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# Max Planck RESEARCH

The Science Magazine of the Max Planck Society 2.2019

# Energy

**COMPUTER ETHICS**
Digital humanism

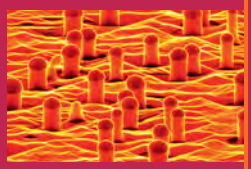
**PLANT RESEARCH**
Fill up the bowl!

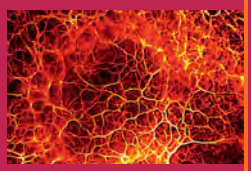
**MACHINE LEARNING**
Programming fairness

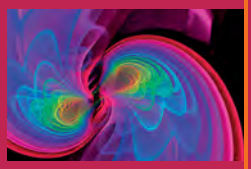
Special
**Black holes**

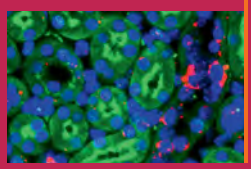
Max-Planck-**Innovation**

Connecting **Science and Business.**









Max Planck Innovation is responsible for the technology transfer of the Max Planck Society and, as such, the link between industry and basic research. With our inter-disciplinary team we advise and support scientists in evaluating their inventions, filing patents and founding companies. We offer industry a unique access to the innovations of the Max Planck Institutes. Thus we perform an important task: the transfer of basic research results into products, which contribute to the economic and social progress.

# Connecting Science and Business

www.max-planck-innovation.de


# Lab beneath white sails

The *Eugen Seibold* is anything but a normal yacht. With its clear, elegant design it may resemble a luxury yacht at first glance, but anyone taking a closer look will soon notice a number of striking differences. The short cockpit, large deckhouse, high rail, and in particular the large open area in the aft part of the ship featuring a very prominent A-frame for handling large and heavy measuring instruments, all point to the fact that the *Eugen Seibold* is a working vessel.

With its length of 22 meters, a weight of 44 tonnes including all fittings and equipment, and a relatively small sail surface of just under 300 square meters, this yacht is certainly no "high-performance boat" in a sporting sense, but all the more from a scientific point of view. Everything on board is geared towards efficiency and flexibility, and laboratories take up more than half of the indoor area. The vessel can be sailed reliably by a small crew of just two or three people, even on the high seas. Scientific work on deck is facilitated by lightweight measuring equipment and the hydraulically pivotable A-frame. Comprehensive sets of research data can therefore be collected at comparably low cost, both for long-term observations and on shorter excursions.

The idea of Gerald Haug from the Max Planck Institute for Chemistry to create a research sailboat could be put into practice thanks to the Werner Siemens foundation that funded the construction of the yacht. Haug's research target is to achieve a better understanding of the biogeochemical cycle of the oceans. In other words, the synergies between the sea's physics, chemistry, and biology and the marine atmosphere. Haug and his team want to use the sailing yacht to take contamination-free air and water samples. While continuous contamination of the local environment from diesel-powered vessels with metal hulls is unavoidable, research operations on the *Eugen Seibold* can be conducted without using the diesel engine for up to ten hours. This is possible despite the considerable energy consumption of the extensive high-tech equipment on board, thanks to a hybrid engine and a powerful high-voltage battery.

Photo: Michael Amme

# 18 ENERGY



ON THE COVER Rays of light for the energy transition: in future, regenerative energy sources are planned as a replacement for coal, gas and mineral oil. Here, nuclear fusion could offer an alternative to power from wind turbines and solar power systems. The tracer of an electron beam in a plasma shows that a magnetic field confines its charged particles as needed, which melt in a fusion power plant and would release large quantities of energy. While fundamental physical and technical questions remain unanswered when it comes to nuclear fusion, to date there are no suitable energy storage facilities for expanding wind and solar power. Batteries from renewable materials or chemical products produced from carbon dioxide could help here.

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SPECIAL

Photos: EHT collaboration; Anna Schroll; Bernd Wannenmacher

# 70 years of academic freedom

German research institutions launch a campaign to mark the anniversary of the Basic Law

Open to discussion: at the Zeit Forum in March, Max Planck President Martin Stratmann (middle) joined Zeit editor Andreas Sentker, Nadia Al-Bagdadi from the Central European University, Anuscheh Farahat from the Friedrich-Alexander-University (FAU) Erlangen-Nuremberg, and Ulrich Blumenthal from Deutschlandfunk to debate the question: academic freedom – a success story?

