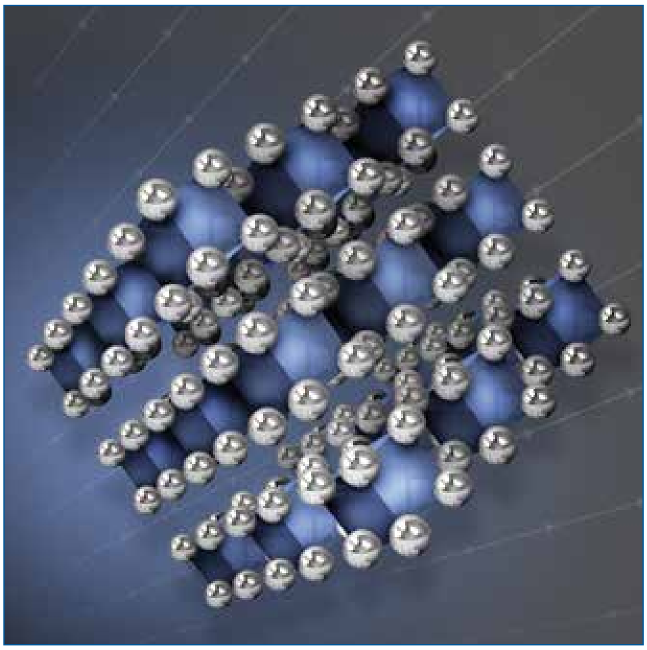
Explosion: When the force of a laser beam meets a solid foil the electrons (blue) speeding out of it accelerate the positively charged protons (red) from the sample.

A whole bundle of sophisticated measurement techniques





Warm dense matter: The high pressure in a planet's interior forces the atoms (blue) to realign so that some of the electrons (red) can move freely.



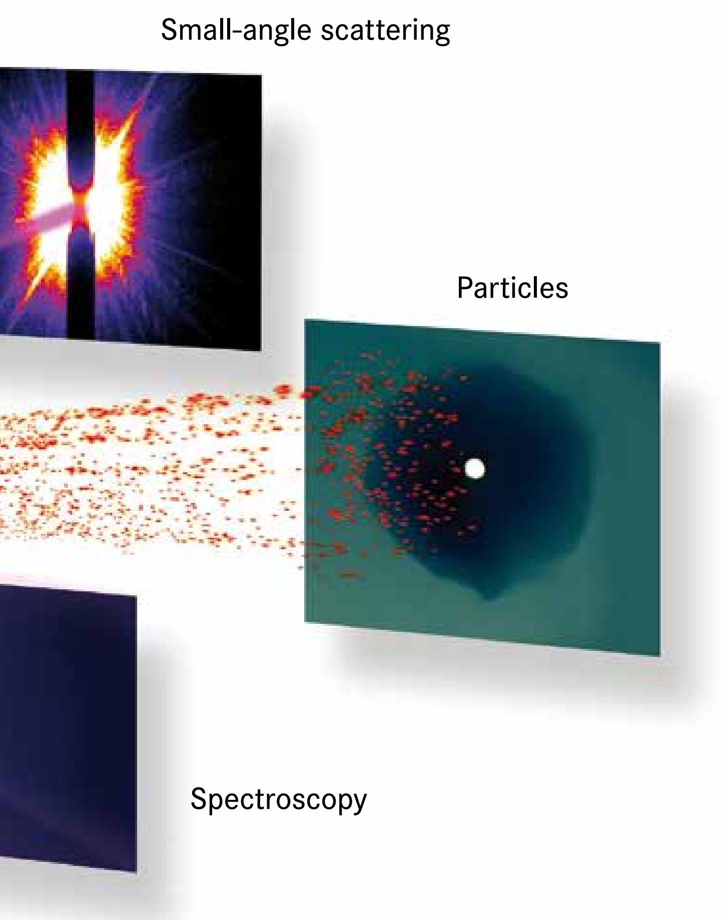
High magnetic fields: With HIBEF's 60 Tesla magnet, novel materials such as high temperature superconductors can be studied.

From the entire world to Schenefeld

The Helmholtz International Beamline for Extreme Fields (HIBEF) is a user consortium to which researchers can apply for beamtime. The consortium itself has priority access to some of this time. The rest is distributed by the European XFEL. In both cases, interested scientists must submit an application in which they describe their experiments in detail. An independent committee then assesses the proposals and awards the relevant beamtime on this basis.

www.hzdr.de/hibef

www.xfel.eu/facility/instruments/hed/index_eng.html



Snapshot: The testing principle on the free electron X-ray laser is similar to a camera shot. While one of the two optical lasers, RE.LA.X or DIPOLE 100X, generates a hot plasma cloud of charged particles when it impacts the sample, the process is illuminated by the ultrashort X-ray flashes. Depending on the object under scrutiny, different methods are available – diffraction, small-angle scattering or spectroscopy. Moreover, on the microscopic scale, the particle shower contains information about the processes within the sample.

Intensive light flashes vaporize tiny samples

"From the laser room, we direct the light flashes to the relevant samples, one level below," explains Toncian. These samples are placed in a vacuum chamber made partly of matt, partly of shiny aluminum. In addition, the European XFEL's X-ray flashes penetrate the almost two meter long and one meter high chamber from the front. At other, circular openings, vacuum pumps are flange-mounted. Whole bundles of cables surround the metal casing to operate the actuators inside or direct data signals from several detectors to the computers.

The samples themselves are barely larger than a pinhead. Even after just one attempt they may be vaporized by the intensive laser flash. In order to be able to carry out a raft of measurements in quick succession nonetheless, researchers prepare dozens of samples which are placed in numerous small toughs in a sample holder that vaguely resembles a kitchen grater. "This holder is designed for up to 100 samples," explains Toncian. It is adjusted by stepper motors down to a millionth of a meter. The dozens of tiny samples can thus be quickly and steadily directed from the outside to the spot where the flash from the HZDR laser and the X-ray beam from the European XFEL intersect. Depending on the state of the sample, the X-ray flashes are absorbed, scattered and deflected. Several detectors trace the horde of diffracted X-ray flashes. Following computer evaluation, it is these signal data that form the basis for a detailed image of the processes that occur in the samples under extreme conditions.

Light pressure of a billion bars

But how does the high-intensity laser generate the desired extremes? "With the pressure of light, the laser can simply accelerate the electrons almost to the speed of light," Toncian explains. In the process, the pressure of light reaches values of some billion bars. In samples of titanium, aluminum or carbon, for example, this generates enormous energy intensity for an extremely short moment. According to Toncian, similar conditions can be found in the thermonuclear core of our sun.

