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The DESY research magazine – Issue 03/16

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DESY

How the amber midge made its mark

Midges are tiny flies that generally attack in a swarm. Over 190 species can be found in Germany alone. Palaentologists have now discovered an unusual species trapped in a piece of amber 54 million years old. While prospecting for this fossilised resin in India, Frauke Stebner from the University of Bonn in Germany came across an inclusion less than a millimetre across. Inside were the remains of this ancient insect. However, it was not until the specimen was placed under the intense X-rays of DESY's PETRA III light source that an unusual feature was revealed. The three-dimensional digital model of the tiny insect showed that the female midge had a unique vesicular structure at the front edge of each of wing. "Today's species of midge don't have these 'pockets' on their wings," Stebner explains. Butterflies, which are substantially more developed than the midge, do have similar structures. "They have very similar pockets on their front wings, which they use to spray pheromones into the air in order to attract a mate," says Stebner. The position at the wing edge means the pheromones are dispersed as widely as possible into the surrounding air.

While today's midges do use attractants, these are emitted from the abdomen rather than the wings. Amazingly, the pheromone spray mechanism of the fossilised insect is significantly more complex than in "modern" midges. Quite possibly, in the virgin forests of 54 million years ago, there were so many different species of insect around, all emitting attractants, that extremely effective spray techniques were required to make a mark at all in this heady brew of scents.

Scientific Reports, 2016; DOI: 10.1038/srep34352

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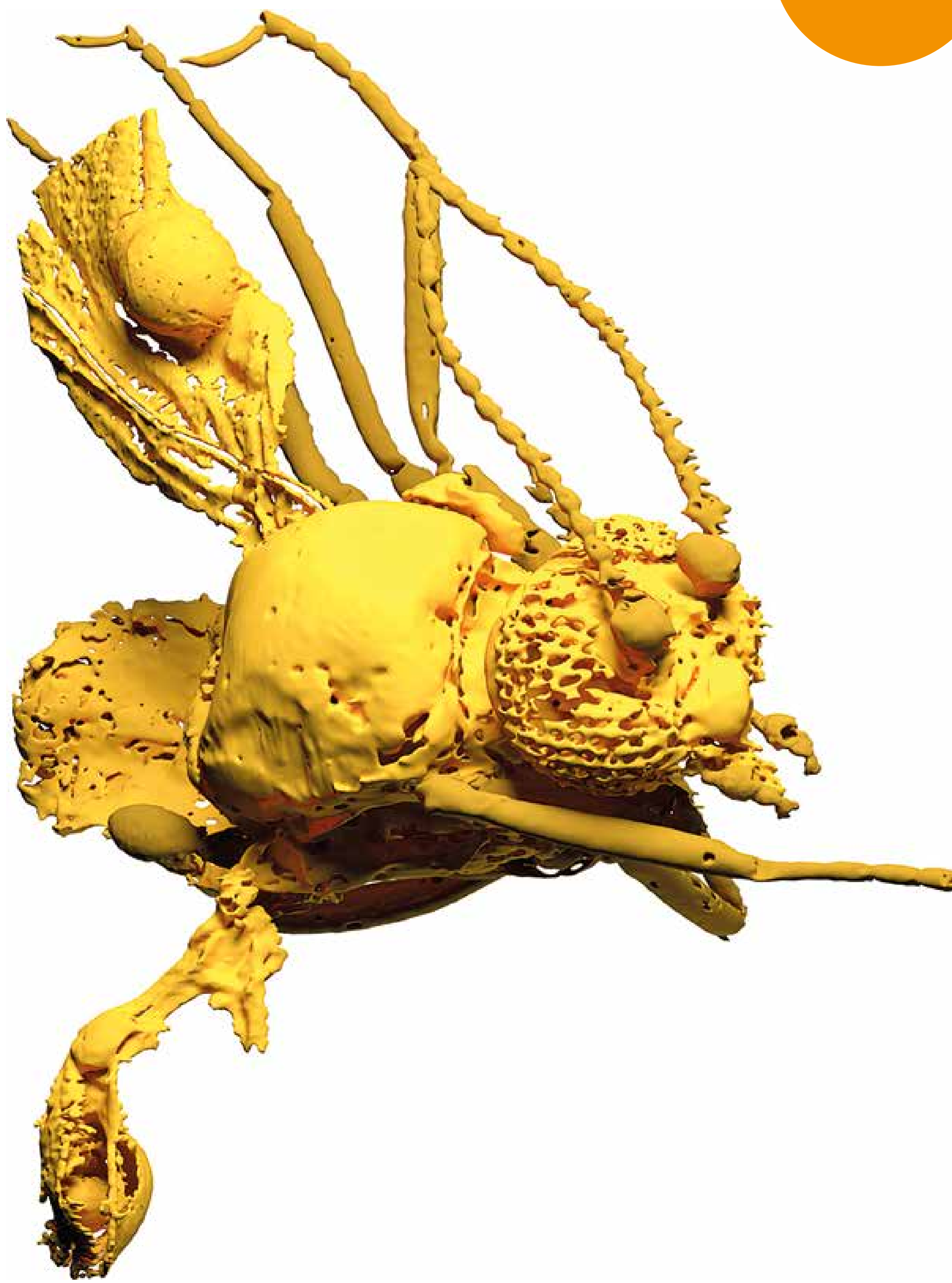

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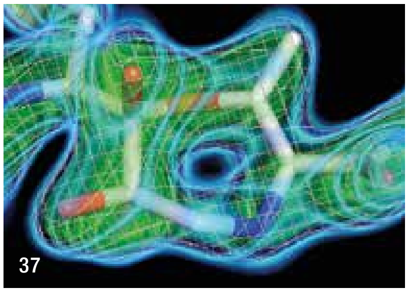
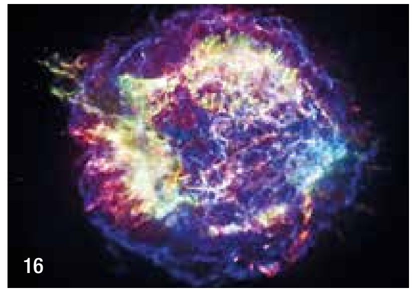
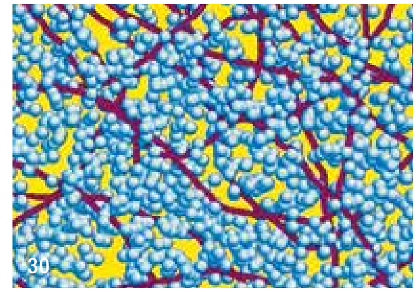






CAMPUS

ZOOM

SPECTRUM

SECTIONS

“The Scream” and the secret of the white spots

An art thriller

It all started with a few mysterious traces on a world-famous painting: “The Scream” by Edvard Munch. The expressive brush strokes of the Norwegian painter are overlaid by smudges of an unknown white substance, around which various speculations have sprung. The nature-loving Norwegians favoured the following explanation: It is known that Munch liked to paint outdoors and that he even stored his paintings there, often only scantily protected from the weather. “The Scream” entered the Norwegian National Museum’s collection directly from the artist’s studio, and the white splatters have always been present. All of this resulted in a theory that Munch would have left “The Scream” outside and that birds flying by literally added another layer of meaning to Munch’s masterpiece.

“Bird droppings can pose a significant threat for monuments, outdoor statues and brand new cars,” says Geert Van der Snickt, cultural heritage scientist at the University of Antwerp, who comprehensively studied “The Scream”. “But I did not associate it with easel paintings, and certainly not with quintessential masterpieces that are valued over 100 million dollars.”

Tine Frøysaker of the University of Oslo, who has been recurrently confronted with bird excrements in the Norwegian Stave churches where she worked throughout her career as conservator, was not convinced by the bird droppings theory either, as the white spots do not look anything like bird droppings under the microscope.

Thierry Ford, paintings conservator at the National Museum, subscribes to that opinion, as “bird excrements are known to have a corroding or macerating effect on many materials, a statement that most car owners can confirm”. In the case of Munch’s painting, the white substance seems to lie on top of the paint. Moreover, in some areas, the white matter seems to have flaked off through the years without leaving any sign of damage.

Bird droppings or paint splatter?

Another argument opposing this theory is the fact that Munch employed a cardboard substrate to paint “The Scream”, a material that would have suffered severe damage when left outdoors. “It seemed more plausible that the splatters were actually white paint or chalk that had accidentally dripped onto ‘The Scream’ while Munch was working on other paintings in his studio,” says Frøysaker.

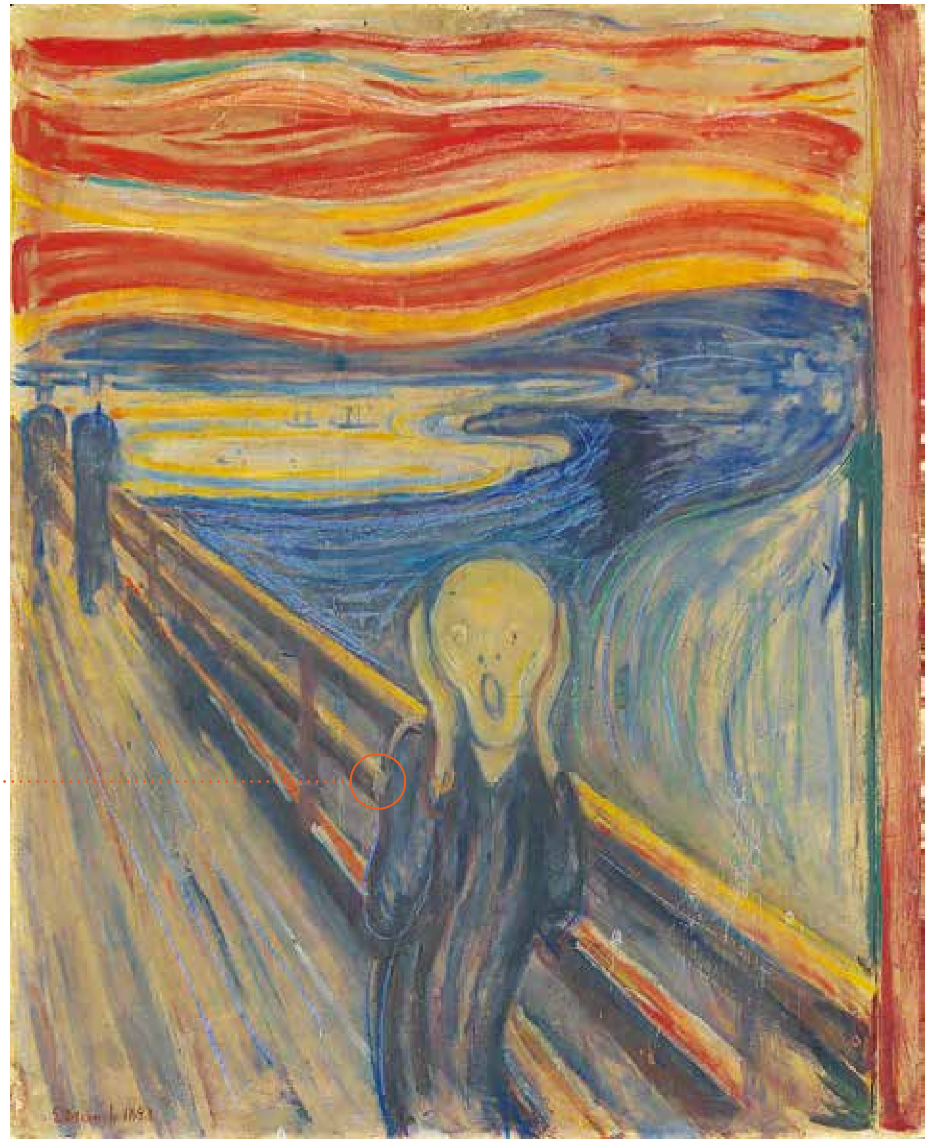
However, in spite of these logic arguments, the urban legend of the bird droppings proved hard to erase, especially as this aspect of the national treasure would dovetail nicely with the Norwegian spirit of nature bonding.

> *“It seemed more plausible that the splatters were actually white paint that had accidentally dripped onto ‘The Scream’”*
>
> *Tine Frøysaker, University of Oslo*

In May 2016, Frøysaker invited the Antwerp team to Oslo in order to characterise the painting materials and techniques used by Munch. As Van der Snickt explains, the bird droppings were certainly not the primary aim, “but it would have been a mistake not to exploit the Antwerp state-of-the-art equipment to try and settle the long-standing bird droppings dispute”.

The painting was therefore submitted to a mobile X-ray fluorescence scanner developed in Antwerp. Surprisingly, this investigation ruled out the paint option, as neither white pigments nor calcium were detected inside the enigmatic smudges.

“The Scream” by Edvard Munch (1863–1944) has become an icon of the European art canon. “In the final years of the nineteenth century, Edvard Munch made four versions of ‘The Scream’, a painting that is nowadays considered as vital for the later development of Expressionism,” explains Nils Ohlsen, director of old masters and modern art at the Norwegian National Museum in Oslo. Although one of the versions was sold in 2012 for a staggering 119 million dollars (nearly 100 million euros at the time), the most renowned version is undoubtedly the painting that is part of the collection of the Norwegian National Museum. This work differs from the others not only in the fact that it is considered as the earliest version, but also because it features a series of enigmatic white splatters on the surface (magnified).



Bird droppings or paint? Close-up of a stain.

Pictures: Norwegian National Museum

Undaunted by the result, the scientists decided to take the research to the next level. They extracted tiny samples from the white stains and analysed them using the brilliant X-ray radiation generated by DESY’s research light source PETRA III. “From the X-ray scattering pattern that is produced by the sample under investigation, its internal structure can be determined down to the atomic scale,” explains DESY researcher Gerald Falkenberg, head of the measuring station where the examinations took place. Particle accelerators such as PETRA III produce particularly intense X-ray light with special properties.

“The introduction of particle accelerators has caused a revolution in our understanding of how historical paint systems behave”

Koen Janssens, University of Antwerp

“The introduction of particle accelerators for the investigation of paint materials has caused a revolution in our understanding of how historical paint systems behave,” says chemistry professor Koen Janssens from Antwerp. “In the last few years, we were able to unravel various complex chemical degradation processes that cause paintings to discolour or flake, ››

Edvard Munch with his paintings in the snow (Ekely near Oslo)

knowledge that will eventually lead to an improved conservation."

The case is closed

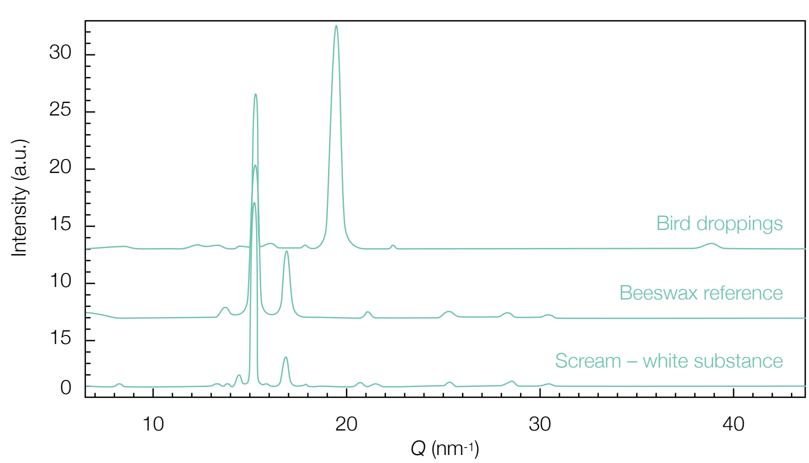
PhD student Frederik Vanmeert, who analysed the DESY measurement data of Munch's "Scream", had a surprise in store. "I immediately recognised the diffraction pattern of wax crystals, as I encountered this material several times upon measuring paintings." In the past, unstable paintings were often impregnated with beeswax or a similar waxy material in order to consolidate flaking paint or to attach a new canvas to the back of a degraded old one. In the case of "The Scream", it is most likely that the white spots are in fact splatters of molten wax that accidentally dripped from a candle in Munch's studio onto the painting.

And what about the bird droppings? "Initially, I planned to go sightseeing on my last day in Oslo," recalls Van der Snickt. "It turned out that I spent most of my time looking down, searching for bird droppings on the ground that could serve as reference material. After some time, I found a perfect specimen right in front of the opera building. I must admit I was a little embarrassed collecting this sample material in front of groups of tourists. For a second sample, I decided to look for a more quiet place, around the castle."