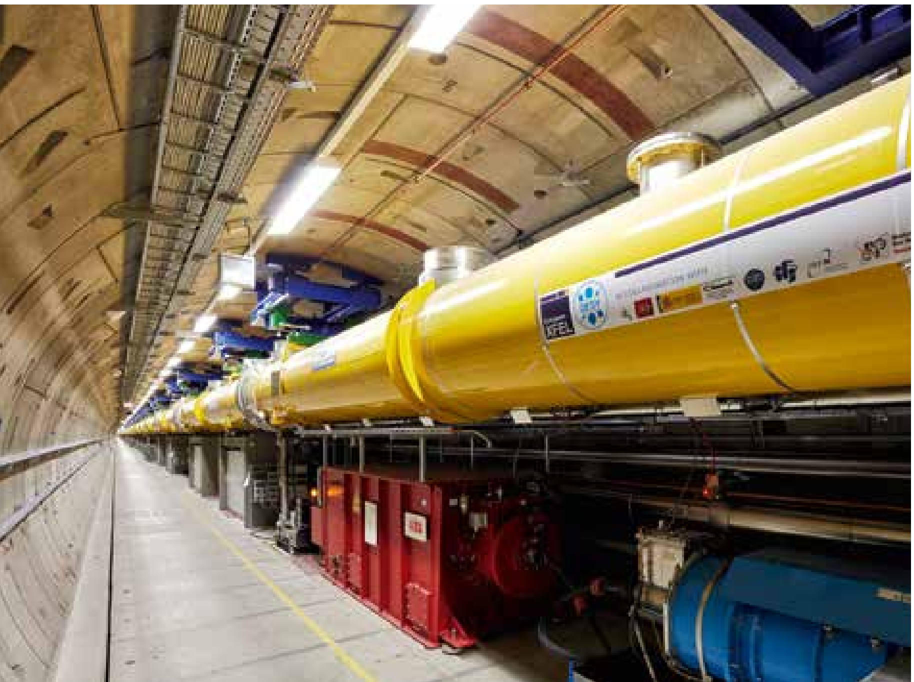
It is not just the processes in the interior of stars that could be reconstructed and better understood using experiments like this. Materials researchers, for instance, would be able to discover new properties in extremely highly excited materials. And basic research could benefit, as well, analyzing the spread of extremely fast particles in matter. Even the limits of quantum theories could be experimentally verified. The physicists in the HIBEF consortium thus expect to measure the electromagnetic effects founded on the theory of quantum electrodynamics. "The experiments could even deliver ideas for new applications, such as novel, laser-driven proton sources for materials research or medical technology," Toncian reports.

The physicist is confident about the coming months because both the high-intensity laser itself and the necessary synchronization with the XFEL's X-ray flashes have been successfully demonstrated. On behalf of a collaboration involving more than 50 scientists from 13 institutes, Toncian has already submitted a beamtime application to officially launch user operations. As of then, his team will support visiting researchers from all over the world, introducing them to the complex measurement techniques and also conducting their own complex experiments. But that will in no way exploit HIBEF's full potential. Toncian's team will install a second laser, this time for extremely high energies. "It has already been sent by our colleagues from Oxford and will be set up right next to the high-intensity laser," says Toncian.

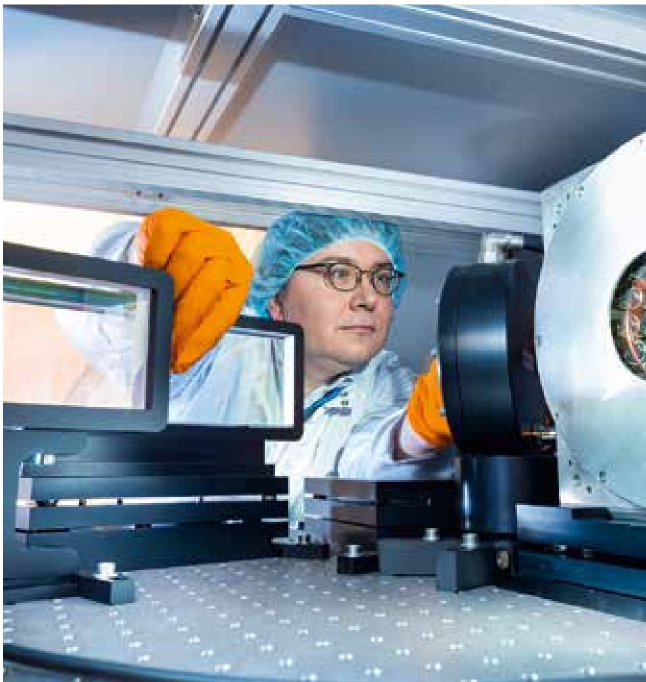
British laser generates shockwaves

It is a 100 Joules ytterbium ceramic laser which can abruptly build up extremely high pressure in the material samples and produce compression waves. In the process, the electrons are rapidly extracted from the atoms in the samples – again,

Below the ground: European XFEL tunnel with linear accelerator. Source: European XFEL/Heiner Müller-Elsner



Cleanroom conditions: Physicist Toma Toncian at the RE.LA.X laser. Source: European XFEL/Jan Hosan



dozens of them arranged on a sample holder – producing a plasma of ionized particles. And, once again, these processes can be investigated in detail at high temporal resolution with the European XFEL's X-ray flashes. This time, the extreme conditions do not mimic the interior of stars but of exoplanets, for example. In addition to astrophysicists, material researchers are waiting to be able to analyze their samples using this experiment, which will probably be available from 2022. They expect to gain insights into exotic phase transitions or even discover completely novel materials.

All those using the high-intensity or high-energy lasers will, however, have to share the valuable beamtimes with other partners in the HIBEF consortium and the international user community. A state-of-the-art diamond anvil cell is already fit for use. It stands in the measurement hut directly next to the vacuum chamber used for the laser experiments. It can be quickly moved on its system of rails into the X-ray beam. Developed under the leadership of the Hamburg research center DESY (German Electron Synchrotron), this experiment also focuses on extreme pressures. However, they are not generated by laser light, but mechanically, by two diamonds. When the diamonds compress the sample, static pressure of up to four million bars is exerted. Moreover, using additional lasers, the sample can be heated up to 10,000 degrees Celsius.

Simulating the interior of a super-Earth

In this state, the conditions resemble those in the mantle or outer core of our Earth. Geophysicists can thus acquire insights into the state and behavior of liquid rocks and crystals as they are found in the interior of the Earth. New knowledge about geological processes beckons: from the movement of tectonic plates, via earthquakes, through to volcanic activity. Thanks to the extreme static pressures, researchers are confident they will even be able to mimic the interior of super-Earths in their experiments, that is, very large exoplanets, especially as it is thought highly likely that the surface of these planets is very strongly influenced by the dynamics in the planet's interior.

The HIBEF facility is set to be completed by about the end of 2021. Then researchers will not only be able to subject their samples to extreme pressures or intensive laser pulses but also to the extreme cold of minus 269 degrees Celsius and enormous pulsed magnetic fields of up to 60 teslas. This makes the magnetic fields a good 40 times stronger than the strongest permanent neodymium, iron and boron alloy magnet. Produced by electromagnets, however, the extreme magnetic fields last merely a few microseconds. It is only the quick succession of X-ray flashes from the XFEL that generate enough intensity to be able to harvest reliable data in such a short time.

It will then be possible to measure and understand previously unexplained magnetic effects in solids with crystalline structures. Special materials periodically change their electrical conductivity, for example, when exposed to low temperatures and strong magnetic fields. And under these extreme conditions it would also be possible to analyze the exact behavior of correlated Cooper electron pairs, which are responsible for zero resistance in superconductors. Materials researchers, above all, can expect to derive new approaches to developing completely novel materials from the measurements.

"As part of the High Energy Density station at the European XFEL, HIBEF will generally be open to all researchers worldwide," says Toncian, looking ahead. Today already, many research groups are preparing their experiments with theoretical models and new ideas for samples and measurement conditions, discussing and refining their concepts for extreme tests at numerous workshops. Thus, at HIBEF and HED, uniquely complex measurement technology meets accumulated knowhow from various disciplines. There is, therefore, a good chance that far into the next decade, the measurement station will deliver astounding insights into the stars and new materials. It is very possible that, by then, the cows will have disappeared from the meadows around the lab building and been replaced by thousands of people in a new part of town surrounding the XFEL.

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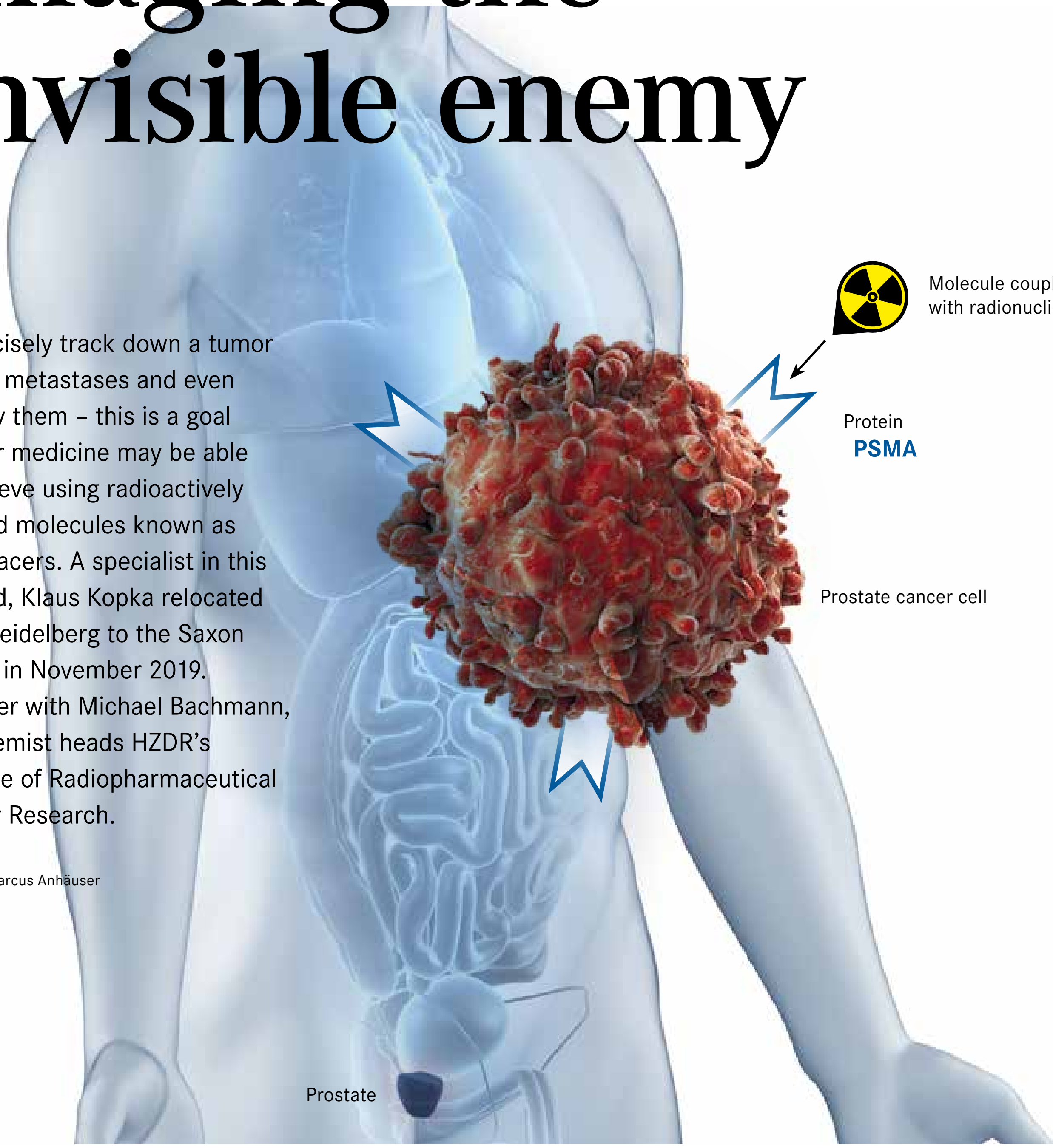
Imaging the invisible enemy

To precisely track down a tumor and its metastases and even destroy them – this is a goal nuclear medicine may be able to achieve using radioactively labelled molecules known as radiotracers. A specialist in this method, Klaus Kopka relocated from Heidelberg to the Saxon capital in November 2019. Together with Michael Bachmann, the chemist heads HZDR's Institute of Radiopharmaceutical Cancer Research.

_ **Text** . Marcus Anhäuser



Insight: The prostate-specific membrane antigen (PSMA) is found on the surface of prostate cancer cells and otherwise hardly occurs in the body at all. Researchers have developed a small molecule that binds specifically with the PSMA and is labelled with weakly radioactive substances known as radionuclides. It can even trace the tiniest source of cancer cells and image them with the aid of so-called positron emission tomography (PET). Image collage: CLIPAREA/Custom media, Kateryna Kon, Helmholtz

Today, Klaus Kopka

has come in by bicycle, last week he cycled in twice. From Loschwitz, it is more than ten kilometers to HZDR, a considerable distance through the Dresden hinterland. "That was something I had promised myself in my first year," the chemist explains. A love of cycling is apparently something people from Münster like him are born with. But he enjoys sport in general, as you can tell when you meet the 53-year-old. Until the age of 35, he regularly shot baskets, for 25 years all told. Then his team sport days came to an end. But you can still get plenty of exercise on your own, not least in Kopka's new home of Dresden. "It's great jogging along the Elbe," he notes.

Even though he has been a loner in the sporting arena for many years, in Dresden, he has now found his scientific team, at the Institute of Radiopharmaceutical Cancer Research. Here, research groups of chemists, biologists and physicists work together to find ways of imaging potentially lethal tumors and their metastases using tailored molecules to fight them more precisely. In day-to-day business, what sounds easy involves painstaking effort down to molecular level.

Kopka is an expert in this kind of precision work: he develops radiotracers. These are combinations of molecules that act as tracers, tracking down cancer tumors in the body. They are like navigation lights at sea. One part of the pair of molecules functions like an anchor. It has a strong affinity with cancer cells and binds with receptors on their outer surface. The other part is a glowing radioactive lantern: it makes the cell visible. Like this, the medical researchers can recognize a sea of navigation lights on the images, reconstructed by means of positron emission tomography (PET). And this enables them to trace and characterize tumors on the molecular level at an early stage. At the same time, they can also measure whether radiation and chemotherapy are successfully combating the diseased cells.

But some radiotracers can do even more. They not only image the tumors, they also destroy them. In the last few years, Klaus Kopka has helped to develop a substance of this kind. And he intends to employ this principle – seek, find, destroy – at the Dresden research center, as well.

Münster, his home

He was born in Münster in 1968, his mother an elementary school teacher, his father a postal worker, although he had really wanted to pursue a craft. "But this was the post-war period when people were obsessed with job security. That affected me, too," Kopka reports. The parents of that generation would have done anything to ensure that their children could go to university, which was precisely what happened in the case of Kopka and his two brothers. The older one is a plant physiologist at the Max Planck Institute of Molecular Plant Physiology in Golm, near Potsdam, the younger a senior engineer with Carl Zeiss in Oberkochen.

Kopka remained in the city of his birth for a long time, studied chemistry and took his doctorate there in 1996. In the following year, he became a postdoc in the Department of Nuclear Medicine at Münster University Hospital. It was here, in Otmar Schober's team, that he completed his habilitation. Finally, in 2013, he was tempted away from Münster – to Heidelberg where he assumed the Professorship in Radiopharmaceutical Chemistry while heading the division of the same name at the German Cancer Research Center (DKFZ).

His predecessor, Michael Eisenhut, and his then postdoc, Matthias Eder, and colleagues had developed the diagnostic agent PSMA-11. This molecule binds with the prostate-specific membrane antigen PSMA that is extremely highly regulated in prostate cancer, the most common form of cancer in men worldwide. By subjecting the tumor and its metastases to radioactive radiation with the gallium-68 labelled PSMA-11 radiotracer, which is taken up in excess by the tumor and its metastases, they can be specifically revealed in three-dimensional tomographic images using the PET method.