"The measurement data of bird droppings do not match the material of the white spots, which match the data of beeswax"

Gerald Falkenberg, DESY

In order to make sure, the bird droppings were also examined at PETRA III. "It can be seen at first glance that the measurement data of bird droppings do not match the material of the white spots, which match the data of beeswax," says Falkenberg. "It is true that the composition of bird droppings is strongly dependent on the nutrition of the bird, but I sincerely doubt that Munch's painting was sprayed by birds that happened to be fond of wax," concludes Van der Snickt. "As such, I think we can close the case on the bird droppings."



Measurement data from bird droppings, the mysterious white spots and beeswax, analysed at DESY's X-ray light source PETRA III

Picture: University of Antwerp

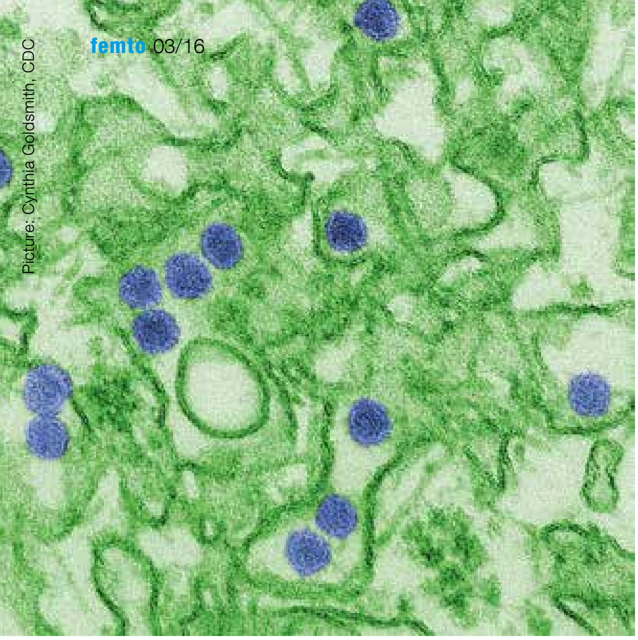
Battling the Zika virus

With the help of X-ray structural analysis, biochemists have laid a key foundation for the development of an effective antiviral drug

Picture: James Gathany, CDC

The yellow fever mosquito (*Aedes aegypti*) is a type of mosquito found in tropical and subtropical regions. It is the chief vector of Zika, yellow fever, dengue fever and other viral diseases.

Viruses are unpredictable: some are dangerous, others much less so. Some can alter their structure, their mode of transmission, or their propagation strategy. It's a devious behaviour pattern – one that is also displayed by the Zika virus. Science has known about the virus for a long time. It was first isolated in a monkey back in 1947 in the Zika forest of Uganda. For the last 60 years or so, scientists have kept a watchful eye on it. There have been several human epidemics of the disease in Micronesia and other island states in the Pacific. The virus is currently rife is Central and South America. From there, it has now spread to the southern states of the USA, particularly Florida. Experts have also confirmed the local transmission and spread of the virus several thousands of kilometres away, in Singapore. Immunologists are perplexed as to why the Zika virus has spread so widely since 2015. In this light, the search for a vaccine or drug against the virus has taken on a new urgency. ››



Transmission electron microscope (TEM) image of the Zika virus. The virus particles (coloured blue) are 40 nanometres (millionths of a millimetre) in diameter.

A number of potential vaccines are already undergoing clinical trials. At the same time, a research group headed by Rolf Hilgenfeld from the University of Lübeck in Germany has now laid a key foundation for the development of an effective antiviral drug. Using the brilliant light from DESY's X-ray source PETRA III, the biochemists have been able to image the three-dimensional structure of a key enzyme of the Zika virus with atomic resolution. The virus uses this enzyme, which is known as NS2B-NS3 protease, to generate essential proteins and parts of the viral envelope of new virus particles.

The fever continues to spread

The chief vectors of the virus are mosquitoes of the genus *Aedes*. In many cases, the disease is accompanied by no symptoms or, at worst, mild flu-like symptoms. That is also why the Zika virus was never a candidate for vaccine or drug development before 2015. Since then, however, there has been a proliferation of cases, with more than one million infections in 60 countries registered. The associated risks for pregnant women and their unborn children are especially high. If transmitted during pregnancy, the virus can lead to microcephaly in the foetus. To date, thousands of babies have been born with this condition, a deformation of the skull that prevents the head from developing to its proper size.

As Hilgenfeld explains, four of the virus' enzymes offer the most promising targets for drugs. Of these, there is only one – NS2B-NS3 protease – whose three-dimensional structure has now been imaged with atomic resolution, using X-ray structural analysis at PETRA III. "None of the other candidates is anything like as advanced," says Hilgenfeld. What's more, this protease is an ideal target, since it is essentially the engine that enables the Zika virus to replicate. If you can block it, you've disabled the pathogen. "Viruses have a limited lifespan; that's why they need to keep on replicating," Hilgenfeld explains. "If they can't do that, then the infection is stopped."

Several stages of structural analysis

To analyse the molecular structure of this key enzyme with the help of short-wave X-rays, Hilgenfeld and his team first had to crystallise the NS2B-NS3 protease – a tricky task, since biomolecules do not like being forced into a rigid crystalline form. The next step was to irradiate the crystals with X-ray light. This produces an X-ray diffraction image with a distinctive pattern of bright dots, known as Bragg peaks. Using the position and intensity of these dots, a computer is able to reconstruct the structure of the crystal and therefore of the enzyme molecule.

> *"On the basis of this three-dimensional structural analysis, we can produce improved inhibitors and can, hopefully, soon have a molecule that is suitable for drug development"*
>
> *Rolf Hilgenfeld, University of Lübeck*

It took Hilgenfeld and his team thousands of attempts before they were able, with the help of a robot, to crystallise the key enzyme of the Zika virus. And then came the next surprise. Under the brilliant X-ray light of PETRA III, Hilgenfeld saw that the crystals "displayed a rare phenomenon: they were twinned". In other words, there was one crystal lattice lying on top of another. "It seemed like fate was against us," says Hilgenfeld. "Separating the two lattices mathematically is by no means straightforward." Finally, however, they had what they wanted: a three-dimensional model of the protease from the Zika virus.

Along with the enzyme, the team was also able to crystallise an inhibitor that blocks and thereby disables the viral protease. This so-called boronic-acid inhibitor was produced by a team led by Christian Klein from the University of Heidelberg in Germany. “Unfortunately, this inhibitor is not very specific,” says Hilgenfeld. “It blocks not only the viral enzyme but also other enzymes in the human body.” This makes the inhibitor unsuitable as a drug. “But on the basis of this three-dimensional structural analysis, we can produce improved inhibitors and can, hopefully, soon have a molecule that is suitable for drug development,” says Hilgenfeld.

Search for a universal inhibitor

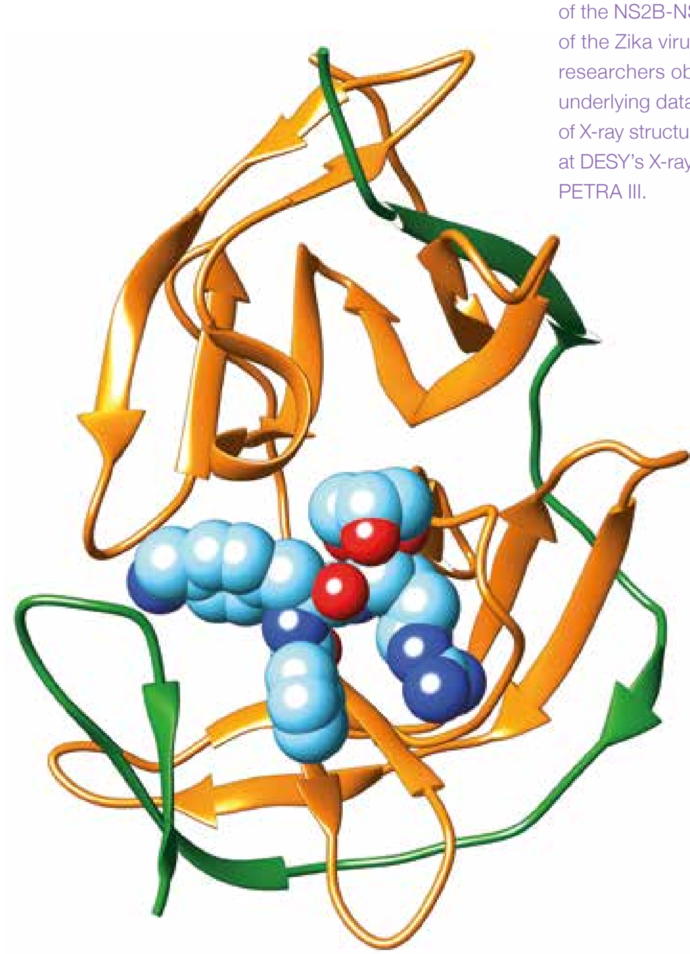
The researchers are adopting two approaches. On the one hand, they are computer-searching substance libraries containing over two million small molecules and filtering out those that theoretically might fit the active site of the protease. “We’ll buy the first 50 that fit and then test them to see if they inhibit the protease,” says Hilgenfeld. On the other hand, the researchers are also trying to develop a new inhibitor by synthesising ligands that fit the binding sites on the surface of the protease. As Hilgenfeld explains, their ambitious goal is “to search for a universal inhibitor that blocks the viral enzymes but doesn’t affect human enzymes”. Such an inhibitor would also disable the enzymes of other flaviviruses, such as those responsible for yellow fever, dengue fever and West Nile fever.

A further complication with the Zika virus is the difficulty of developing a medication suitable for pregnant women. The aim is therefore to give it as a prophylactic drug to people who are in contact with pregnant women and so break the transmission chain of the yellow fever mosquito. The researchers also hope that such a drug will eliminate the long-term neurological effects of a Zika virus infection.

Other researchers are also interested in Hilgenfeld’s structural analysis. “You can see that by the number of requests we’ve already had,” he says. In other words, his work is already being used in other areas of drug development. Hilgenfeld is optimistic that there will soon be an inhibitor for the Zika virus protease. Nevertheless, it will still take time before a new drug reaches the market. Before a drug is approved, it is must undergo years of clinical trials. “That won’t help the people who are already infected with the Zika virus,” says Hilgenfeld. “That’s why we’re looking for a broad-spectrum antiviral drug, which will, hopefully, be effective against all flaviviruses.”

New approach to crystal growing

In the battle against the Zika virus and future viral infections, Hilgenfeld’s team is also working closely with the biochemist Lars Redecke, who is looking into a new method of crystallising proteins. The University of Lübeck and DESY have recently created a joint professorship for his interdisciplinary research. Redecke’s innovative approach exploits the ability of living cells to grow crystals. According to his own words, the process sounds amazingly easy: “You simply introduce the protein gene into insect cells and then wait and see. With a bit of luck, and if everything works out, you get crystals, which you then just have to harvest.” In future, however, the researchers are not planning to leave everything to luck. Once they have understood how the insect cells crystallise the proteins, they want to adapt the method specifically to different proteins. In this way, they will be able to develop an alternative way of crystallising those proteins that resist the classic methods of crystallography. ››



Three-dimensional structure of the NS2B-NS3 protease of the Zika virus. The researchers obtained the underlying data by means of X-ray structural analysis at DESY’s X-ray light source PETRA III.

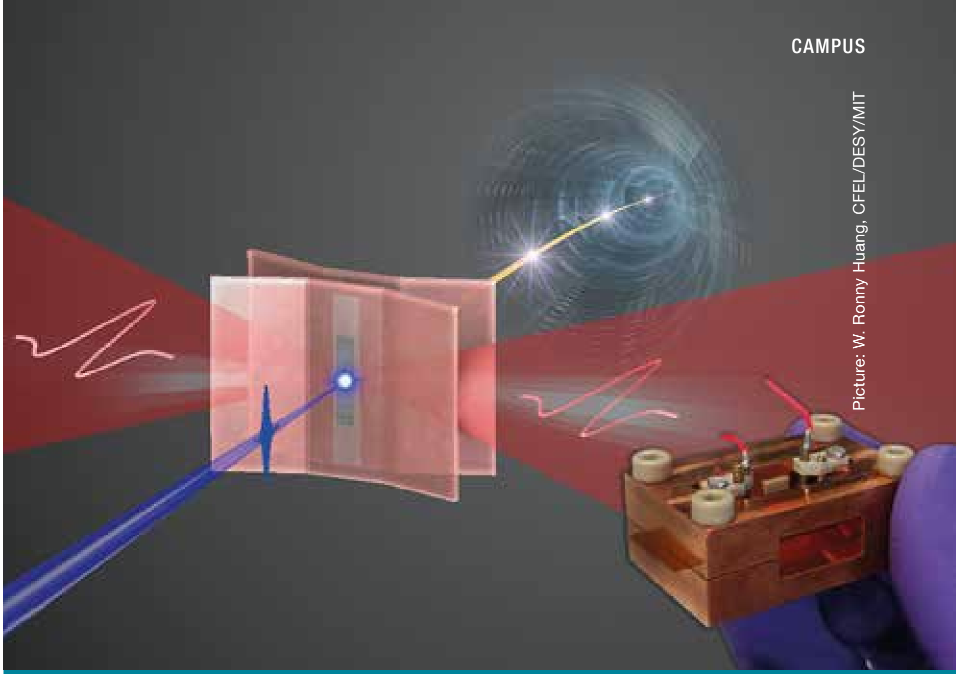
Picture: Rolf Hilgenfeld, University of Lübeck

Ultimately, their ambitious goal is to establish a kind of production line process for growing protein crystals. "When a new virus appears, we can then analyse the crystal structure of a large number of viral proteins in a relatively short time," says Redecke. This in turn would accelerate the development of new drugs.

> *"When a new virus appears, we can then analyse the crystal structure of a large number of viral proteins in a relatively short time"*
>
> *Lars Redecke, University of Lübeck*

Using insect cells, Redecke and his team have already been able to crystallise two further Zika proteins. Alongside the NS2B-NS3 protease, these could serve as further drug targets. "If we can crystallise these two proteins in sufficient quantities and then analyse their structure, it would be a big advance in the research and development of a new drug to combat the Zika virus," underlines Redecke.

Science, 2016; DOI: 10.1126/science.aag2419



Picture: W. Ronny Huang, CFEL/DESY/MIT

Scientists shrink electron gun to matchbox size

An interdisciplinary team of researchers from DESY and the Massachusetts Institute of Technology (MIT) has built a new kind of electron source – also called electron gun – that is just about the size of a matchbox. The miniature electron gun generates short and tightly collimated beams of electrons that can be used for the investigation of various materials, from biomolecules to superconductors. It can also provide tailored electron bunches for the accelerators of the next generation of X-ray lasers. The team of DESY scientist Franz Kärtner presented its miniature electron gun in the scientific journal *Optica*.

The new device uses laser-generated terahertz radiation instead of the usual radio frequency fields to accelerate electrons from rest. As the wavelengths of terahertz radiation are much shorter than those of radio frequency radiation, the new electron gun can be made much smaller than conventional ones. While state-of-the-art electron guns can have the size of a car, the new device measures just 34 by 24.5 by 16.8 millimetres – which is smaller than a matchbox.

"Electron guns driven by terahertz radiation are miniature and efficient," explains main author W. Ronny Huang from MIT, who carried out this work at the Center for Free-Electron Laser Science (CFEL) in Hamburg, a cooperation of DESY, the University of Hamburg and the German Max Planck Society. "Also, the materials used to guide the radiation are susceptible to much higher fields at terahertz wavelengths as compared to radio frequency wavelengths, allowing terahertz radiation to give a much stronger 'kick' to the electrons. This has the effect of making the electron beams much brighter and shorter."

A miniature electron gun driven by terahertz radiation: An ultraviolet pulse (blue) back-illuminates the gun's photocathode, producing a high-density electron bunch inside the gun. The bunch is immediately accelerated by ultra-intense single-cycle terahertz pulses to energies approaching one kiloelectronvolt. These high-field, optically driven electron guns can be utilised for ultrafast electron diffraction experiments or injected into accelerators for X-ray light sources.

The ultrashort electron beams with narrow energy spread of the individual particles, high charge and low jitter could be used for ultrafast electron diffraction experiments to resolve phase transitions in metals, semiconductors and molecular crystals, for example.

"The accelerating field was almost twice that of current state-of-the-art electron guns"

W. Ronny Huang, MIT

"Our device has a nanometre-thin film of copper which, when illuminated with ultraviolet light from the back, produces short bursts of electrons," describes Huang. "Laser radiation with terahertz frequency is fed into the device, which has a microstructure specifically tailored to channel the radiation to maximise its impact on the electrons." This way, the device reached an accelerating gradient of 350 megavolts per metre. "The accelerating field was almost twice that of current state-of-the-art electron guns," says Huang. "We achieved an acceleration of a dense packet of 250 000 electrons from rest to 500 electronvolts with minimal energy spread. Because of this, the electron beams coming out of the device could already be used for low-energy electron diffraction experiments."

CFEL boasts high-power laser labs in which the required laser radiation can be produced. In the new device, the ultraviolet flash used to eject the electrons from the copper film is generated from the same laser as the accelerating terahertz radiation. "This ensures absolute timing synchronisation, substantially reducing jitter," explains Huang. The device worked stably over at least one billion shots, easing every-day operation.

"Electron guns are used ubiquitously for making atomic-resolution movies of chemical reactions via ultrafast electron diffraction as pioneered in Dwayne Miller's group at the Max Planck Institute for the Structure and Dynamics of Matter and CFEL," says Kärtner. "With smaller and better electron guns, biologists can gain better insight into the intricate workings of macromolecular machines, including those responsible for photosynthesis. And physicists can better understand the fundamental interaction processes in complex materials."

"Furthermore, electron guns are an important component of X-ray laser facilities," explains Kärtner. Next-generation terahertz electron guns producing ultrashort and ultrabright electron bunches up to relativistic energies and of only ten femtoseconds (quadrillionth of a second) duration are currently in development at CFEL. "These devices will be used as photoinjectors for attosecond table-top X-ray lasers," says Kärtner. An attosecond is a thousandth of a femtosecond. At DESY, such electron guns and X-ray lasers are being developed within the AXSIS (Frontiers in Attosecond X-ray Science: Imaging and Spectroscopy) programme.

Optica, 2016; DOI: 10.1364/OPTICA.3.001209

Franz Kärtner leads the Ultrafast Optics and X-rays group at DESY. He is also a professor at the University of Hamburg and runs a research group at the Massachusetts Institute of Technology (MIT) in the USA.

"With better electron guns, biologists can gain insight into the workings of molecular machines responsible for photosynthesis"

Franz Kärtner, DESY

ZOOM

The discovery of cosmic particle accelerators

Astrophysicists explore the high-energy universe

From the heavens above, a high-energy shower of subatomic particles rains down continuously onto our planet. Every second, around 500 quadrillion high-speed atomic nuclei enter the Earth's atmosphere. Some of these cosmic particles possess as much energy as a powerfully hit tennis ball. Ever since the discovery of these so-called cosmic rays around a century ago, researchers have puzzled over what could be responsible for accelerating the particles to such energies – which are a million times higher than what the largest particle accelerators ever built by human hands can achieve. Step by step, astrophysicists are unveiling the mysteries of these natural particle accelerators in outer space.

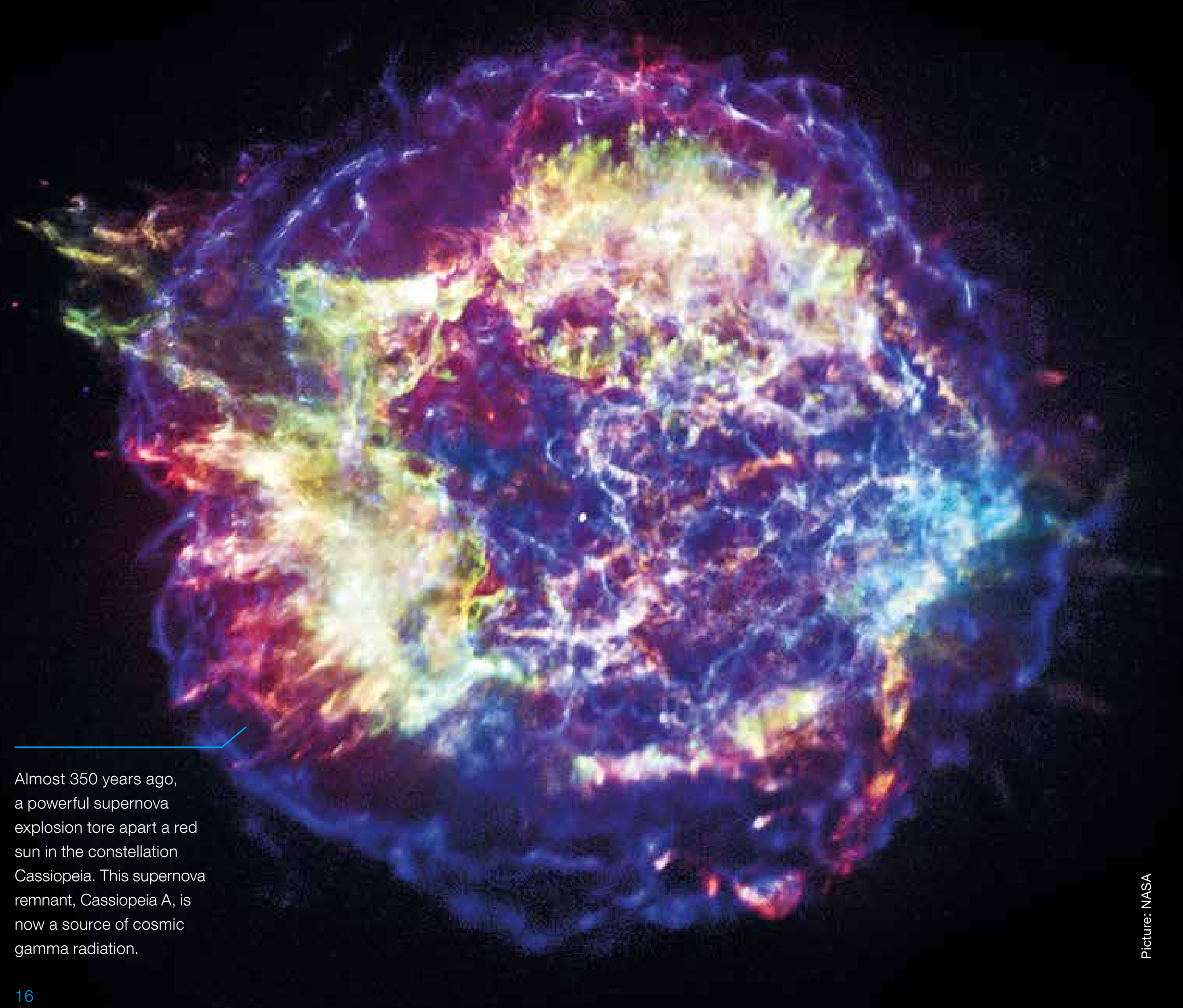
Picture: ESO/M. Kornmesser

Artist's impression of the centre of an active galaxy: Rotating around the central black hole, which has already swallowed up the mass of around one billion stars, is a gigantic maelstrom of matter swirling into the hole. A portion of this matter is reflected and ejected vertically into space as tightly focused streams of matter, known as jets. This type of cosmic particle accelerator can accelerate atomic nuclei to energies a million times greater than are feasible with any terrestrial accelerator.

Beyond the peacefully twinkling heavens lies a high-energy universe full of extreme phenomena: exploding stars that transmit shock waves across the galaxy, gigantic maelstroms sucking entire stars into black holes and exotic binary stars ejecting tightly collimated particle beams into space. “The universe is full of natural particle accelerators,” explains Christian Stegmann, head of the DESY location in Zeuthen. “To date, we have identified around 150 of these fascinating objects, and we’re beginning to have a nascent scientific understanding of them.” Thanks to new methods and instruments, researchers are exploring the high-energy cosmos in ever greater detail.

“The universe is full of natural particle accelerators”
Christian Stegmann, DESY

This quest involves more than just an understanding of the phenomenon of cosmic radiation. “A crucial question is what role cosmic radiation plays in the development of the Milky Way and of the universe as a whole,” says Stegmann. “For example, cosmic radiation is what prevents the disc of the Milky Way from collapsing.” It’s the high energy of these speedy particles that makes them so important. The energy density of cosmic radiation is comparable to that of optical photons in space or to that of cosmic magnetic fields. Moreover, as DESY researcher Stefan Ohm explains, cosmic-ray particles not only stabilise our own galaxy but can also play a role in the creation of new stars: “Cosmic rays penetrate interstellar molecular clouds, where they trigger complex astrochemical processes.”



Almost 350 years ago, a powerful supernova explosion tore apart a red sun in the constellation Cassiopeia. This supernova remnant, Cassiopeia A, is now a source of cosmic gamma radiation.

Picture: NASA

High-flyer takes Nobel Prize

Picture: VF Hess Society, Echo-physics, Schloss Pöllau/Austria

Victor Hess in the basket of a balloon (1911 or 1912)

Around midday on 7 August 1912, the Austrian physicist Victor Franz Hess descended in his hydrogen balloon to the town of Bad Saarow in Brandenburg, Germany. He had just made a discovery that would have far-reaching consequences. During his seventh balloon trip of that year, at a height of 5300 metres above Lake Schwieloch in south-eastern Brandenburg, he had demonstrated – with the aid of three devices for measuring ionisation – the existence of a penetrating radiation at altitude. Only many years later did scientists realise that this so-called cosmic radiation is in fact first and foremost a shower of high-energy electrically charged atomic nuclei and other particles. Twenty-four years after his discovery, Hess was awarded the Nobel Prize.

"The detection of cosmic radiation was a ground-breaking discovery that has given us completely new insights into the universe," emphasises Christian Stegmann. "At the same time, it was one of the pillars of early particle physics. Before the development of particle accelerators, it was cosmic radiation that enabled the discovery of a number of important elementary particles, such as the positron – the antiparticle of the electron – as well as the muon and the pion."

Whereas the chance discovery of X-rays was immediately celebrated and, within a few years, brought about a revolution in medical diagnostics, it was more than 15 years before cosmic radiation achieved general scientific recognition. Research into the properties of cosmic rays began only in the second half of the 1920s. It soon became evident that contrary to previous assumptions, cosmic radiation consists of particles, which in the atmosphere produce cascades of secondary particles known as air showers.

The discovery of the positron in 1932 launched the field of elementary particle physics. Over the following 15 years, until the start of operation of the first particle accelerator in Berkeley in the USA, the study of cosmic rays provided the field's chief source of knowledge. At the beginning of the 1950s, elementary particle physics research shifted to experiments with accelerators.

The field of astroparticle physics focused initially on the investigation of high-energy air showers. To this day, however, the origin of cosmic radiation has not yet been fully explained.

We now know that almost 90 percent of the shower of particles from space is made up of hydrogen nuclei, i.e. protons. The remainder consists primarily of helium nuclei, so-called alpha particles. Altogether, heavy atomic nuclei account for a share of only around one percent. Whereas the composition of cosmic rays is now very well researched, astrophysicists still do not properly understand their origin. The big challenge regarding the sources of cosmic radiation is that the protons and other high-speed atomic nuclei in cosmic rays carry an electrical charge and are therefore deflected by the numerous magnetic fields in the universe. For this reason, the direction from which these rays hit the Earth's atmosphere does not point back to their initial origin.

Luckily for researchers, however, cosmic particle accelerators almost always also generate high-energy gamma radiation and high-speed neutrinos. Neither gamma rays nor neutrinos – which are electrically neutral elementary particles – are deflected by cosmic magnetic fields. In other words, their direction of approach shows exactly where they originated. "The investigation of cosmic rays has led to new branches of research – in particular, new types of astronomy – and these have a very promising future," explains Sir Arnold Wolfendale, former Astronomer Royal to the British Crown. "Whereas neutrino ››

> *"The investigation of cosmic rays has led to new branches of research"*
>
> *Sir Arnold Wolfendale, former Astronomer Royal to the British Crown*

astronomy is just beginning, gamma astronomy is already well under way."

Unfortunately, both of these cosmic messengers are difficult to observe. Neutrinos very rarely interact with other particles – but this is the only way they can be detected. Around 60 billion neutrinos whizz through each square centimetre of the Earth's surface every second of the day, almost all of them without leaving any trace whatsoever. An international consortium including DESY as one of its leading members has built the world's largest particle detector at the South Pole to hunt for these cosmic neutrinos. Known as IceCube, this underground observatory comprises over 5000 photomultipliers distributed within a cubic kilometre of ice. These highly sensitive devices are on the lookout for the flashes of light that indicate the very rare collision between a neutrino and a particle locked in the ice.

The observatory has already detected spectacularly high-energy neutrinos from the far reaches of outer space. To date, however, scientists have only been able to roughly narrow down the direction of origin of these particles. "Following these initial discoveries with IceCube, our aim now is to progress as soon as possible to precision measurements in neutrino astronomy," explains DESY researcher Markus Ackermann. To this end, scientists are already looking at options for expanding the international observatory.

Particle showers faster than the speed of light

Meanwhile, the field of gamma astronomy is somewhat further advanced. The images it produces are not as sharp as those of optical astronomy. Nevertheless, in the interesting energy range, it still provides a resolution of between two and three hundredths of a degree, which is around one twentieth of the diameter of the full moon as visible from Earth. The big challenge for gamma astronomy is to sift out the comparatively few gamma quanta from the multitude of atomic nuclei in cosmic rays.

When energetic nuclei or gamma quanta from outer space enter the Earth's atmosphere, they collide with air particles and smash them to pieces. The resulting debris travels so fast that it breaks up further particles, the fragments of which, in turn, destroy even more particles. The result is a cascade of secondary particles that physicists refer to as an air shower. The particles in this air shower move at velocities that are even greater than the speed at which light travels through air. Nevertheless, they do not violate Albert Einstein's universal speed limit, as this corresponds to the speed of light in a vacuum, whereas the speed of light through air is somewhat lower.

As these particle showers are moving faster than the speed of light through air, the result is something like the optical equivalent of a sonic boom: a bluish flash of light known as Cherenkov radiation, which is named after its discoverer, the Soviet scientist Pavel Cherenkov. Ground-based gamma-ray telescopes are therefore trained not on space but rather on the Earth's atmosphere, which is itself effectively part of the observatory. The air shower typically produced by a cosmic gamma quantum looks slightly different to that produced by a high-speed atomic nucleus. The Cherenkov telescopes of the H.E.S.S. (Namibia), MAGIC (Canary Islands) and VERITAS (USA) observatories are able to distinguish between these two events so precisely that an international alliance of research institutes

DESY researcher Markus Ackermann works in the IceCube group.

Picture: DESY/Milde Science Communication

The Cherenkov Telescope Array (CTA) consists of three different types of telescope. DESY is responsible for the design and construction of the mid-sized telescopes.

Cherenkov telescopes such as the ones of CTA register the bluish light generated in the Earth's atmosphere by particle showers moving faster than the speed of light.

is now building the next-generation gamma observatory, the Cherenkov Telescope Array (CTA).

"The Cherenkov Telescope Array will enable us to observe thousands of cosmic accelerators with a sensitivity never before achieved and thereby expand our understanding of the universe," Stegmann explains. "It will be the observatory of the future for gamma-ray astronomy." CTA will consist of over 100 individual Cherenkov telescopes of three different types. They are to be located at two sites: one in the southern hemisphere, the other in the northern hemisphere. Over 1000 scientists and engineers from more than 30 countries have teamed up in the 400 million euro project. The facility is to be set up over the next five years and then operated for at least a further 20 years.

"We expect CTA to provide us with a profound understanding of the role of high-energy processes in the evolution of our universe"

Werner Hofmann, Max Planck Institute for Nuclear Physics, Heidelberg

Amongst other tasks, DESY is responsible for the design and construction of one of the three types of CTA telescopes.

The scientific centre of CTA is to be located at DESY in Zeuthen, the administrative headquarters in Bologna, Italy. "We are delighted that we have won the international bid and have been able to base the scientific coordination of CTA in Germany," says Beatrix Vierkorn-Rudolph from the Federal Ministry of Education and Research (BMBF). "Germany has a long and successful tradition in the field of gamma-ray astronomy; we can make very good use of that experience for the scientific coordination of CTA," adds CTA spokesperson Werner Hofmann from the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. "CTA will revolutionise this branch of astronomy. We expect CTA to provide us with a profound understanding of the role of high-energy processes in the evolution of our universe and to deliver a host of scientific surprises."