Kopka's team managed to chemically refine the radioligand and thereby replace the gallium-68 used for the imaging by the therapeutic radionuclide lutetium-177. This was how Martina Benešová in her doctoral thesis developed the PSMA-ligand [^{177}Lu]Lu-PSMA-617, which had been individually used with patients for the first time just a few years previously by doctors working with the director of the Department of Nuclear Medicine at Heidelberg University Hospital, Uwe Habenkorn. By employing this class of tracers for endoradiotherapy, it is not only possible to reliably diagnose prostate cancer, but also to target treatment delivery.

"The development of this tracer is a successful example of a so-called theranostic radioligand as well as for the principle of 'seek, find, destroy'. It's a substance that can be used concurrently for diagnostics and therapy," Kopka explains. "What's more, it's a positive example of translational medicine because the whole process from the pre-clinical and clinical phase, from development to use on patients, only took about seven years." An aspect which is very important to Kopka.

Don't just image it, destroy it

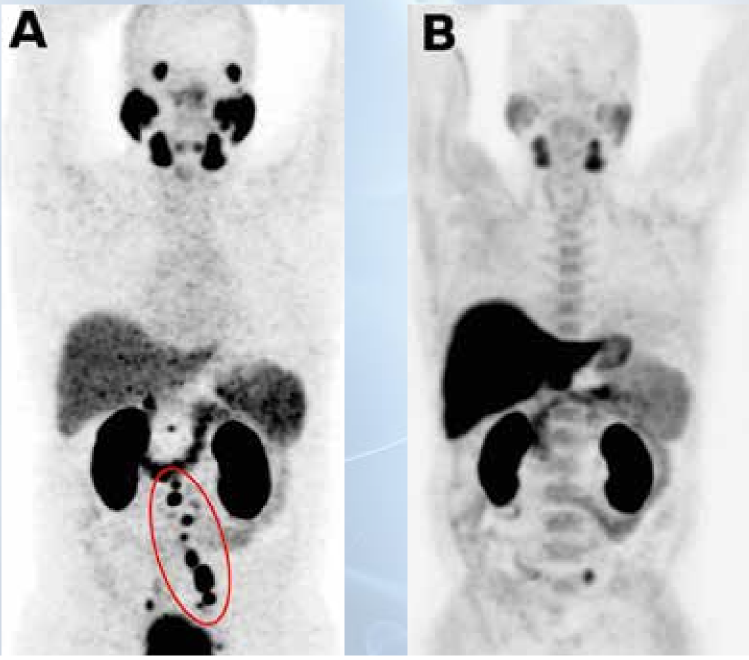
So, in just a short time, he has established a new department at HZDR titled "Translational TME-Ligands". In the framework of a habilitation, small tracers are now to be developed to image the tumor microenvironment (TME). In doing so, Klaus Kopka is augmenting the research of the other director of the institute, Michael Bachmann, who works on therapeutic UniCar T cell systems. This method involves coupling molecules that target the microenvironment of the tumor and specifically fight the tumor cells. "When we can image that as well, it will also be a theranostic concept," says Kopka, looking ahead.

And his thinking goes beyond the classic system: "It doesn't have to be the radiotracer concept on its own: you could also combine it with surgical tumor treatment." To do so, in addition to the radioligand, a dye would be coupled with the molecule that binds to the receptor to make the metastases more visible during surgery which would be conducted in combination with a robotic surgical system. "The relevant PSMA ligand that is also labelled with gallium-68, for example, has been developed by my former doctoral student Ann-Christin Baranski in Heidelberg," Klaus Kopka reports. "Clinical transfer has just started."

For the purposes of his research, Kopka is sure Dresden is the right place for him. Having cooperated for years with his predecessor, Jörg Steinbach, as a colleague and collaborative partner, he is already well acquainted with the center and many of the staff members. "The conditions here are ideal. The institute is extremely well positioned in the core competencies, whether we are talking about radionuclide production, developing complexing agents, small animal imaging or biological assay expertise, and even GMP-compliant production of radiopharmaceuticals for their use in nuclear medicine."

Avoiding blinkers with detachment

But all the detailed work on molecules and receptors should not mask the fact that, in the last resort, it is all about treating sick people whose lives are threatened by cancer, Kopka points out. On the one hand, it is his family who prevent him from becoming blinkered and, on the other, the 15 years he spent working in nuclear medicine with Otmar Schober at Münster University Hospital. "That's where I learned hospital-type routines in nuclear medicine. Away from the lab bench, the focus was clearly on the patient. I got to the lab early in the morning and prepared the syringes with technetium radiopharmaceuticals so that the examinations could begin at 8 o'clock."



Progress: (A) PSMA-11 – coupled here with gallium-68 – images prostate carcinoma metastases with the help of positron emission tomography (PET). (B) The prostate cancer tracer fluorocholine that was previously used does not reveal the metastases. Source: DKFZ

And then there are also the conversations with nuclear medicine physicians and oncologists in Dresden which ensure he doesn't lose sight of the patients. Given its partnerships with Dresden University Hospital, the National Center for Tumor Diseases (NCT), the German Consortium for Translational Cancer Research (DKTK) and the National Center for Radiation Research in Oncology – OncoRay, HZDR provides very good opportunities.

What this actually means for Klaus Kopka is that the experts from the medical hospital help him to pursue research that is relevant to clinical practice. "This is something I pass on to my staff and colleagues to motivate them every day: before you get bogged down in your research, ask the physicians about clinical relevance and unmet clinical needs. Perhaps there is even a genuine need for a particular substance for one type of cancer that you can search for specifically."

After the success of PSMA-617 and other radioligands like PSMA-1007, an optimized PET tracer for diagnosing prostate carcinoma, he now wants to discover the areas where there are further clinical needs in Dresden. By extension, he is now thinking, for example, about breast cancer, the most common carcinoma in women, pancreatic cancer, the deadliest of all types of cancer, or colon cancer, where therapeutic options are limited. Because, in the end, according to Kopka, the whole point is that as an employee of a Helmholtz center, which is publicly funded, it is a social duty to strive for better patient care.

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When materials research meets cancer medicine ...

Use nanotechnology to trace disease or monitor the efficacy of therapies – this is a vision Larysa Baraban and her research group want to realize. With their interdisciplinary approach they bring together two of HZDR's major research areas.

_ Text . Kai Dürfeld

The catheter gently slides through the vein. It is about to reach the heart where it will take a closer look at the coronary arteries. But even on its journey, the agile device has already taken an image of its environment, continuously measured oxygen saturation or identified a raft of different biomarkers in the blood and wirelessly transmitted the results to the team of doctors in the operating theater. If Larysa Baraban has her way, in future, a scene like this could become standard medical practice – because together with her HZDR research group "Nano microsystems for life sciences", the physicist is developing nanometer-sized sensors for medical diagnosis.

The fact that her group brings together the Institute of Ion Beam Physics with the Institute of Radiopharmaceutical Cancer Research for the purpose is only surprising at first sight. "The electronic bio-nanosensors we material scientists develop interact with the biomolecules and cells. That produces characteristic signals," Larysa Baraban explains. "Our sensors can specifically convert the charges combined with the biomolecules into current or voltage and then relay them for evaluation," she continues. "Which takes us to the very heart of cancer research. Because these signals can indicate cancerous cells, for example, or show whether a drug is having the desired effect."

Health and materials: Larysa Baraban's research brings together two of HZDR's three major research areas. The idea of forming such interdisciplinary research groups had been around for some time, she explains. "Nano microsystems for life sciences" was now one of the "prototypes" that was set to breathe life into cross-sectoral research in the coming years. At the start of 2020, the physicist relocated to HZDR from TU Dresden and immediately began to build her research group. In the meantime, it boasts two postdocs, five doctoral candidates and two Master's students.