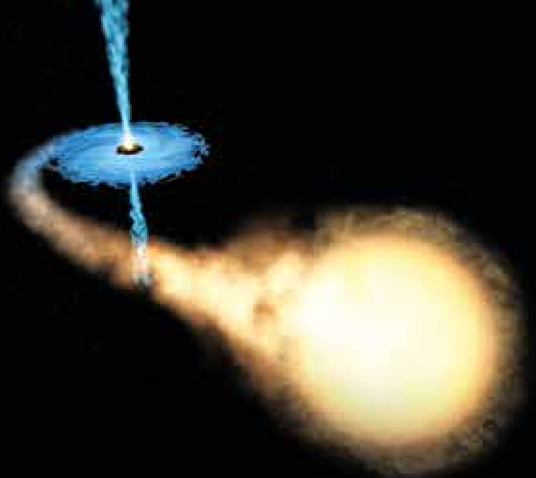
Surprises guaranteed

Scientific surprises are practically guaranteed. At the High Energy Stereoscopic System (H.E.S.S.) in Namibia, for example, researchers have recently identified the most powerful particle accelerator in the Milky Way. It sits at the heart of the galaxy, from where it fires protons into space with energies of up to one petaelectronvolt. That is around 100 times greater than can be achieved with the most powerful accelerator on Earth, the Large Hadron Collider (LHC) at the CERN research centre in Geneva, Switzerland. The galactic centre is thus one of the most important sources of cosmic radiation in our galaxy.

H.E.S.S. is responsible for discovering the majority of the 150 or so sources of ultrahigh-energy cosmic gamma rays so far identified. This has regularly yielded surprise discoveries. ››

Picture: DESY/Milde Science Communication

Picture: STScI

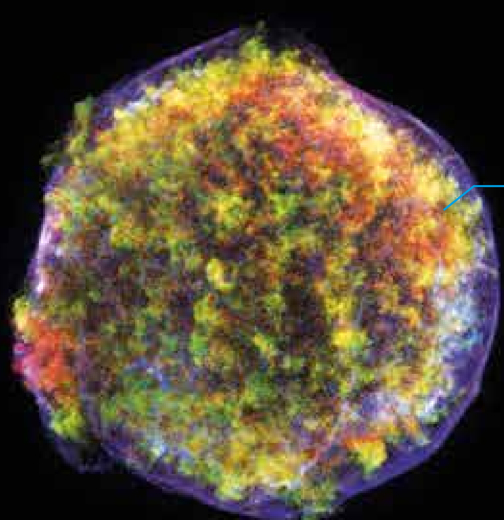


Artist's impression of a neutron star sucking up material from its companion and shooting jets of matter into space

Examples of cosmic particle accelerators

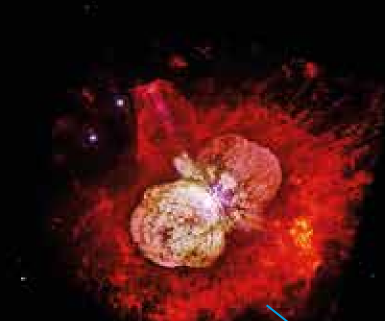
Picture: NASA/JPL-Caltech/STScI/CXC/UofA/ESA/AURA/JHU

In starburst galaxies such as M82, not only are lots of new stars formed, there are also many supernova explosions. Combination image in infrared, visible and X-ray light.



Picture: NASA/CXC/Rutgers/J.Warren & J.Hughes et al.

X-ray image of the explosion cloud of "Tycho's supernova", an exploding star of 1572 that is now a powerful source of gamma radiation.



Picture: NASA/HST/J. Morse/K. Davidson

The binary star system Eta Carinae is located within the Homunculus Nebula and is a source of gamma radiation generated by the collision of stellar winds.

Picture: ESO/M. Kornmesser

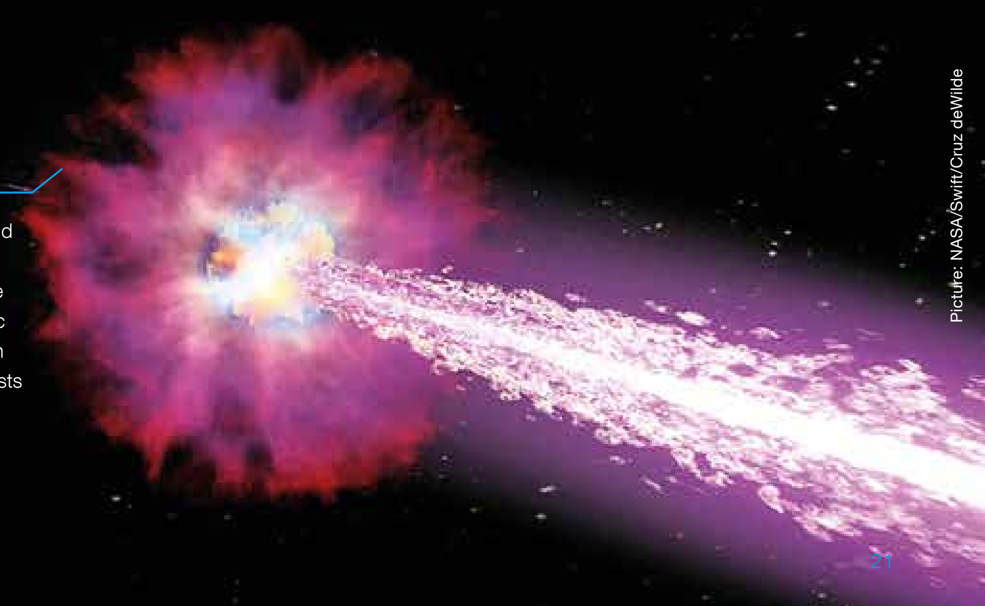
Supermassive black hole at the centre of an active galaxy (artist's impression)

Picture: ESO/M. Kornmesser

Mosaic image of the Large Magellanic Cloud, a satellite galaxy of the Milky Way. In the region above and left of the centre, researchers have discovered a so-called superbubble, which emits gamma radiation.

Picture: NRAO

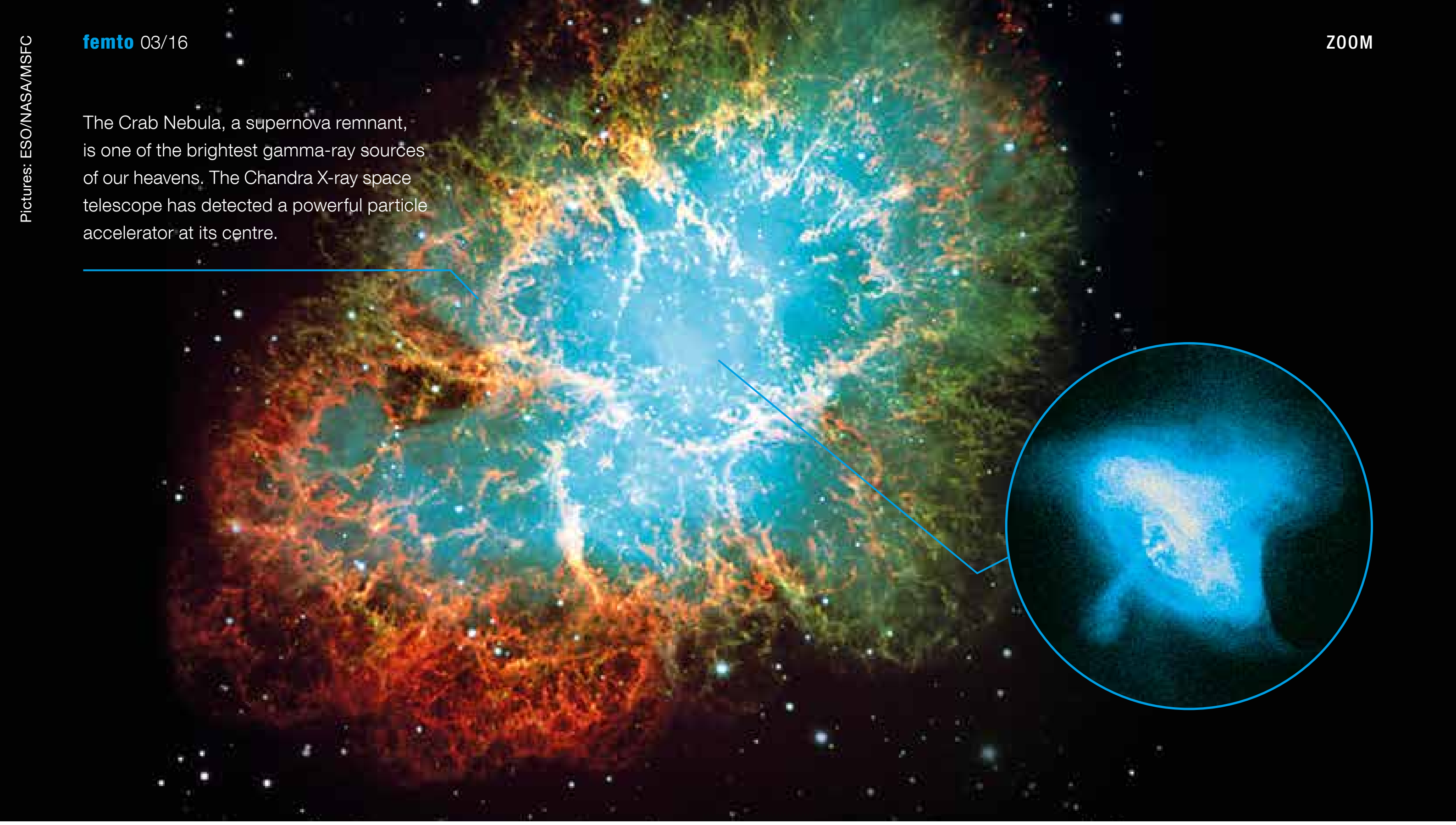
Radio wave image of the centre of the Milky Way, where astronomers have identified the most powerful particle accelerator in our galaxy.



Picture: NASA/Swift/Cruz deWilde

Colliding neutron stars and red giants collapsing into a black hole can produce short, extremely energetic pulses of gamma radiation known as gamma-ray bursts (artist's impression).

Pictures: ESO/NASA/MSFC



The Crab Nebula, a supernova remnant, is one of the brightest gamma-ray sources of our heavens. The Chandra X-ray space telescope has detected a powerful particle accelerator at its centre.

"While it was observing the Monoceros supernova remnant, for example, H.E.S.S. happened upon a gamma-ray point source," explains DESY researcher Gernot Maier. Some two years later, however, when trying to replicate this observation, the VERITAS observatory was unable to discover this source. "But one year later, VERITAS also observed this object in gamma-ray light. Therefore, it must have been a variable source," says Maier. "By now, we have observational data from more than ten years, so that we now know that it is in fact a binary star system with a period of 320 days, which intermittently becomes completely dark in the gamma and X-ray ranges. We think that it must be a binary system consisting of a pulsar and a massive star of around ten solar masses, but we still don't exactly know how this source works."

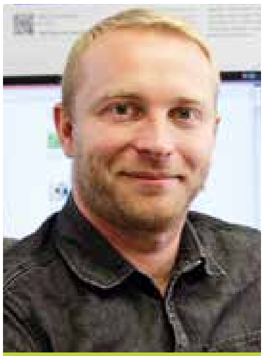
H.E.S.S. has also discovered a new type of gamma-ray source – known as a superbubble – in the Large Magellanic Cloud, which is one of our neighbouring galaxies. The source is a huge shell-like cavity 270 light years in diameter, which has been blown into shape by a number of supernova explosions and powerful stellar winds. Observations indicate that the superbubble is filled with high-energy particles and that it, in addition to the individual supernova remnants, produces cosmic gamma rays.

The superbubble carries the catalogue number 30 Dor C and lies in the Tarantula Nebula, the largest star-forming region in the Large Magellanic Cloud. Here, H.E.S.S. also observed two further gamma sources: the pulsar wind nebula N157B and the supernova remnant N132D. Pulsars are rapidly rotating stellar corpses, so-called neutron stars, with a strong magnetic field. They emit a wind of extremely high-speed particles that can form a kind of nebula.

"This confirms the hypothesis that supernova remnants may be substantially brighter than was once assumed"

Stefan Ohm, DESY

The supernova remnant N132D was already known as a bright object in the radio and infrared spectrum. The H.E.S.S. observations also indicated that it is one of the oldest and most powerful supernova remnants still emitting in the ultrahigh-energy gamma range. The debris of exploding stars generates gamma rays as the explosion front penetrates the surrounding interstellar gas at an extremely high speed. The



Stefan Ohm investigates the high-energy cosmos at the H.E.S.S. observatory.

resulting deceleration produces a shock front with powerful magnetic fields. These magnetic fields cause electrically charged particles to repeatedly switch back and forth from one side of the shock front to the other, a process that results in them being accelerated to very high energies. If these high-speed particles hit a light particle or a slow-moving proton in the interstellar gas, this may generate a particle known as a pion. The pion then decays into two gamma quanta, which can then be detected on Earth.

The explosion front is slowed down by the surrounding interstellar gas to such an extent that particle acceleration comes to a halt after what is, in cosmic terms, a relatively short period of time. However, this is not quite as quick as was once thought. After all, N132D is already 2500 to 6000 years old and is still emitting more gamma radiation than the brightest supernova remnants in the Milky Way. "This confirms the hypothesis based on previous observations with H.E.S.S., namely that supernova remnants may be substantially brighter than was once assumed," explains DESY researcher Ohm, who was closely involved in the interpretation and modelling of the observational data from the Large Magellanic Cloud.

First robust proof

Supernova remnants such as N132D are the only objects that have to date been demonstrated, in a scientifically robust manner, to be a source of cosmic rays. As the pion decays, its entire mass is converted into energy, in line with Einstein's famous equation $E=mc^2$. Each of the two gamma quanta receives half of this energy. If the model is correct, there should be no detectable gamma rays with energies below a level that corresponds to half of the mass of the pion.

The Fermi gamma-ray space telescope, operated by the US space agency NASA, has confirmed this pion cut-off in observations of the supernova remnants IC443 and W44 in the Milky Way. "Over the past century, we discovered a lot of new things about the cosmic rays that reach the Earth. We were also pretty sure about what the source of their acceleration was, but it's only now that we have clear proof," says Stefan Funk, who led the analysis at the University of Stanford in the USA and now works at the University of Erlangen in Germany.

"The next step is to study the acceleration process in more detail, so that we can understand up to what energies these particles are accelerated to," says DESY researcher Rolf Bühler from the Fermi team. "We know today that it is almost impossible for a star to explode without accelerating protons and other atomic nuclei," explains Maier. "So the question is: How many and for how long?"

In addition to supernova remnants, pulsar wind nebulae, binary stars and superbubbles, the other sources of cosmic gamma radiation identified by astrophysicists are so-called starburst galaxies and, first and foremost, the huge black holes at the centre of active galaxies. In the case of all of these sources, researchers assume that they also propel extremely energetic particles into space. "The various sources of cosmic radiation are extremely diverse. Some are only ten kilometres in diameter, whereas others are thousands of light years across," says Bühler, who is also part of the CTA group at DESY.

> *"Over the past century, we discovered a lot of new things about the cosmic rays that reach the Earth"*
>
> *Stefan Funk, University of Erlangen*

Tightly collimated streams of matter – known as jets – often play an important role. These are ejected into space above and below a variety of systems. For example, jets occur when a portion of the matter that is being sucked into the gigantic vortex of a black hole is ejected vertically into space – up and down – before it reaches the actual black hole. When these high-speed jets of matter meet the surrounding gas, this again produces a shock front that can accelerate protons and other atomic nuclei to extremely high energies.

"You encounter jets on all scales: from individual stars and binary systems all the way up to black holes with millions of stellar masses," Maier explains. "All of these are cosmic particle accelerators." When, for example, the Chandra X-ray observatory identified such an accelerator at the heart of the Crab Nebula, one of the brightest sources of gamma radiation in our skies, it was discovered that here too the central neutron star of this supernova remnant ejects collimated streams of matter into space.