Apart from physicists, nano and biomedical technicians, she has also recruited an expert for wireless communications. "If we put nanosensors in the body, we have to get the readings out again," she says. "And, of course, we don't want to be laying cables in the patient." The team also cooperates very closely with clinicians. "We come up with an idea which we then discuss with the physicians. This nearly always generates a veritable explosion of new ideas. We then use them to refine our approach."

Physics for a long, healthy life

Baraban's interest in natural science and especially in physics dates back to her school days. "At senior high school we had a new physics teacher," she remembers. "She explained the teaching matter so clearly that I caught the bug and definitely wanted to learn more." So, it was just a logical step to study radiophysics at Taras Shevchenko National University of Kyiv. She subsequently took her doctorate in physics at the University of Konstanz, was a postdoc focusing on microfluidics in Paris and finally moved to Dresden, to work at TU. Her speciality there was to combine nanoelectronics with biology. She was, for example, a member of an international research group that developed the first neurotransistors – an electronic circuit that imitates the function of the human brain.

But what drives a young physicist to devote her talent to cancer research? She admits it was not personal experience of the disease that made her choose this field of research. Her motivation was different: "Thanks to modern medicine, we live longer than ever and that's good," Larysa Baraban observes. "But, on the other hand, a long life also means that the probability of being diagnosed with cancer increases." And that was a really strong incentive, the young physicist admits. "When I think of my own child and later my child's children, I want to do everything I can today to understand cancer better and find ways of healing it." She is particularly fascinated by the interdisciplinary cooperation with physicians. The thought that the sensors she has helped to develop actually save lives spurs her on every single day.

Medical lab on a chip

For its investigations, the research group dives into the world of the tiniest things. The miniscule wires, for example, that form their nanocapacitor measure less than 100 nanometers. That is not even one percent of the breadth of a hair. In this world, a material's properties are not the main consideration – it is the most diverse effects on their surfaces that determine the functions. And as the ratio of surface to volume is greater in nanowires than in traditional structures, the nanometer-sized shrimps are ideal for medical measurements.

In the service of cancer research: physicist Larysa Baraban. Source: HZDR/A. Wirsig

In comparison with their conventional counterparts, nanowire sensors can be vastly reduced in size – despite significantly higher sensitivity. Several of these sensors, each with a different analytical purpose, can be integrated in a "lab-on-a-chip". A whole analytical lab is mounted on a glass or plastic carrier the size of a credit card. With this, for instance, a flow cytometer can be created that counts the immune cells in the blood and concurrently assigns them to different categories in real time. In this way, cancer therapists can test whether the treatment is working as it should.

Cancer medicine is, however, only one of the fields of application the physicist and her team have in mind. They are also investigating the coronavirus SARS-CoV-2 and the disease it triggers: COVID-19. "Together with Michael Bachmann's group at the Institute of Radiopharmaceutical Cancer Research, we developed a sensor which can conduct multiparametric diagnostic tests in the shortest possible time," explains Larysa Baraban. "On the one hand, we want to detect the active pathogen in a sample and thus verify current infection. On the other, however, we also want to look out for antibodies and thus determine whether an infection has been overcome." For this research, the Free State of Saxony awarded the institute two million euros in funding.

Systems like this usually work ex vivo, that is, outside of the body. This is fine for examining tissue and blood samples. But the researchers working with Baraban are also investigating sensors that take measurements in the living organism – that is, in vivo – including those that could turn future heart catheters into real-time labs.

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Same method! Same result?

In order to elicit the world's secrets, researchers in all disciplines employ the most diverse techniques. But, how can they be really certain that their tools work as well as they suppose? Scientists at HZDR's Institute of Resource Ecology wanted to know for sure and launched an international comparative test of spectroscopic methods – which uncovered a decidedly surprising finding.

_ Text . Marcus Anhäuser

That was something they had not been expecting: it turned out to be the very last step, the publication of their comprehensive results of this huge and important project that was the hardest. Harald Foerstendorf, Katharina Müller, Robin Steudtner and Satoru Tsushima did not make any new scientific discoveries, nor did they confirm an existing theory. The four Dresden spectroscopy and quantum chemistry experts focused on their own branch of research: the spectroscopy of radioactive heavy metals. "The whole point was to hold up a mirror to ourselves and examine how we and our colleagues work, how our knowledge is generated via a simple system and how far we and our methods actually correlate," explains Harald Foerstendorf whose research focuses on vibrational spectroscopy. The Dresden group did not act alone. They cooperated with 41 co-authors from 20 labs in six countries on three continents.

Scientists refer to this method of validation as a round robin test, a name derived from the French term "rond ruban" or "round ribbon". Originally, it described a special way of enabling several people to sign a document. So that the form did not reveal who played a leading role in the group, the signatures were arranged in a circle like in a wide, round ribbon. In games, round robin denotes a tournament in which every contestant meets every other contestant in turn. In science, as in industry, it is an established procedure for examining and comparing techniques, tools and methods of work in different groups – for example, in environmental analysis when different environmental labs receive the same sample for analysis to discover whether they all get the same results.

That this kind of comparison of methods would not be child's play was something the four researchers had suspected. After all, a global check involving so many labs and colleagues scattered all over the northern hemisphere from the US via France and Germany through to Singapore was already a logistical challenge. The last time a similar check was carried out in spectroscopy – albeit on a much smaller scale – was almost two decades ago.

The procedure was more sophisticated than only investigating the same substance using the same method in different labs. In the first step, the scientists now analyzed the same samples using five spectroscopic techniques. Then, in a second step, the idea was to compare the various methods with one another, match the results of the experiments with the quantum chemical calculations and put it all together to gain an overall picture of the chemical system.

Glimpse of the truth

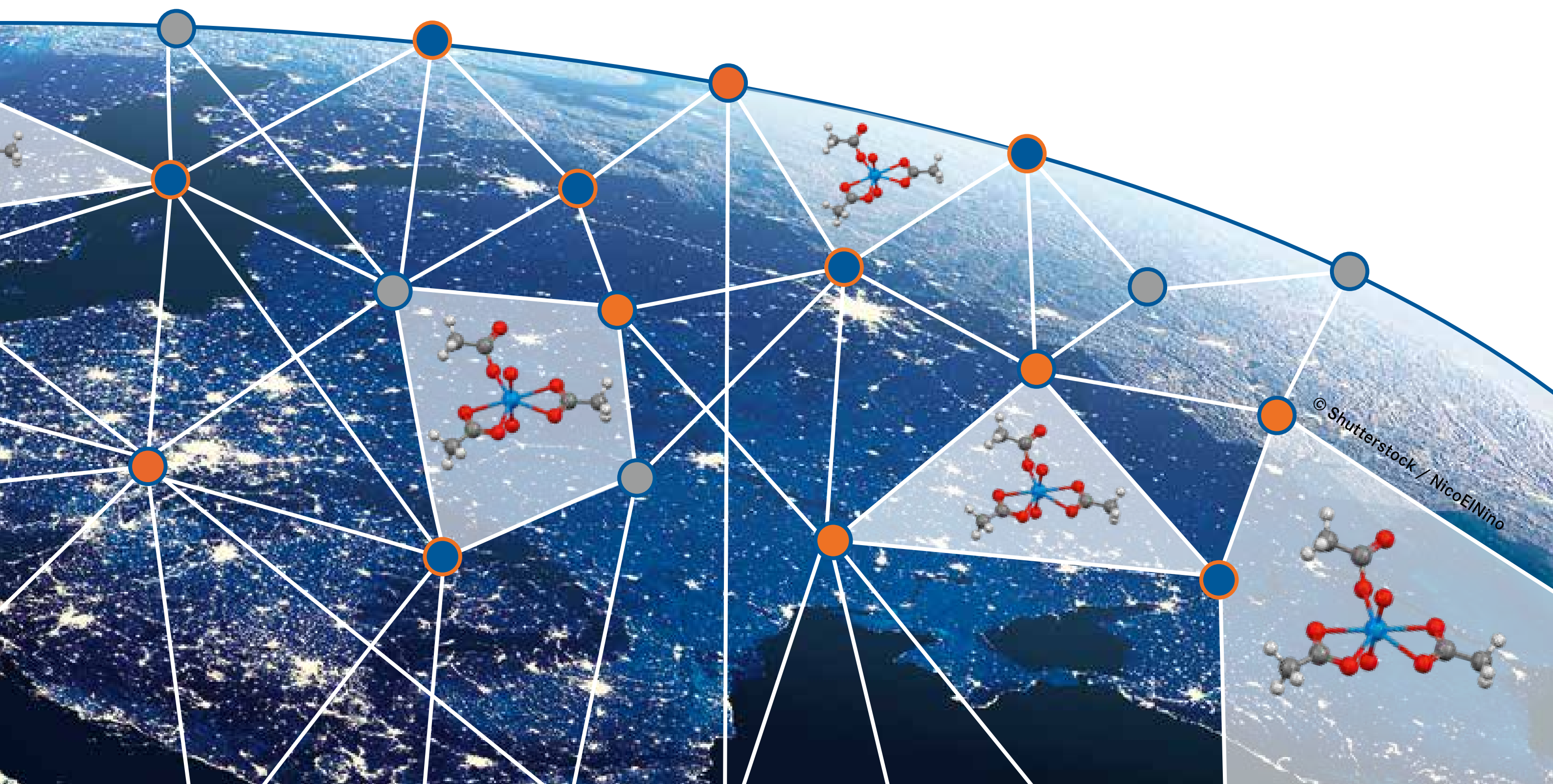
The idea is that every method provides a specific perspective on the same object and delivers a slightly different, valuable glimpse of the truth. Only when the various tools come together one will get a comprehensive picture. Often, researchers are highly focused on the methods they use in their laboratories, so that it is quite difficult for them to sufficiently understand the results and the interpretations obtained from other techniques and to set them in relation to their own results. The idea was also born of the need for a better understanding of the requirements of the various disciplines with regard to other colleagues' data and results. "Especially between the theoreticians and the experimental scientists, the expectations are fundamentally different," Katharina Müller explains.

Every method has its advantages and disadvantages. The Dresden round robin test was designed to facilitate understanding between labs and methods in order to finally achieve a "complete picture" of an analysis. The idea for this mammoth round robin came up during the closing session of the first ATAS (Advanced Techniques in Actinide Spectroscopy) workshop in Dresden in 2012, which was firmly established in the international community since then. "We thought about how we could strengthen communication and networking and were looking for an approach that we could all tackle together," reports Robin Steudtner, a chemist by training and a specialist in fluorescence spectroscopy. At the beginning, he continues, it was quite a "crazy idea".

All the researchers they approached were immediately taken with the idea of conducting such a test. "Of all the colleagues who volunteered right at the beginning, a good 80 percent were still around at the end," says Steudtner.

What does the spectrum reveal?

The various spectroscopic methods, such as vibrational, luminescence, X-ray absorption or magnetic resonance spectroscopy, each examine certain properties of a molecule based on so-called spectra. The latter occur when the substance being analyzed is exposed to electromagnetic fields, which excite electrons, cause molecules to vibrate or atoms to start rotating. In each case, energy is released or absorbed, which researchers can measure and map in a characteristic spectrum. From this, they can derive information about the molecules' and atoms' most diverse chemical and physical properties like bonding distance, electron spin or the composition of the molecules. >



One focus of the research conducted by the Dresden scientists is on radioactive heavy metals, which include uranium, plutonium and thorium as well as those lesser known to non-specialists like neptunium, curium and americium. They try to glean as much knowledge as possible from these substances, both in basic and applied research, in order to understand how they behave under certain conditions and in certain environments. What sounds very granular is, in fact, of considerable practical use.

Their results, for example, play an important role in searching for the best location with the highest safety for a repository for radioactive waste. This is in particular important considering the upcoming nuclear phase-out of German nuclear power plants in 2022. The Dresden researchers' results help to understand what happens when – in the case of the maximum credible accident, that is, water entering the repository – radionuclides are released and radioactive substances spread, endangering humans and nature. Such an understanding down to the molecular level is essential for reliable predictions also in case of nuclear accident scenarios like Chernobyl and Fukushima just as it is for contaminated sites of former uranium mining activities in Saxony and Thuringia.

Given that the researchers were not looking to generate new knowledge about a substance but about their tools and methods, they decided on a simple model system. "After careful deliberation, and because most participants had expressed their interest, we decided on the uranyl acetate system," says Harald Foerstendorf. This is a yellow crystalline material and although it is poisonous, it is only weakly radiotoxic. Uranyl acetate has been the object of investigation since the 1950s. Thus, there is much experience and scientists require relatively little effort to analyze the system with their spectrometers.

At this point, the organizers started discovering the particular regulations of various countries concerning shipment of radioactive samples, which the technicians had all carefully prepared and packed by hand. Steudtner and Foerstendorf shudder when they recall the red tape they had to contend to get permission to send four samples to India. They did eventually arrive, but sadly, far too late. "I had received confirmation from the Federal Office for Economic Affairs and Export Control that I could send my four samples. But the experimental part of the test was already over by that time," Steudtner explains. Today, he can laugh about it. "Things like that just happen."

Very good correlations

The reward for their enormous effort was a huge amount of data and very satisfactory outcomes. In many aspects of the experiments there was a strong correlation of results, especially in the first phase in which the various labs each compared one method. In the case of Raman spectroscopy, a form of vibrational spectroscopy, the results correlated completely. "But then it emerged that the literature contained some wrong data which we could correct with our test," says Harald Foerstendorf. The differences are easy to explain because the existing data were already a few years old. Today, improved technologies allow the measurement with higher accuracy, Robin Steudtner adds.

Only in a few cases, significant deviations were observed in the current comparisons, such as in fluorescence spectroscopy. "It emerged that the groups work somewhat heterogeneously when calibrating the equipment," Steudtner admits, looking slightly sheepish. What he is actually trying to say is that some researchers were apparently not conducting the important calibration of the spectroscopes at the start

of measurements as conscientiously as others. "It is one of the disadvantages of this method that the spectrometers still have to be adjusted by hand using a calibration lamp. And that is quite an effort," the chemist explains. "If you just want to check a measurement 'quickly', the calibration may sometimes fall by the wayside. And then afterwards, you ask yourself why the bands in the spectrum have shifted and are not where they really should be."

This result has had implications for Steudtner's own work. On the one hand, he now takes special care to check that the staff at the institute, especially the younger generation, calibrate their spectrometers before every measurement, not least to ensure that the results within the institute and the research groups are comparable. On the other hand, when he is peer-reviewing articles, he now looks for information on whether and how the calibration was conducted. If this information is missing, it rouses his suspicion. To ensure that this process can be carried out regularly and consistently within the community, in their article, the Dresden scientists suggest procedures for making the adjustments in order to achieve comparable results.

Theory and practice

When it came to the comparison of theory and experimentation the results were somewhat mixed. "It appears that you can achieve very good results for some methods in theory – for others it is still difficult," says Katharina Müller. There is a fundamental problem, according to Satoru Tsushima: "Differences occur, for example, because the experiments are conducted in aqueous media whereas we in theoretical modelling compute with a vacuum."

The reason is that water complicates the calculations. To factor in all the reactions of the countless water molecules and the influence of other parameters leads to extremely long computing times. That is why theoretical modelling is done with a vacuum where no other molecules than the target one needs to be considered. "This could change in the future if algorithms improve and computers get faster, especially if we think in terms of quantum computers", Foerstendorf opines.