New messengers from the cosmos

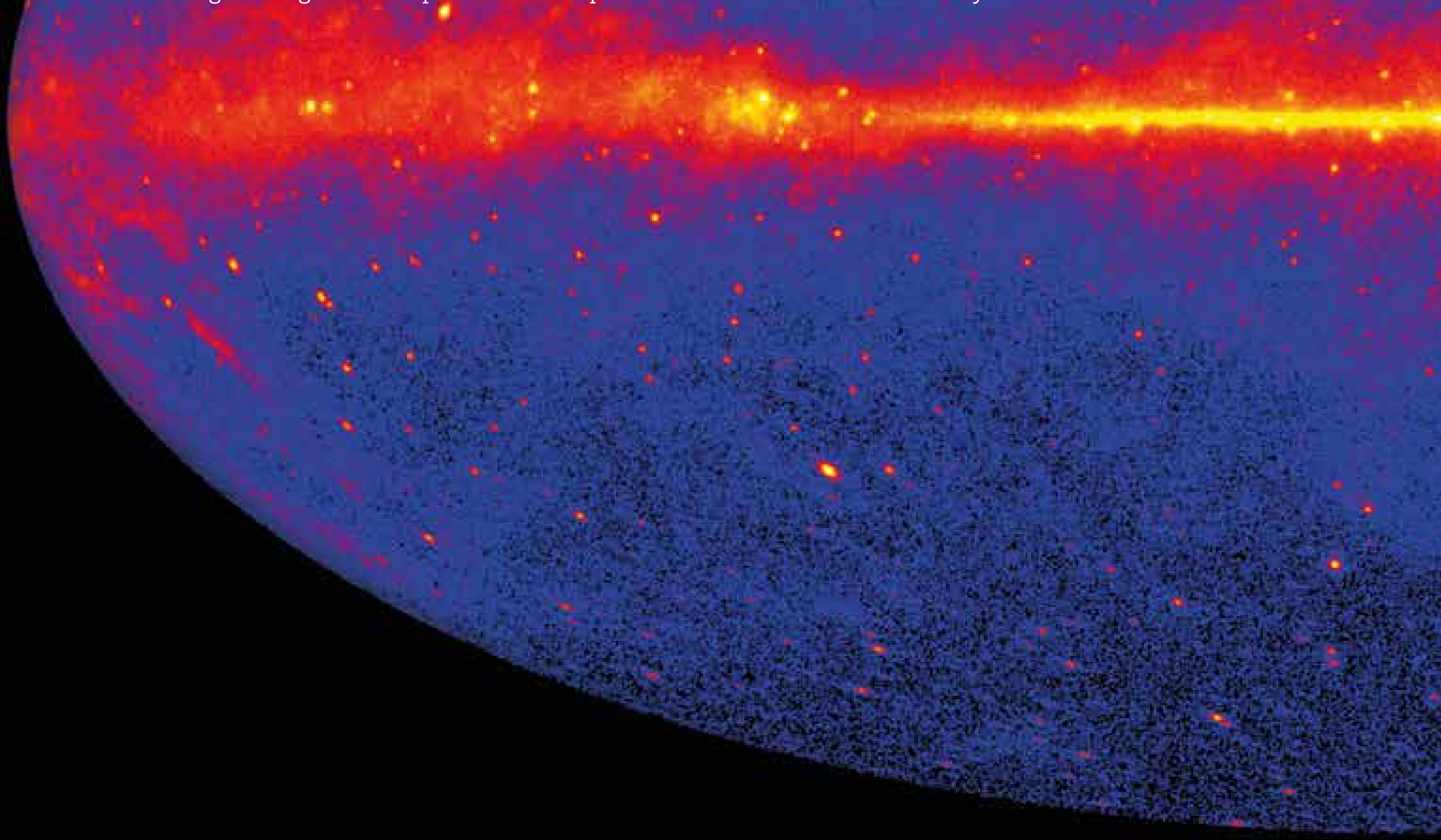
The Fermi space telescope complements, at lower energy ranges, ground-based observations ›› of gamma rays. In recent years, it has mapped out the entire sky and, in the process, discovered around 3000 sources of cosmic gamma radiation, not all of which have yet been identified.

> *"It's amazing how normal it is to find particle accelerators in space"*
> Rolf Bühler, DESY

"It's amazing how normal it is to find particle accelerators in space," says Bühler. Researchers are confident that the Cherenkov Telescope Array will yield a similar haul of new discoveries at high gamma-ray energies. "For the purpose of interpretation, other wavelengths are always important: X-rays, radio waves and sometimes optical observations," Maier explains. In the future, neutrinos should also play a key role.

"We see the gamma sources, of course, but that doesn't mean that they are the only sources of cosmic rays," explains IceCube researcher Anna Franckowiak. She heads one of the Young Investigators Groups sponsored by the Helmholtz Association at DESY. And not all gamma-ray sources are necessarily sources of high-speed particles. "The particles in cosmic rays interact with photons from the source and thereby produce gamma quanta and neutrinos. But gamma radiation can arise in other ways. That's one reason why we also need to investigate the neutrinos," says Franckowiak. And these ghostly elementary particles have another advantage: "Neutrinos may also carry information from within the source – information that can't be seen in gamma-ray light." At the heart of a supernova explosion, for example, photons are largely dispersed and absorbed before they can reach the surface. Neutrinos, by contrast, escape unimpeded and unfiltered. Neutrinos from the famous supernova 1987A reached the Earth around three hours ahead of the flash from the explosion.

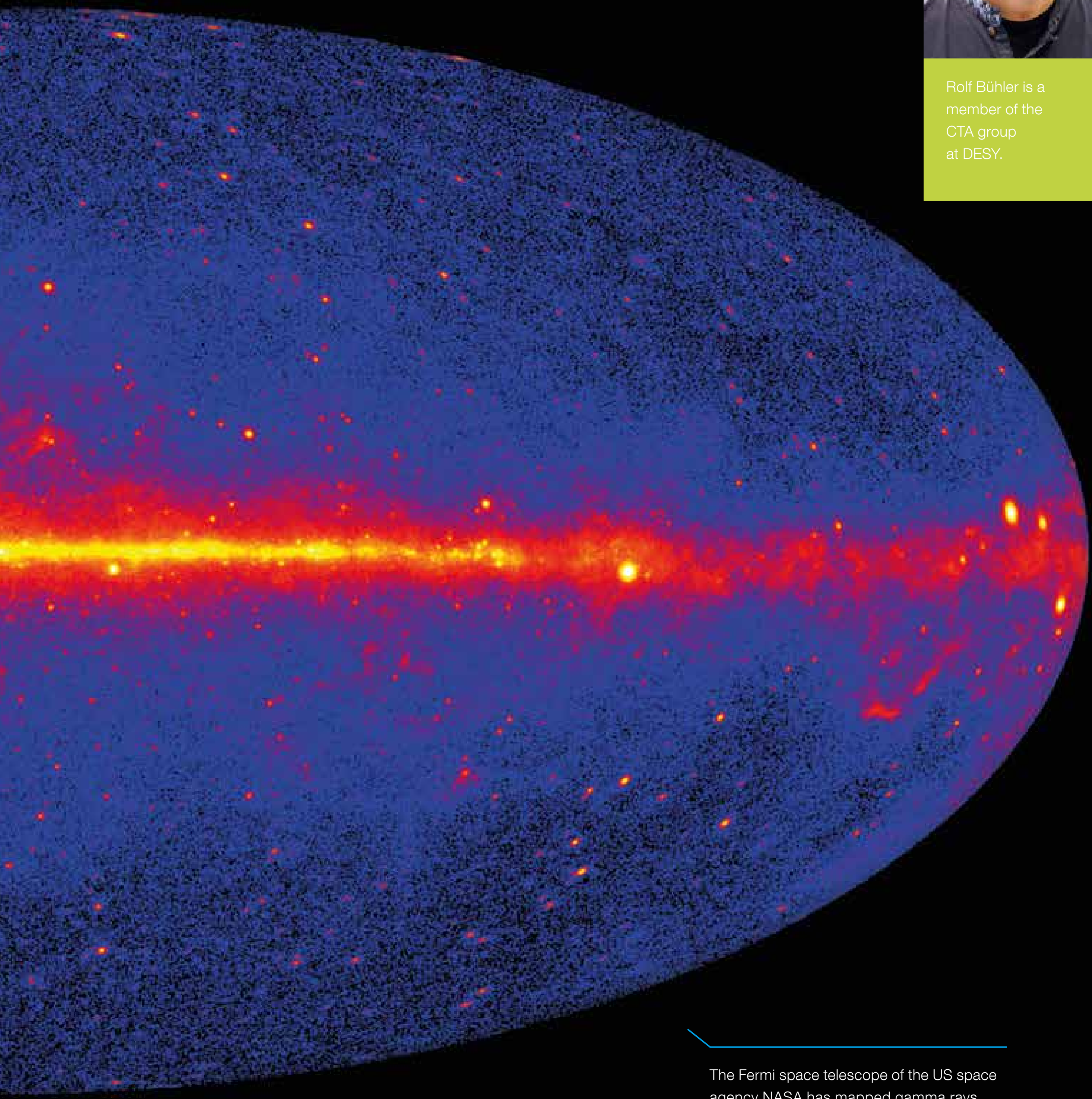
Researchers from the IceCube observatory at the South Pole have already observed astrophysical neutrinos – from the depths of outer space – that must have an origin that lies somewhere beyond our solar system. "Cosmic neutrinos are the key to understanding previously unexplored areas of the universe and may well ››



Picture: NASA/DOE/Fermi LAT Collaboration

Picture: TUHH

Rolf Bühler is a member of the CTA group at DESY.



The Fermi space telescope of the US space agency NASA has mapped gamma rays across the entire sky and, in the process, discovered around 3000 sources of this type of radiation. Of these sources, only a portion has yet been identified. Ground-based gamma-ray telescopes, which observe high-energy gamma radiation, have so far discovered around 150 sources.

The IceCube lab is located in the Amundsen-Scott research station in the Antarctic.

Picture: Sven Lidstrom, IceCube/NSF

reveal the origin of extremely high-energy cosmic rays," explains IceCube spokesperson Olga Botner from Uppsala University in Sweden. "The discovery of astrophysical neutrinos heralds the dawn of a new era in astronomy."

The observations to date also permit an initial analysis of the rate at which these ghostly particles of different energy ranges hit the Earth. "Thanks to the combination of several independent data sets, we can now not only say 'Great, we've seen neutrinos!' We can also measure the energy spectrum of these particles with great precision and determine the relative

"Neutrinos may also carry information from within the source – information that can't be seen in gamma-ray light"

Anna Franckowiak, DESY

proportions of the various types of neutrinos that reach us from outer space," explains Ackermann. "This gives us information about the origin of the neutrinos and the physical processes that create these particles in the universe," adds DESY researcher Lars Mohrmann, who processed the combination of data sets.

Each year, IceCube registers around 100 000 neutrinos. However, most of these arise in the Earth's atmosphere as a result of interaction with cosmic rays. Billions of atmospheric muons, which are created in the same interactive processes, also leave their traces in the detector. Researchers must comb through all these traces for signs of just a few dozen astrophysical neutrinos. Here, they exploit a proven method used by neutrino telescopes: they observe the universe through the medium of our planet, thereby letting the Earth filter out the extensive background radiation resulting from atmospheric muons.

At the highest energies recorded – in excess of around 100 teraelectronvolts – the observed number of particles can no longer be explained exclusively on the basis of neutrinos produced in the Earth's atmosphere. Instead, there must also be an astrophysical origin. IceCube is able to determine the direction of origin of these high-speed particles to an accuracy of just a few degrees. Among the cosmic neutrinos so far detected, however, there has been no prevalence of particles from one particular direction, which would indicate a determinate astrophysical source. The neutrino flux measured by IceCube from the northern hemisphere has the same intensity as the astrophysical flux

Junior research group leader Anna Franckowiak from the IceCube group at DESY from the southern hemisphere. This indicates the existence of numerous extragalactic sources; otherwise, sources in the Milky Way would dominate the flux in the galactic plane.

As to the origin of these cosmic neutrinos – Franckowiak's junior research group is hoping that multimessenger observations will help to answer this question. By combining neutrino data with observations from optical and gamma-ray observatories, they will be able to search for neutrino emissions from potential sources such as supernova explosions. An important role for optical observations will be played by the Zwicky Transient Facility (ZTF). This new wide-angle

"The discovery of astrophysical neutrinos heralds the dawn of a new era in astronomy"
Olga Botner, Uppsala University

telescope is currently under construction in a project involving DESY and is due to start taking data in 2017. "The discovery of the first neutrino sources would open up a new window onto the high-energy universe," says Franckowiak.

It is hoped that neutrino observatories such as IceCube will provide astronomy with a totally new messenger particle for investigating the universe. "There's a time lag between gamma and neutrino astronomy. In the future, hopefully, we'll be able to do in neutrino astronomy what we're now already doing in gamma astronomy," says Stegmann. "We expect both fields to yield fascinating insights into the universe's natural particle accelerators. This in turn will shed new light on the remaining mysteries of cosmic radiation."

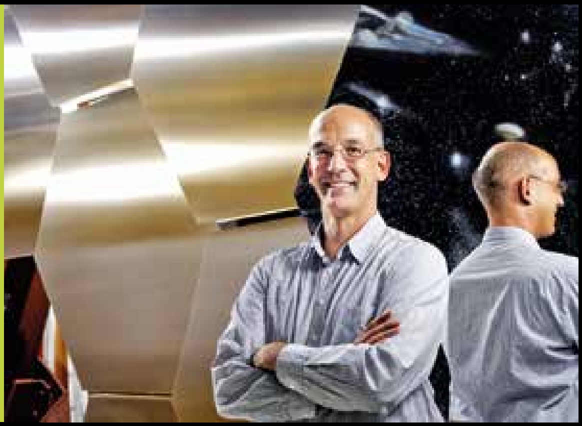
Picture: The IceCube Collaboration

The IceCube detector comprises over 5000 highly sensitive photomultipliers buried in the polar ice at a depth of up to 2.5 kilometres.

"Completely new insights into the universe"

Christian Stegmann on the CTA observatory

The astroparticle physicist Christian Stegmann heads the DESY location in Zeuthen.



On clear nights, the CTA observatory will detect the Cherenkov light that is generated when high-energy gamma rays enter the Earth's atmosphere. CTA will consist of around 100 Cherenkov telescopes sited in the southern hemisphere and around 20 in the northern hemisphere. Together, they will enable scientists to observe the entire night sky. Paranal, a peak in the Chilean Andes, has been selected as the southern-hemisphere site; La Palma, one of the Canary Islands in Spain, as the northern-hemisphere site.

DESY makes up the largest group within the international project and is responsible for, amongst other things, the design and construction of the mid-sized telescopes, which have a mirror of around 12 metres in diameter. All in all, three different sizes of telescope will be used. In addition, the Science Management Centre of CTA is to be located at DESY in Zeuthen. This will make it a major hub for gamma-ray astronomy, as Christian Stegmann, head of DESY in Zeuthen, explains.

femto: What are the next steps for CTA?

Christian Stegmann: There are things to do on many levels, all at the same time. On the one hand, it's now up to the international funding agencies. They will sign a watertight agreement on the financing of the observatory. Germany has taken a leading role here, along with Italy, though that's not to underestimate the contribution of other partner countries such as Spain, Japan, France and Switzerland. First and foremost for the coming months, however, will be the establishment of an effective project management office in Bologna, Italy, which will organise the construction of the entire observatory. This will coordinate the various contributions from the partner groups, which range from complete telescopes to core infrastructure such as computing centres. Here in Zeuthen, we're already well advanced with our preparations for building the components that we're going to be contributing to CTA. In the first instance, that means the mid-sized telescopes plus computing and software. That's all going to be happening over the next few months and will involve substantial participation by the people here at DESY. After that, we'll be starting to set up the Science Management Centre, together with CTA, here in Zeuthen.

femto: What makes you believe that CTA will provide a much more detailed picture of the gamma skies?

Christian Stegmann: We're expecting nothing less than a revolution in the way we see the cosmos at very high energies. Recent years have shown that high-energy radiation plays a much more important role in our universe than was previously thought. But with the instruments we have at the moment, it's also obvious that we're only seeing a fraction of the whole picture. For example, current experiments have only searched a quarter of the Milky Way for gamma-ray sources. In other words, we only know the tip of the iceberg. What's more, the images we have are not yet sharp enough to be able to draw any absolutely certain conclusions about the basic mechanisms of acceleration. CTA will enable us not only to discover every gamma radiation-emitting supernova remnant – which are the probable sources of cosmic rays in the Milky Way – but also to investigate these sources in detail. This will eventually enable us to understand which processes are responsible for generating the gamma rays. CTA's sensitivity and accuracy of measurement will open up an entirely new perspective on the universe. And I'm also convinced that CTA will deliver some new and totally surprising discoveries.

"We're expecting nothing less than a revolution in the way we see the cosmos at very high energies"

femto: What does CTA mean for the DESY location in Zeuthen?

Christian Stegmann: CTA represents a massive opportunity for the Zeuthen location. It will enable us to continue to play a leading role as a research centre in the metropolitan region of Berlin-Brandenburg, in Germany and internationally. For us, the location of the CTA Science Management Centre in Zeuthen is a milestone on our journey to becoming an international centre for astroparticle physics. Along with our partners in the region – the University of Potsdam, Humboldt University in Berlin, the Leibniz Institute for Astrophysics in Potsdam, and the Albert Einstein Institute of the Max Planck Society – we're on the way to becoming one of the leading regions for astronomy, astrophysics, and astroparticle physics.

We live in an age in which ground-breaking discoveries in astronomy can turn our picture of the universe on its head. The discovery of gravitational waves – with the participation of the Albert Einstein Institute – or the IceCube observatory's discovery of high-energy cosmic neutrinos – which involved the DESY IceCube group in Zeuthen – are just two examples of this. The building of such a powerful observatory as CTA and the location of the CTA Science Management Centre in Zeuthen will make us an attractive destination for scientists from around the world.

femto: What are the key areas of science here in Zeuthen?

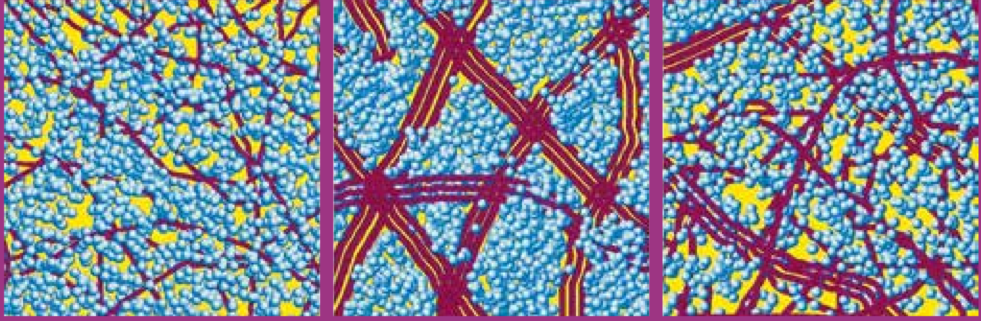
Christian Stegmann: Over the past few years, there has been a determined effort to turn the DESY location in Zeuthen into a centre for astroparticle physics. In particular, we're focusing on investigating the universe at high energies using gamma radiation and neutrinos. Both messenger particles – gamma-ray photons and neutrinos – are electrically neutral and therefore tell us directly where they originated. Using these messengers, we can do astronomy and learn something about the high-energy processes where they actually occur. We're also setting up a research group in the field of theoretical astroparticle physics here in Zeuthen. That will enable to us to directly link up experimental results with theory. In other words, we're offering a full and well-rounded research profile, which makes us an attractive research centre.

femto: What opportunities are there for junior researchers?

Christian Stegmann: The DESY location in Zeuthen is a good stepping stone for young people looking to work in the field of astroparticle physics. Two young scientists have just chosen Zeuthen as the place to set up their own junior research groups. One group is going to be looking for the source of high-energy cosmic neutrinos, the other will be doing work beyond the Standard Model of particle physics using CTA. What we've been seeing for a number of years now is that Zeuthen is becoming more and more attractive, particularly for young scientists from around the world who want to do research in astroparticle physics. Our proximity to Berlin also certainly is a factor. But it's also true that we're developing a research environment that offers a special atmosphere for young scientists.

The tessellated mirror of a Cherenkov telescope of the High Energy Stereoscopic System (H.E.S.S.) in Namibia

Wear-out of plastic solar cells



Picture: Christoph Schaffer, TU Munich

The inner structure of the active layer of the solar cell without solvent additive (left), with solvent additive (centre) and after loss of solvent additive during operation (right)

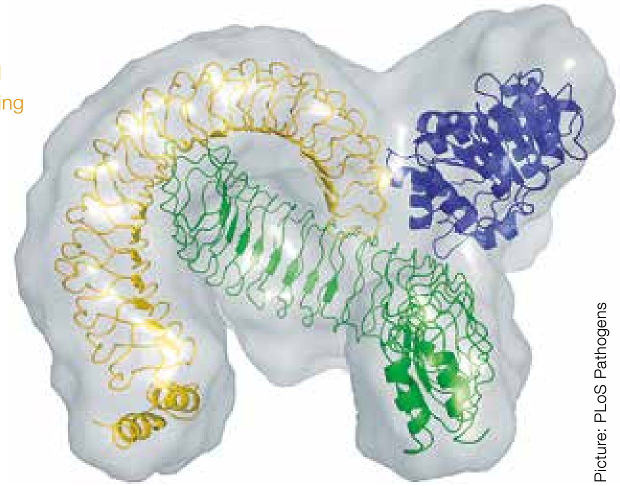
A team of scientists led by Peter Müller-Buschbaum from the Technical University of Munich have used DESY's X-ray radiation source PETRA III to observe the degradation of plastic solar cells. Their study suggests an approach for improving the manufacturing process in order to increase the long-term stability of such organic solar cells.

Unlike conventional solar cells, which are made of silicon, organic solar cells produce electricity in an active blended layer between two carbon-based materials. When one of these is a polymer, the resulting cell is often referred to as a plastic solar cell. These are particularly promising because they can be manufactured simply and cheaply. In general, however, organic solar cells are less efficient and sometimes have a shorter lifetime than silicon-based ones.

The scientists used PETRA III to study the degradation of so-called low-bandgap polymer solar cells, which absorb particularly large amounts of light. In many cases, these require the use of a solvent additive during the manufacturing process to achieve high efficiencies. However, as the researchers found out, structural changes induced by loss of solvent during operation lead to a drop in the efficiency of the solar cell. "Therefore, it is essential to come up with strategies for stabilising the structure. This could be achieved through chemical bonding between the polymer chains, or using customised encapsulating substances," explains Müller-Buschbaum.

Advanced Energy Materials, 2016; DOI: 10.1002/aenm.201600712

Shuttling in the cell



Structural model of the YopM/DDX3 complex based on small-angle X-ray scattering and crystallographic data

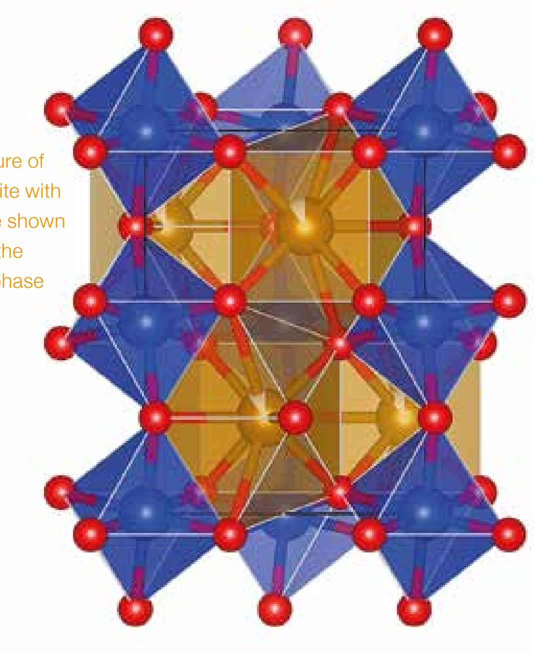
Picture: PLoS Pathogens

Bacterial pathogens have developed sophisticated mechanisms to evade the immune system and spread in the human host. A team of researchers from the University Medical Center Hamburg-Eppendorf, the University of Hamburg and the European Molecular Biology Laboratory (EMBL) has succeeded in analysing an important mechanism of such a bacterial infection strategy. The researchers studied pathogenic *Yersinia*, including *Yersinia pestis*, the causative agent of bubonic plague. These bacteria use an especially effective infection strategy: They succeed in injecting a protein called YopM into host cells. YopM enters the nucleus and directly elevates the transcription of anti-inflammatory cytokines, which suppress the host immune system.

The team identified a nuclear protein that transports YopM out of the nucleus and thereby enables its nucleo-cytoplasmic shuttling. The researchers could demonstrate that the nuclear level of YopM is proportional to its immunosuppressive effect. "Thus, the newly identified mechanism of nucleo-cytoplasmic shuttling of YopM directly contributes to the ability of the bacteria to cause infection," explains Martin Aepfelbacher from the University Medical Center Hamburg-Eppendorf.

Using special X-ray techniques at DESY's light source PETRA III, the scientists determined the three-dimensional structure of the proteins involved. Knowledge of this structure is essential for developing novel pharmaceutical ingredients for the treatment of *Yersinia* infections.

PLoS Pathogens, 2016; DOI: 10.1371/journal.ppat.1005660



Crystal structure of iron bridgmanite with the iron phase shown in yellow and the silicon oxide phase shown in blue

Picture: Leyla Ismailova, University of Bayreuth

Insights about the Earth's lower mantle

Scientists X-ray the most abundant mineral on Earth

Using DESY's X-ray light source PETRA III, a team of scientists has discovered unexpected facts about the most abundant mineral on Earth. The mineral bridgmanite makes up roughly one third of Earth's entire volume and is the major component of Earth's lower mantle. Thus, its physical properties are one of the deciding factors for understanding the dynamics of our planet, with a direct impact on life on Earth's surface, ranging from deep-focus earthquakes to geochemical cycles leading to formation of mineral deposits. However, bridgmanite is rather hard to study under its "normal conditions", that is, at the high pressures and extreme temperatures reigning in the Earth's mantle. Therefore, its physical properties are being discussed controversially within the scientific community.

The new study revealed that, at a pressure of 45 gigapascals, bridgmanite can form a previously unknown iron-bearing variety that had never been synthesised in laboratories before. This variety could exist throughout the entire lower mantle. The discovery could change the view of the properties of our planet and its behaviour deep underneath the surface, as the team led by Leonid Dubrovinsky from the University of Bayreuth in Germany reports in the journal *Science Advances*. In addition, the scientists observed that defects within bridgmanite's crystal lattice continue to have a significant effect on the material's properties even under high pressure, which was unexpected.

Science Advances, 2016; DOI: 10.1126/sciadv.1600427

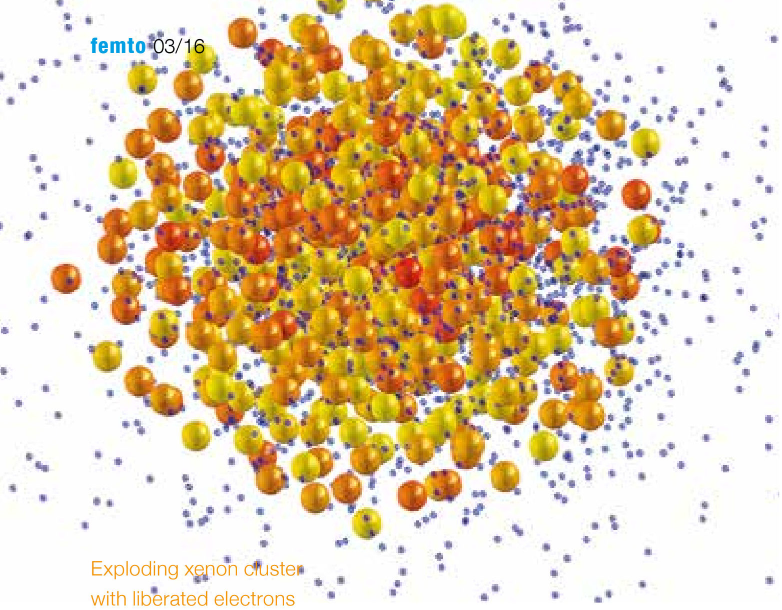
Picture: DESY, Gesine Born

New research halls at X-ray light source PETRA III

Two new experimental halls enhance the research opportunities at DESY's X-ray light source PETRA III. The halls have been named after famous scientists: the Israeli Nobel laureate Ada Yonath, who conducted important research at DESY for her structural examination of ribosomes, the "protein factories" of living cells, and Paul P. Ewald, one of the pioneers of structural analysis using X-rays.

The two new PETRA III experimental halls will provide highly-specialised measuring stations to scientists from all over the world, and thus ideal conditions for examining materials and structures on the atomic scale and optimising them for future applications. Three of the beamlines in PETRA III's new experimental hall "Ada Yonath" were built in collaboration with scientists from India, Sweden and Russia.

"We are pleased that, with the new experimental halls, Hamburg has been able to satisfy the science community's exacting expectations of a research centre," said Olaf Scholz, the First Mayor of Hamburg, on the occasion of the celebration. "Science needs a united Europe. Only because it was firmly integrated into the European community was Hamburg able to grow into a major, international centre of science and innovation. We are now beginning a new chapter at the Hamburg-Bahrenfeld research campus, a success story that would be unthinkable without this environment."



Picture: Thomas Fennel, University of Rostock

Exploding xenon cluster with liberated electrons (blue dots)

Exploding xenon nanoparticles

A team of researchers led by Daniela Rupp from the Technical University of Berlin has used DESY's X-ray laser FLASH to study the ultrafast, light-induced explosion of nanoparticles made up of xenon. Studying these xenon clusters provides new insights into the fundamental interaction between intense radiation and matter.

The scientists fired ultrashort, high-intensity pulses of laser light from FLASH at tiny xenon nanoparticles, roughly 400 nanometres (millionths of a millimetre) across, whereby the radiation reached intensities of up to 500 trillion watts per square centimetre for a few trillionths of a second. By comparison: The intensity of sunlight striking the surface of the Earth is around 0.1 watts per square centimetre. The bright pulse of radiation liberated numerous electrons from the xenon atoms in the cluster, creating a plasma – a hot gas consisting of electrically charged atoms, so-called ions, with electrons racing around between them.

The physicists were able to use their experimental setup to monitor the development of individual xenon clusters and determine their size as well as the precise energy with which they were struck. The scientists also detected a previously unnoticed heating effect within the plasma: "Every time an electron is recaptured by a xenon atom, it releases energy to the surrounding plasma," explains Rupp. "As a result, those xenon ions that do not recombine with electrons receive a larger proportion of the energy in the end – the electrons heat up the ions, so to speak."

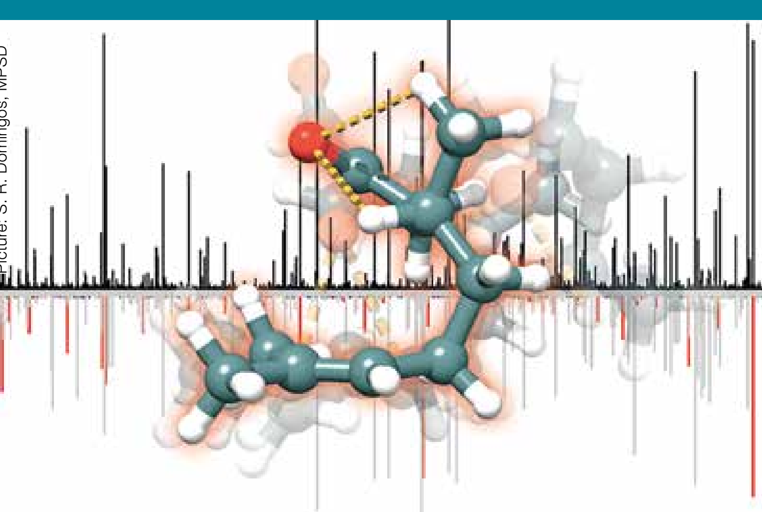
Physical Review Letters, 2016; DOI: 10.1103/PhysRevLett.117.153401

Flexible odorant molecules

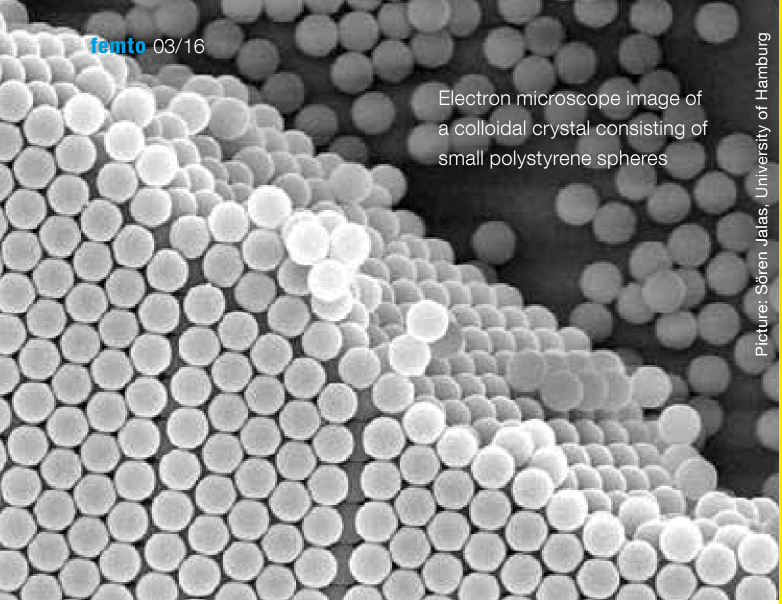
The sense of smell is shrouded in mystery. We do know, however, that the functionality of a specific biomolecule is directly related to how the molecule "fits" in its target biological receptor, much like a key that only fits in a certain door lock. To shed some light on these mechanisms, researchers from the Max Planck Institute for the Structure and Dynamics of Matter at the Center for Free-Electron Laser Science (CFEL) and from the Hamburg Centre for Ultrafast Imaging (CUI) led by Melanie Schnell have investigated an odorant biomolecule: citronellal, a versatile biochemical precursor that naturally appears in many plant oils. It has a distinct lemon scent and is often exploited in the cosmetics industry.