Everyone was keen to discover how well the results of the three large storage rings in France and Germany would correlate. A comparison like this of such complex facilities had never been attempted before. Some of the storage rings are among the largest machines ever built by humans. The most famous is the gigantic synchrotron at CERN close to Geneva, but there are many others around the world, such as the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, with a circular length of nearly 850 meters. Moreover, colleagues from the synchrotrons at the Angströmquelle in Karlsruhe (ANKA) and SOLEIL Université Paris-Sud in Orsay with a length of more than 350 meters also participated.

The researchers at these facilities were very confident and fully expected their results to correlate precisely. The Dresden scientists were doubtful, but all the more curious for that very reason. Steudtner has first-hand experience of facilities like this and knows how enormous and, above all, complex these machines are. But the colleagues at the synchrotrons were right: "The biggest surprise for me was that the results measured were one hundred percent identical," he comments.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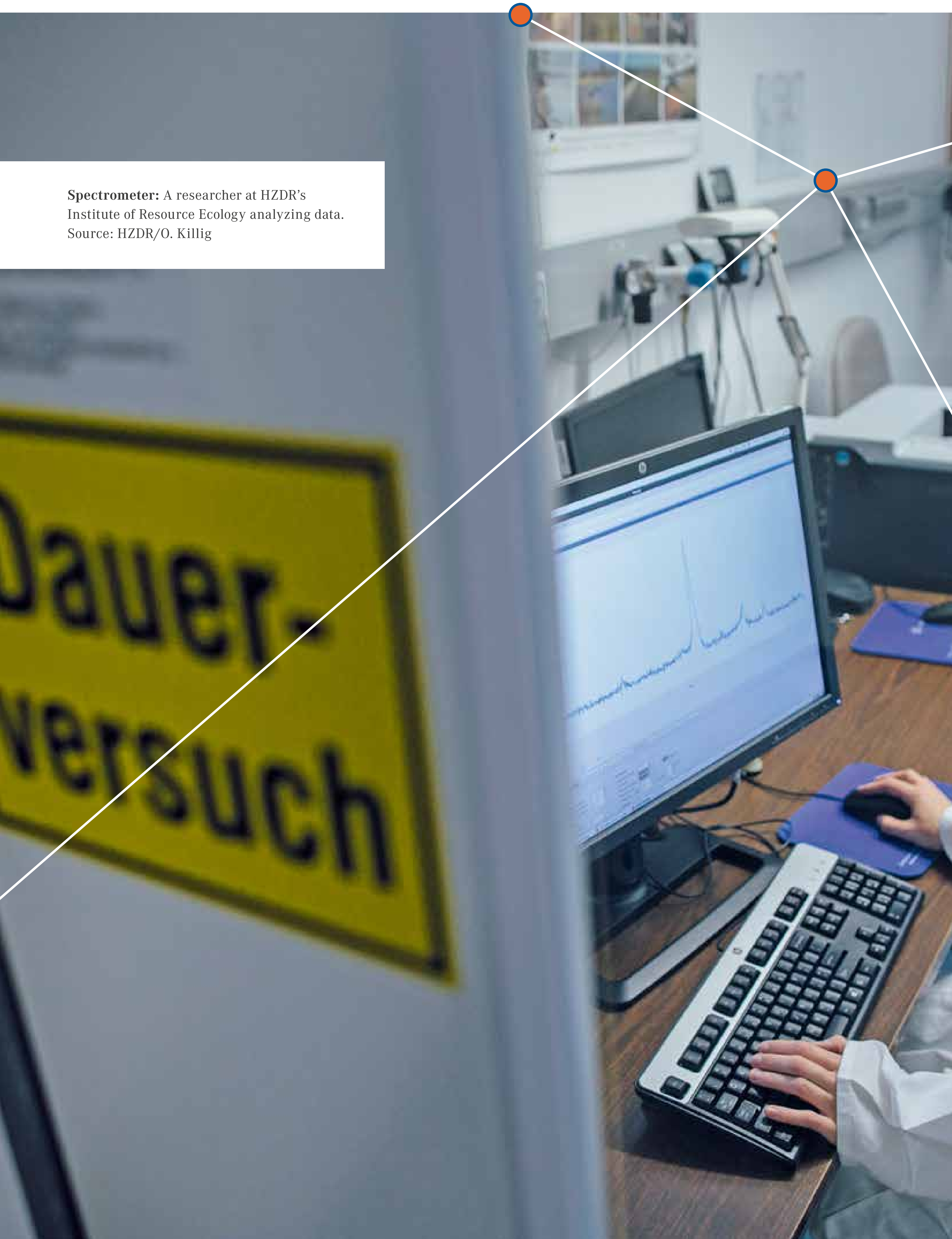

Spectrometer: A researcher at HZDR's Institute of Resource Ecology analyzing data. Source: HZDR/O. Killig

Unexpected insight

A less positive surprise awaited Steudtner, Foerstendorf, Tsushima and Müller, however, when they went about publishing their findings. It took much longer than expected. Admittedly, to coordinate a 60- to 80-page document with more than 40 co-authors was a challenge in its own right. However, the unexpected part came afterwards: "How difficult it is to place a publication like this in a common, scientific journal," says Harald Foerstendorf. In the end, they had submitted the mammoth article to four journals before it was finally accepted.

Foerstendorf suspects there were two reasons why it was so difficult. The one was the sheer volume of information, which apparently overstretched some of the reviewers. The scientists noticed that some had not read the manuscript right the way through and had not understood what it was all about. Furthermore, according to Foerstendorf, "Today people are fixated on new insights and when they are not so obvious, many think they are not interesting enough to be published."

They had the same experience with every journal. "Some of the reviewers were totally enthusiastic, but there was always one who thought there was nothing new," says Robin Steudtner. This was the initial reaction of the open-access journal ACS Omega, as well, which did eventually publish the piece in May 2019. In this case, the editor overruled the one critical reviewer because he thought the findings were so relevant. Amazing that something as important as the comparison of essential scientific tools could be so difficult to disseminate. Nevertheless, good on them that they did it. Now, they and their colleagues around the world can return to their daily business in peace, knowing that they can trust their methods.

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Innovation: virus-free room air

Uwe Hampel (right) and Gregory Lecrivain. Source: O. Killig

What happens when two leading international experts in fluid dynamics address the issue of increased COVID-19 infection rates in indoor spaces? A novel disinfection device that binds aerosols in a disinfectant liquid and thus purifies the air. On March 16, 2021, Uwe Hampel and Gregory Lecrivain were awarded the first prize in HZDR's Innovation Contest 2020. In comparison with conventional air purifiers, their device is not only particularly quiet but also deactivates the dangerous pathogens in the filter.

To turn a scientific idea into a marketable product – that is the aim of HZDR's Innovation Contest. Second place went to the junior research group headed by Franziska Lederer, BioKollekt, who wants to use innovative methods to detect plastics. In third place came another recycling idea from the Helmholtz Institute Freiberg for Research Technology (HIF) at HZDR. Tony Helbig and Norman Kelly produced a convincing concept for a recycling plant for extracting iron. The three winning teams had previously tested their ideas during a workshop devoted to utilization potential, market situation and fields of application. Successful teams have the opportunity of receiving up to 200,000 Euro from HZDR's Innovation Fund to continue developing their ideas.

www.hzdr.de/innovationswettbewerb

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

HZDR INNOVATION

Tip

The new film about HZDR's technology transfer vividly illustrates innovations deriving from its research.

www.hzdr.de/technologietransfer

Cross-border cooperation

In mid-March, HZDR's Scientific Director, Sebastian M. Schmidt, and the Rector of the University of Wrocław, Przemysław Wiszewski, signed a Memorandum of Understanding. This declaration of intent is designed to intensify future cooperation. Together, the two institutions want to reinforce the central European research area as well as the connections between Saxony and Poland. They will achieve this by jointly recruiting researchers, organizing workshops and exchange programs as well as sharing scientific information.

As the example of CASUS shows, the two partners have already established a stable foundation for cooperation. In the Center for Advanced Systems Understanding that is currently being set up under HZDR leadership in Görlitz, the University of Wrocław contributes, above all, its wealth of experience in autonomous driving and machine learning. With more than 23,000 students, it is one of the largest universities in Poland.

In the Department of Computer Science, the Computational Intelligence Research Group develops algorithms and systems for interpreting and predicting the behavior of various actors on the road – one of the biggest challenges facing autonomous driving. Moreover, in the project "Aleph One", the university operates a research platform for testing autonomous vehicles under real-life conditions and collecting the relevant data.

A woman's place is in the lab

Kristina Kvashnina. Source: ESRF/Molyneux

This was the title of the magazine "Forbes Russia" on February 11, 2021 – the international day of women and girls in sciences – when it chose the top ten Russian female researchers. They included Kristina Kvashnina, a physicist at the Helmholtz-Zentrum and a professor at Moscow State University. She works at HZDR's beamline ROBL at the European Synchrotron (ESRF), decoding the basic chemical structure of elements in the lanthanide and actinide groups, which include uranium and plutonium as well as some of the rare earths.

Just six weeks later, she was nominated by the Swiss National Science Foundation for the international database AcademiaNet which aims to help women in science become more visible and increase the percentage of women in scientific leadership positions. Since the nomination is undertaken exclusively by some 40 European science organizations, only the best candidates in their field are to be found there. In recent years, Kristina Kvashnina not only managed to acquire an ERC Starting Grant from the European Research Council but was also awarded a "Megagrant" by the Russian Ministry of Research.

www.forbes.ru
www.academia-net.org

Reconciliation of work and family life

In March, following an audit, the Board of Trustees of berufundfamilie GmbH, an initiative run by the non-profit Hertie Foundation, reconfirmed HZDR's status as a family-friendly employer, a certification it has held since 2008. "The new award emphasizes that our family-conscious HR policy really is sustainable," said a delighted Diana Stiller, HZDR's Administrative Director. The audit is seen as a strategic management tool offering solutions to improving the reconciliation of work and family life. The certificate is valid for a further three years.

From the Spree back to the Elbe

Science manager Diana Stiller became Administrative Director of HZDR in December 2020. She had previously been in charge of the main Administrative Department as well as the Finance and Accounting Departments at Helmholtz-Zentrum Berlin. Together with the Scientific Director, Sebastian M. Schmidt, she is now responsible for the future of the HZDR. With some 1,400 members of staff and an annual budget of approximately 157 million Euro, it is one of the largest non-university research institutions in Eastern Germany. The new board member will now be responsible for all commercial and technical matters: finance and accounting, legal matters, human resources, controlling, building and technical property management as well as all infrastructures and real estate. Born in Meißen, Diana Stiller acquired her extensive knowledge of these areas in her previous positions. "Four years ago, I left HZDR as a financial expert," she reports. "Now, I'm returning as a generalist for all commercial issues."

Diana Stiller. Source: A. Wirsig

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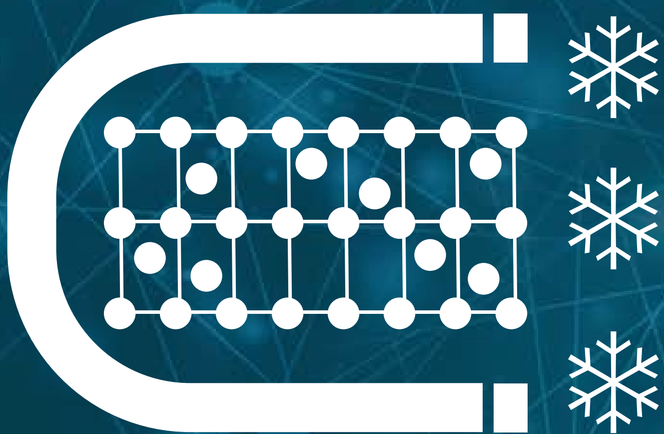
Research machines

Driving matter to extreme states in order to penetrate their innermost secrets – this is one of HZDR's research specialties. At the three large-scale research facilities, light and particle currents as well as magnetic fields, millions of times stronger than that of the Earth, are available for often unique experiments. And they are not only there for our own research teams. The center develops, builds and operates these facilities as a service provider for scientists around the globe.

New insights into the world of atoms are of inestimable value because research into the behavior of matter and materials under extreme conditions touches not only on our fundamental understanding of the world, but also has practical implications for future technologies.



XXL microscope

In the ELBE Center for High-Power Radiation Sources, scientists have a huge choice of experiments at their disposal. They can X-ray building blocks of matter and materials as well as biomolecules with electromagnetic radiation or bombard them with different types of particles. Each of these methods delivers further information about the samples. In the case of future materials, for example, the crystal structure, pore density or the electrical and magnetic behavior can be unraveled. With this acquired knowledge, researchers can equip materials with innovative functions, facilitating, for instance, ultrafast mobile phone connections and wireless networks.

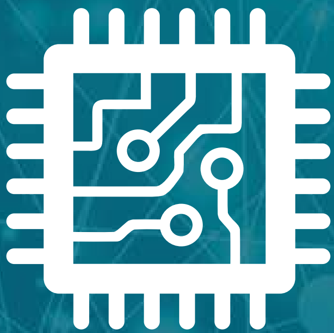
Moreover, the DRACO lasers at ELBE mean HZDR can boast two superlative high-performance systems. The lasers' high beam power accelerates particles in fractions of a second. In comparison with established accelerators, the forces generated are many thousands of times greater. One important goal of activities here is to develop compact equipment for treating tumors with protons.

Highest magnetic fields in the European alliance

A perfect example of sustainable cooperation at EU level is the alliance of the three leading high magnetic field laboratories, the European Magnetic Field Laboratory (EMFL), which includes the Dresden High-Magnetic Field Laboratory (HLD). The super-strong magnetic fields generated here can specifically impact material properties, uncovering new details about superconductors, magnetic materials and semiconductors – all basic knowledge that is not only fundamental to the development of future materials but also for tomorrow's advanced technologies. The magnet experts' know-how is thus also in demand worldwide for developing efficient, environmentally-friendly cooling techniques.

Fast charged particles for industry

Ion beams are an important tool for researching and developing new materials. At its Ion Beam Center (IBC), HZDR has one of the world's most high-performance research facilities of its kind. With the help of the HZDR Innovation GmbH, an HZDR subsidiary, firms and enterprises can get support in using modern ion beam technologies for innovative products – from materials with tailored surfaces through to novel or greatly enhanced components. The micro-electronics and the automotive sectors, in particular, take advantage of this opportunity.



But that's not all!

HZDR builds and operates other large-scale facilities for its three research programs matter, energy and health.

… AT THE DRESDEN SITE:

- Underground accelerator laboratory in the *Felsenkeller* Dresden
- High-performance computing center
- Thermohydraulic test facility TOPFLOW
- DRESDYN – European platform for sodium experiments
- Center for Radiopharmaceutical Tumor Research (ZRT)
- Accelerator facility at *Universitäts Protonen Therapie Dresden* (UPTD), which is jointly operated with the Faculty of Medicine

… AT SCHENEFELD:

- Helmholtz International Beamline for Extreme Fields (HIBEF) at the European XFEL

… IN GRENOBLE, FRANCE:

- Rossendorf Beamline (ROBL) at the ESRF

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