By means of a high-resolution rotational spectroscopy study, the researchers discovered that this molecule can adopt an impressive number of shapes, so-called conformations, simply by rotation around five single carbon–carbon chemical bonds. Those orchestrated rotations result in a surprisingly large number of stable forms of the molecule. "The extraordinary shape-shifting ability of this odorant molecule provides particular insights about the relation between structure and function of a biomolecule. Not only did we find fifteen keys, but we also discovered which ones might fit better in the door lock," explains group leader Melanie Schnell.

Structure of the most stable, globular form of citronellal



Picture: S. R. Domingos, MPSD



Electron microscope image of a colloidal crystal consisting of small polystyrene spheres

Picture: Sören Jalas, University of Hamburg

femtomenal

Photonic crystals in 3D

Scientists at DESY have developed a method to record the inner structure of individual photonic crystals and similar materials in 3D. The technique directly reveals the positions of the individual building blocks of a crystal, without the need for assumptions, models or averaging. The team around Ivan Vartaniants from DESY reported their work in the scientific journal *Physical Review Letters*. Photonic crystals have a wide range of applications in information technology, chemistry and physics.

Photonic crystals are composed of particles in the size range of roughly 200 to 400 nanometres (millionths of a millimetre). Their inner structure is thus larger than the one of ordinary crystals, lying in the range of the wavelengths of visible light. This submicrometre structure enables various effects for manipulating optical photons – hence the name photonic crystals.

The team used the brilliant, coherent X-rays from DESY's research light source PETRA III to investigate the inner structure of artificially produced photonic crystals. "Our method opens up new ways to visualise the inner three-dimensional structure of mesoscopic materials like photonic crystals with coherent X-rays," says Vartaniants.

Physical Review Letters, 2016; DOI: 10.1103/PhysRevLett.117.138002

2000 kilometres of cable and 20 tonnes of niobium

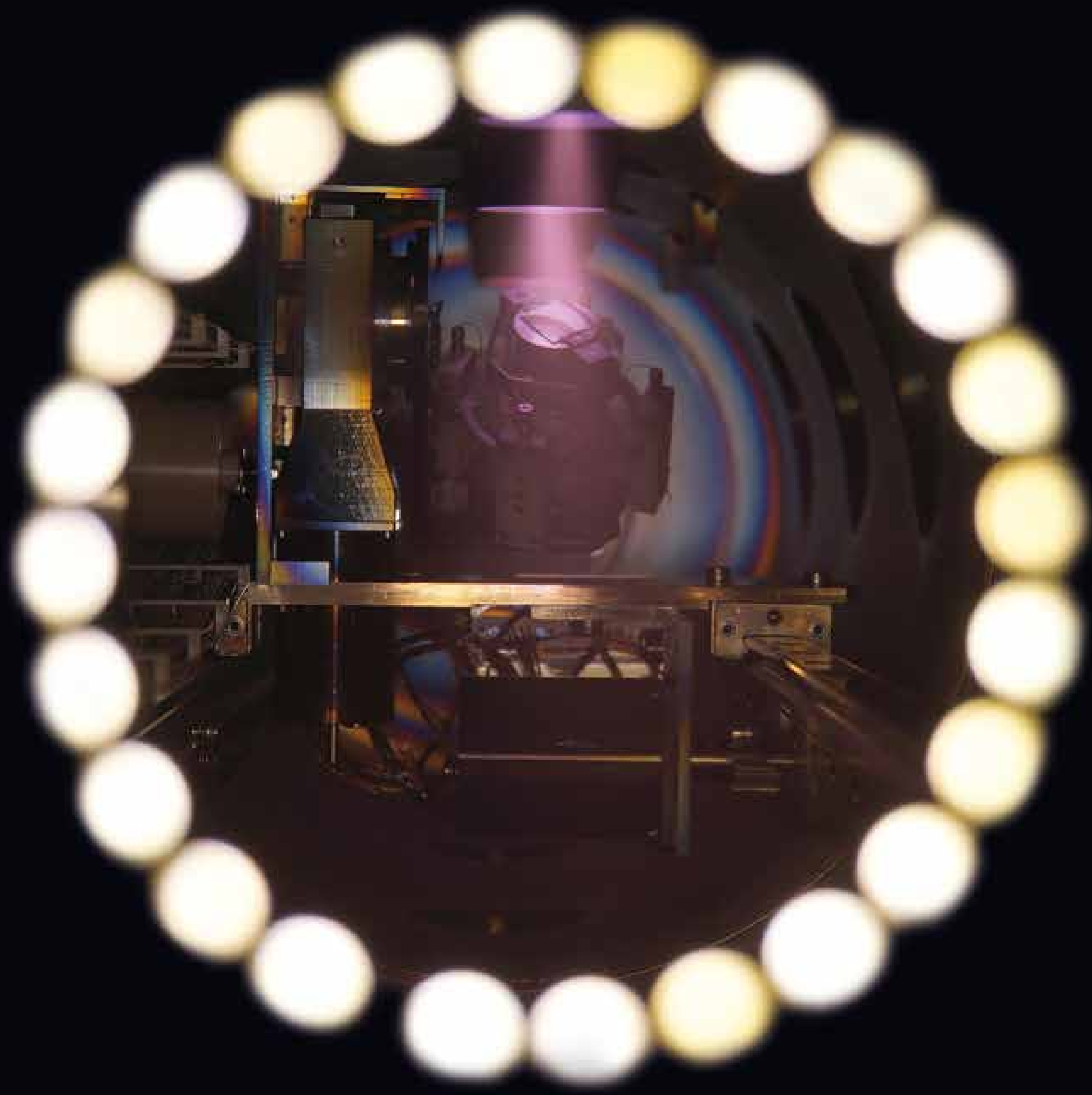
Back in October, the finishing touches were applied to the European XFEL, the world's largest X-ray laser, which is now being progressively commissioned. The massive construction project is coming to an end. The underground engineering alone took 2183 days. All in all, 543 348 cubic metres of soil were excavated above and below ground. A total of 180 474 cubic metres of concrete and 30 392 tonnes of reinforcement steel went into the facility.

Such huge dimensions also mark the installation of the incredibly sophisticated accelerator technology. The 1.7-kilometre-long linear accelerator comprises 96 modules containing 768 accelerator elements made of niobium. All in all, 20 tonnes of this rare superconducting metal have been installed in the European XFEL – that's the world's highest concentration of high-purity niobium. What's more, there are over 2000 kilometres of cable and 800 magnets in the accelerator tunnel – not to mention some 20 000 vacuum flanges held in place by 160 000 screws.

It will take several months to commission the extremely complex X-ray laser. The superconducting accelerator has to be cooled to an operating temperature of minus 271 degrees Celsius with the help of 4.5 tonnes of helium. After that, the various components of the facility will be progressively switched on, adjusted and calibrated.

Picture: Heiner Müller-Elsner, European XFEL

Custom-made magnetic sensors



A tailor-made vacuum deposition chamber is used to fabricate multilayer stacks with new sensor functionalities. One translation and two rotation motors position the wafer relative to the deposition sources, and nanometre-thin film stacks are grown in subsequent deposition cycles.

Pictures: DESY, Kai Schlage

Scientists at DESY have discovered a method that paves the way for a new generation of magnetic sensors. Their procedure can be used to greatly extend the functionality of such sensors, which is limited when conventional production methods are used, so that sensors can now be individually tailored to a wide variety of new applications.

Magnetic sensors – or more accurately, magnetoresistive sensors – are tiny, highly sensitive and efficient components that surround us everywhere in our daily lives. In cars, they measure the speed of rotation of the wheels for ABS and ESP systems; they are also found in mobile phones, they read data from hard drives and contribute to our safety by detecting microscopic cracks in metal components. The variety of these applications means that the sensors' functionality needs to be individually tuned to each.

Magnetoresistive sensors are made up of microscopic stacks of alternating magnetic and non-magnetic layers, each just a few nanometres thick. When an external magnetic field is applied to such a multilayer stack, the electrical resistance of the stack changes. Although this giant magnetoresistive effect (GMR), for the discovery of which Albert Fert and Peter Grünberg were awarded a Nobel Prize in Physics in 2007, has revolutionised sensor technology, one problem has persisted: the magnetic field strength at which the resistor switches is largely fixed.

Controlled properties

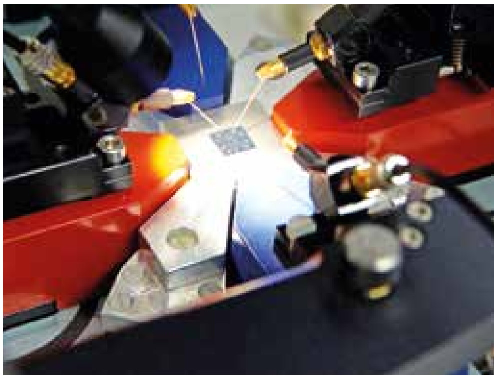
Researchers at DESY have now developed a procedure that allows them, for the first time, to take control of the magnetoresistive properties of multilayer sensor systems. Their method allows the field strength at which each individual magnetic layer in the minute stack switches to be precisely and flexibly adjusted. In addition, the preferential direction for the magnetisation of the individual layers, the so-called "easy axis", can be set in any chosen orientation. As a result, a multitude of new sensor properties can be achieved by straightforward means. "Until now, it has often been necessary to adjust the application to fit the sensor; our technology means that we can customise the sensor to fit the intended application," explains DESY researcher Kai Schlage.

"Our technology means that we can customise the sensor to fit the intended application"

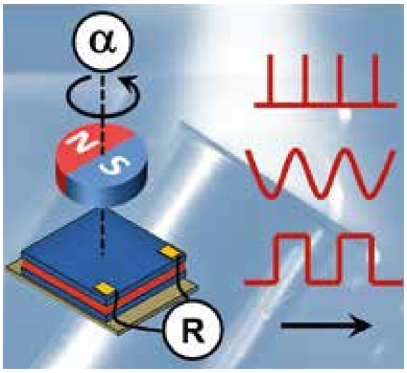
Kai Schlage, DESY

The improved sensor technology is based on a process known as oblique incidence deposition, or OID. The method, which is already used for single layers, allows arbitrary magnetic materials to be magnetically shaped on arbitrary substrates. The angle of deposition can be precisely varied and provides a simple way of determining whether a magnetic layer switches when the external magnetic field reaches a strength of 0.5 milliteslas or one hundred times that level. This corresponds approximately to the difference between 10 and 1000 times the strength of the Earth's magnetic field.

The DESY scientists discovered that this procedure can not only be used for single layers, but is also ideally suited for a large number of multilayer systems, thus considerably expanding the possibilities available in conventional design as well as the functionalities of magnetic multilayer stacks. The researchers manufactured their multilayer systems in vacuum installations specifically designed for this purpose. The physicists then conducted experiments at DESY's X-ray light source PETRA III to precisely measure the magnetic properties of each layer of the stacks, thereby demonstrating that OID permits arbitrarily complex and, most importantly, new magnetisation structures to be created in extensive multilayer stacks with extremely high precision. ››



Experimental measuring station to characterise the sensing properties of the microstructured nanometre-thin film stacks. The tailor-made setup allows rotary magnetic fields of well-defined strength to be generated, while thin needle probes are used to detect the change in electrical resistance.



The new deposition procedure in oblique incidence allows scientists to freely adjust and create new magnetoresistive sensor functionalities. The example shows a magnetoresistive trilayer and corresponding sensor characteristics that can be realized with the new technology

Smart solution

In terms of magnetic sensors, this means that it is now possible to straightforwardly produce microstructured multilayer stacks having identical compositions of materials and thicknesses but exhibiting very different and novel sensor characteristics.

"Our procedure allows the production of magnetic sensors that deliver significantly more precise signals containing more information that are also easier to process," says group leader Ralf Röhlsberger. "This allows for instance rotational movements to be monitored much more precisely than possible today, significantly improving the safety of motors, drive units and engine control systems, especially under extreme conditions."

The group has already filed a patent application for its method and hopes to demonstrate its commercial potential in a cooperative venture with industrial partners. To this end, a new plant is being built, and the use of the sensors is tested in the industrial environment. Over the next two years, this project will be funded by the Helmholtz Validation Fund (HVF), which supports particularly promising projects in transferring insights from research into application.

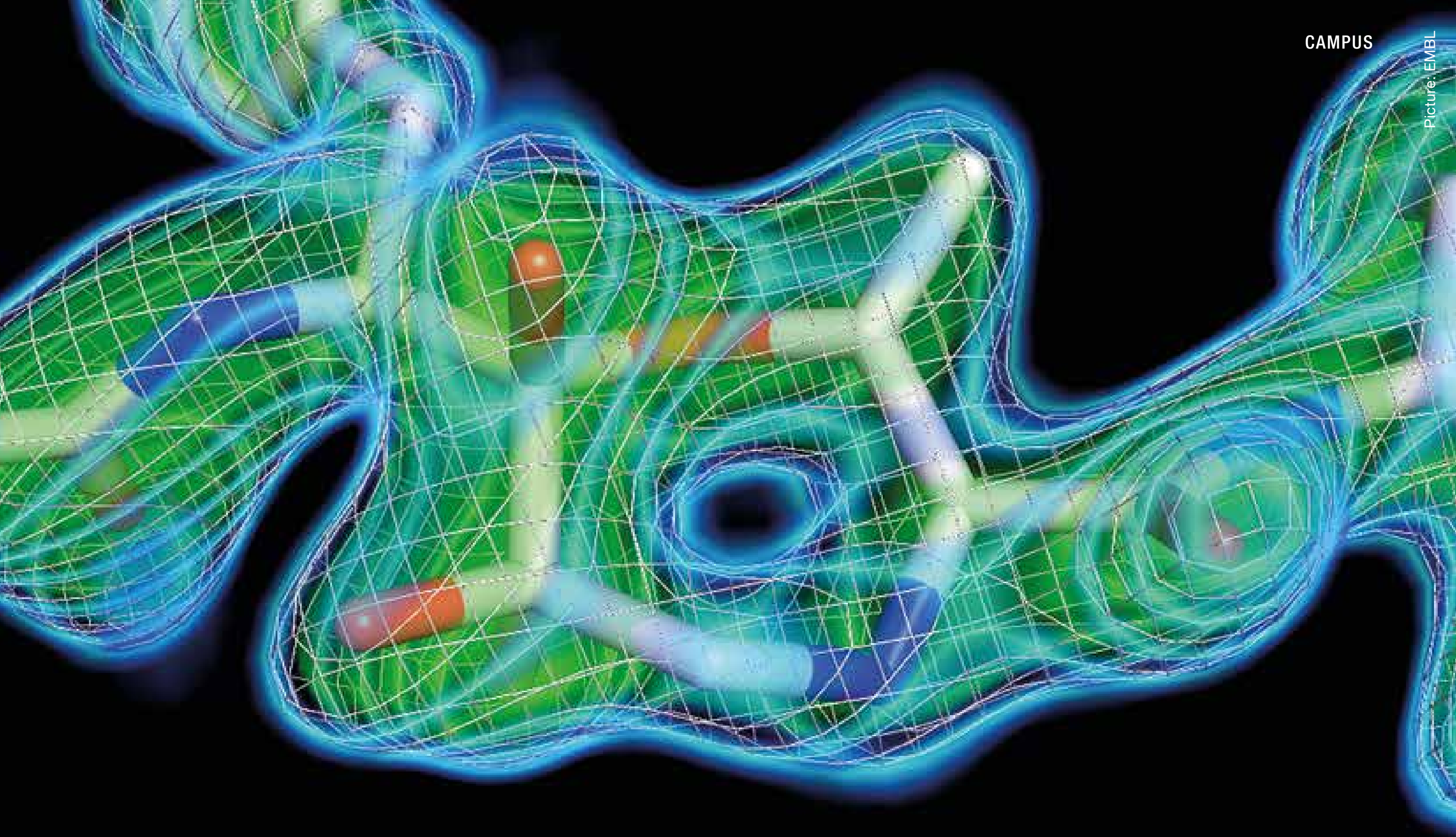
Advanced Functional Materials, 2016; DOI: 10.1002/adfm.201603191

femtopolis

Institute X

The DESY location in Zeuthen can look back on a very varied history. Its roots go back to 1939, when the German Postal Ministry set up a nuclear physics laboratory in Zeuthen known as the Agency for Special Physical Issues. In the previous year, Otto Hahn had discovered nuclear fission. Among other things, the researchers in Zeuthen wanted to find out whether the "smashing of atoms" could be used as a new source of energy and for the creation of bombs with incredible explosive force. However, the Postal Ministry did not make much progress in this regard. The institute was occupied by Soviet troops in May 1945, who immediately disassembled all the technical equipment. In 1950, the newly established German Democratic Republic began to take an interest in nuclear physics, for which it created the Miersdorf Institute at the Zeuthen site. The facility was known as Institute X in internal documents, with the letter "X" standing for nuclear physics, research of which was still forbidden to Germany at the time. The new institute's mission was to create the research basis for nuclear power plants. In 1957, however, East Germany's first research reactor went into operation in Rossendorf near Dresden. This shifted the focus of nuclear research in East Germany, and the scientists in Zeuthen turned to particle physics. The institute was now called the Research Centre for the Physics of High Energies before being renamed the Institute for High-Energy Physics (IfH) in 1968. However, as East Germany did not have a large accelerator of its own, the Zeuthen scientists cooperated with the Joint Institute for Nuclear Research, the Eastern European accelerator centre in Dubna, Russia. In addition, they regularly travelled to the West to take part in experiments at the European particle research centre CERN in Geneva. As of 1986, the IfH was officially allowed to become involved in the H1 experiment, one of the two large particle detectors that were being built for DESY's HERA storage ring. Then, in November 1989, the Berlin Wall fell. This is when the physicists from Zeuthen were rewarded for having stayed in contact with the particle physics centres in the West despite all the difficulties they sometimes faced, and for their participation in top international projects. When independent experts evaluated the institute's scientific quality in 1990, their assessment was very positive and they recommended that the facility should be maintained. Twenty-five years ago, on 11 November 1991, the Federal Republic of Germany signed a state treaty with the states of Brandenburg and Hamburg that incorporated IfH Zeuthen into DESY, which now has two locations, each with a first-rate research profile.

Flashback 1974: Survey of images from bubble chamber experiments in the former Institute for High Energy Physics (IfH)



Every atom counts

How cancer drugs block the cell's "garbage disposal unit"

Malignant cancer cells not only proliferate faster than most healthy cells in our bodies. They also generate more "junk", such as faulty and damaged proteins. This makes cancer cells inherently more dependent on the most important cellular garbage disposal unit, the proteasome, which degrades defective proteins and removes them from circulation. Treatments for some types of cancer, such as multiple myeloma – a type of bone marrow cancer – exploit this dependence. Patients are treated with so-called inhibitors, which selectively block the proteasome. The ensuing pile-up of cellular junk overwhelms the cancer cell, ultimately killing it. A team of researchers from Göttingen and Hamburg have now succeeded in determining the 3D structure of the human proteasome in unprecedented detail and have deciphered the exact mechanism by which inhibitors block the proteasome. Their surprising results will pave the way to develop more effective proteasome inhibitors for cancer therapy.

To understand how cellular machines such as the proteasome work, it is essential to determine their three-dimensional structure in detail. With its more than 50 000 atoms, the barrel-shaped proteasome, however, is a true challenge for structural biologists. A group of scientists led by Ashwin Chari at the Max Planck Institute for Biophysical Chemistry in Göttingen and Gleb Bourenkov at the European Molecular Biology Laboratory (EMBL) in Hamburg have now managed to determine the three-dimensional structure of the human proteasome at an unprecedented resolution of 1.8 Ångström using the brilliant X-rays from DESY's light source PETRA III – enabling them to pinpoint the position of single atoms in the garbage disposal unit.

In a next step, the researchers solved the structure of the proteasome bound to four different inhibitors that are either already used in the clinic or are currently undergoing clinical trials. "The substantial improvement in resolution compared to previous proteasome structures has allowed us to establish the exact chemical mechanism by which inhibitors block ›› the proteasome," says Chari. "This knowledge makes it possible to optimise inhibitor design and efficacy – since only inhibitors tailored to the proteasome shut it down completely."

The scientists discovered an important detail in the so-called active site of the proteasome. The active site is what enables the proteasome to degrade the cell's junk, and it is what the inhibitor drugs bind to in order to shut off that activity. In contrast to the common perception, a 7-ring structure is formed by the chemical reaction of inhibitor and proteasome, which contains an additional so-called methylene group. This has far-reaching consequences for the inhibitor's efficacy and chemical mechanism, the researchers explain. "Even though a methylene group just comprises one carbon atom and its two associated protons amidst the more than 50 000 atoms of the proteasome, it decisively influences which chemical features make the inhibitor most effective in blocking the proteasome," says Thomas Schneider, who leads a group at EMBL. The researchers have already filed a patent application for the chemical procedure to design such inhibitors. "Clinical applications are always preceded by knowledge about targets – therefore, the details, where every atom counts, make all the difference," Bourenkov states.

"The substantial improvement in resolution compared to previous proteasome structures has allowed us to establish the exact chemical mechanism by which inhibitors block the proteasome"

Ashwin Chari, Max Planck Institute Göttingen

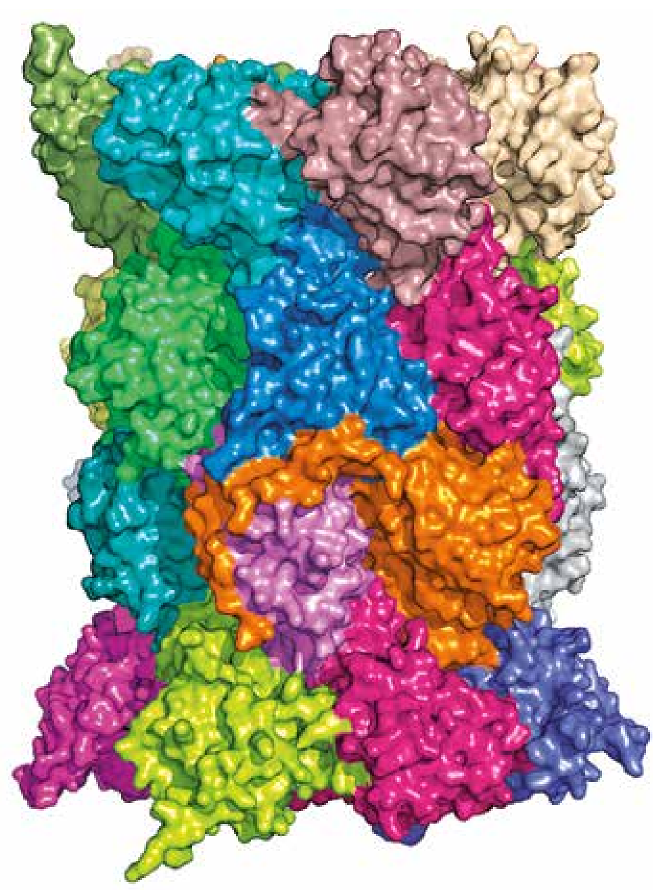
Huge effort reveals small difference

To determine a molecule's structure using X-ray crystallography, scientists grow crystals of that molecule, then shine a powerful beam of X-ray light onto the crystal. Based on how the X-rays scatter after hitting the crystal, researchers can deduce the molecule's three-dimensional structure. In practice, however, this is far more difficult than it sounds, and requires special procedures. The outstanding purity of the samples and the high quality of the crystals were crucial prerequisites for the detailed elucidation of the spatial structure of the proteasome.

The second decisive element for the project's success was the high brilliance of the X-ray light provided by PETRA III. "The DESY light source generates X-rays of exceptional quality. With the help of powerful X-ray optics, we were able to tailor the X-rays to perfectly suit the crystallised proteasome. Only this made it possible to determine the proteasome structure in unprecedented detail," concludes Bourenkov.

Science, 2016; DOI:10.1126/science.aaf8993

Tailored X-rays perfectly matching the dimensions of the protein crystals enabled the scientists to determine the proteasome structure in unprecedented detail.



Picture: EMBL

Arsenic in plants

X-ray study reveals distribution of the toxic metalloid in leaves

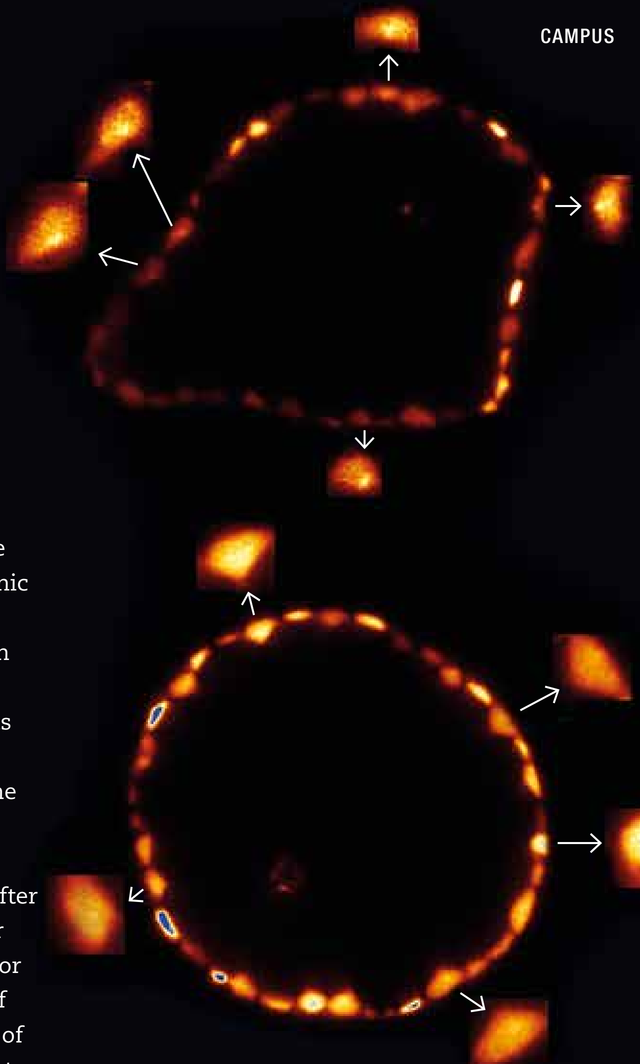
Arsenic is highly toxic and poses a growing environmental and health problem all over the world. The concentration of arsenic in the soil is increasing as a result of human activities, and in many countries – especially on the Indian subcontinent – the concentration of arsenic in the groundwater has become a problem. In humans, arsenic can cause cancer, necrosis, or acute renal and circulatory failure. The metalloid is also toxic to plants. It is taken up by the same transport mechanism as phosphorus, an element that is essential to plants, and even at levels far beneath the lethal concentration, it impairs plant growth and thus reduces crop yields.

"On top of this, humans eat plants, of course, and feed them to their livestock, so that arsenic accumulates in these and eventually ends up in human beings," explains Hendrik Küpper of the Czech Academy of Sciences and the University of South Bohemia in Ceské Budejovice (Czech Republic), who studies the effects of the toxic metalloid together with colleagues. "By carrying out our analysis, we wanted to find out exactly how arsenic poisoning occurs in plants," adds Gerald Falkenberg of DESY, who is in charge of the beamline at the X-ray light source PETRA III where the experiments were performed. The researchers selected the aquatic plant rigid hornwort (*Ceratophyllum demersum*) for their studies, which has proved to be a kind of indicator plant for metals.

Küpper and his team exposed the plant under investigation to arsenic concentrations between one and five micromols per litre, and then shone a narrowly focused X-ray beam through the leaves. "Thanks to PETRA III, we could peer into individual cells of the plant for the first time," reports Küpper. "This allowed us to localise the arsenic more precisely within the cell – after all, it makes a difference whether it is in the cell wall, for example, or in the vacuole." A concentration of one micromol of arsenic per litre of water is still tolerated by the plant. The plant first deposits the toxin in its outer layer, the epidermis. "Surprisingly enough, we found that arsenic initially accumulates in the cell nuclei," Küpper reports. Only when the concentration rises to five micromols per litre, a level that the plants are unable to withstand for prolonged periods, is arsenic also found in the vacuole and thus more or less throughout the entire cell.

"This means that the capacity of the epidermis is exhausted and the plant can no longer get rid of the toxin, and that's when things start to get serious," says Küpper. The arsenic now spreads to the so-called mesophyll, which makes up most of the leaf. This is where photosynthesis takes place, that is, where the plant absorbs light and produces sugars. This shift in the distribution can be clearly observed in the X-ray tomogram of the leaves.

In future studies, the scientists are hoping to find out what arsenic does inside the cell nucleus. "Presumably, it causes genetic damage," says Küpper. For example, arsenic might replace the phosphorus in the genes. Whereas the current X-ray study shows that arsenic already accumulates in the cells' nuclei at low concentrations, the scientists are planning further experiments in which they will look at the chemical bonds that are formed by arsenic in the nucleus as compared with other parts of the cell.



Distribution of arsenic within the epidermis of leaves of rigid hornwort at concentrations of one micromol (top) and five micromols (bottom) arsenic per litre water. At low concentrations, the toxic metalloid accumulates predominantly in the nuclei of epidermal cells, while at high concentrations, it floods the whole cell.

Journal of Experimental Botany, 2016; DOI: 10.1093/jxb/erw238

Was
läuft im
MOLEKÜL
Kino
Wie
LAUT
WAR DER
Urknall?
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eren

WISSEN
vom
FASS

"How loud was the Big Bang?" Jan Louis, physics professor at the University of Hamburg, answered this question using neither Powerpoint nor chalk, in a relaxed atmosphere in the "Hadleys" pub.

Louis brought back the idea of "Wissen vom Fass" ("Science on tap") from Israel. In Hamburg, the event is organised by DESY and the University of Hamburg. Patron is the Hamburg Senator for Science, Research and Equality, Katharina Fegebank.

Alarm on the salad plate? In the "EierCarl" pub at the fish market, Julia Kehr, professor of molecular plant genetics at the University of Hamburg, addressed questions such as: "Does the salad notice that it is being eaten?"

The goal of "Wissen vom Fass" is to inspire people for the natural sciences in an unconventional, relaxed atmosphere – while at the same time showing how fascinating, but also how important research is for culture and society.

The "Schellfischposten" too stood for an evening in the service of science: "What, our genetic makeup contains garbage?" Chemistry professor Ulrich Hahn eloquently explained why this shouldn't worry us.

In the "Elbwerk" on St. Pauli, Robin Santra demonstrated the fascination of light. In his day job, the leading scientist at DESY and professor at the University of Hamburg is dealing with ultrafast processes in intense radiation fields.

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Cover picture:
The central black hole of the active galaxy Centaurus A fires jets of matter far into space. The shock fronts that are formed in the process are visible at X-ray wavelengths (blue). The picture is a composite of images captured at infrared, visible and X-ray wavelengths. Space is full of such cosmic particle accelerators. Using the latest methods and instruments, astrophysicists are unveiling the sources of these high-energy particles.

Picture: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)

The DESY research centre

DESY is one of the world's leading particle accelerator centres. Researchers use the large-scale facilities at DESY to explore the microcosm in all its variety – ranging from the interaction of tiny elementary particles to the behaviour of innovative nanomaterials and the vital processes that take place between biomolecules. The accelerators and detectors that DESY develops and builds at its locations in Hamburg and Zeuthen are unique research tools. The DESY facilities generate the most intense X-ray radiation in the world, accelerate particles to record energies and open up completely new windows onto the universe.

DESY is a member of the Helmholtz Association,
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