In May 2019, Germany celebrated the 70th anniversary of the Basic Law, which states in Article 5 that "sciences, research and teaching shall be free." German's scientific community is using the anniversary as an opportunity to discuss the resulting success stories and the opportunities and risks that this freedom presents, as well as asking what responsibilities it imposes. Originally prompted by the Max Planck Society, the campaign "Freedom is Our System. Together for Science" is an initiative of the Alliance of Science Organizations in Germany, which brings together ten important German research institutions. Over the course of 2019, a series of events, talks, debates, and opinion pieces will highlight the importance of independence in research and teaching – especially for basic research. At the same time, however, the scientists will take a critical look at their own developments and draw attention to potential risks to academic freedom. Among other topics, there will be discussions on the permissible scope of human genome research in the age of CRISPR/Cas9 and the need for regulatory measures in relation to autonomous, self-learning machine systems. The launch event in March was devoted to examining the responsibilities associated with new medical treatment methods.

# Full steam ahead!

The MS Wissenschaft will dock in 27 cities across Germany and Austria

Since mid-May, the MS Wissenschaft – a cargo ship with an on-board science center – has been undertaking another grand voyage. After an inauguration in Berlin, it is sailing to 27 cities via navigable rivers and canals. Covering almost 600 square meters, this year's exhibition is all about artificial intelligence and examines the opportunities of machine learning, the intelligent analysis of large volumes of data, and the interaction between humans and machines, to name just a few aspects of this multifaceted subject area. Over 30 interactive exhibits invite visitors to embark on a journey of discovery, with opportunities for active participation and also for reflection. This year, three Max Planck Institutes are taking part with a broad range of research topics. For example, the exhibit *Der Körper denkt mit* ("The body thinks too") from the Max Planck Institute for Mathematics in the Sciences illustrates that even artificial intelligence isn't independent of the body or its surroundings. The HyperDiver diving robot from the Max Planck Institute for Marine Microbiology uses machine learning to determine the biodiversity and state of health of coral reefs. Lastly, the exhibit from the Kunsthistorisches Institut in Florenz explores the idea that the concept of a non-human form of intelligence is a long-standing source of inspiration for human creativity.

https://ms-wissenschaft.de (in German)


Exhibition on board: with a focus on the subject of artificial intelligence, the MS Wissenschaft will be on a tour around Germany until early October – and exhibits from three Max Planck Institutes are going along for the ride.

Photos: Phil Dera (top); Ilja Hendel/WiD (bottom)

# "Viruses can quickly alter an entire population"

Guy Reeves on the release of genetically modified organisms into nature

Thanks to new techniques such as the CRISPR/Cas9 gene-editing scissors and the so-called gene drive, researchers can edit the genotype much faster than before and propagate these changes in a short time, even in large populations. In the laboratory, genetically modified organisms have been used successfully for some time now – for example, in basic research and drug production. Now, there are also plans to release them into nature. Guy Reeves from the Max Planck Institute for Evolutionary Biology in Ploen views the release of genetically modified viruses with particular concern.

*There are various projects in which scientists or companies want to release genetically modified organisms. What you think about that?*
**Guy Reeves:** What particularly worries me is the release of infectious viruses that have been genetically modified to bring about changes in mammals' immune systems. Many such viruses have already been developed in order to make mammals immune to diseases or even to sterilize them. A genetically modified virus that spreads throughout wild rabbit populations in order to provide them with immunity to two diseases was tested on the Balearic Islands in Spain in the year 2000. In Australia, another virus has been produced that can sterilize mice – but it is yet to be released.

Another example is a research project by the DARPA research agency of the U.S. Department of Defense. This uses insects to transmit genetically modified viruses to corn and tomato plants. At present, the experiments are still being conducted in secure greenhouses. However, if viruses of this kind are to be intentionally released into the environment, then the procedure will have to be tested very carefully indeed. Although these technologies have already reached an advanced stage, the process of testing them is only just getting started.

*Why are viruses so problematic?*
Almost no other biological system can affect an entire population with such speed – that is, within a single generation. In comparison, the gene drive – which is the subject of much discussion nowadays – operates at a snail's pace. What's more, the host range of a virus can be very broad, so it's sometimes difficult to predict which species a virus is able to infect.

*Are you against the release of genetically modified organisms under all circumstances unless they are agricultural crops?*
No, not at all. It's not about standing in the way of new technologies. But we have to be careful and weigh up the potential risks and benefits. Accordingly, infectious genetically modified organisms in particular should only be released following careful testing. In general, I also don't think it's sensible to use viruses whose risks are hard to control if there are alternative techniques that can achieve the same objectives. For example, the number of malaria infections can also be reduced by using mosquito nets and by improving people's living conditions.

*There's a sterility gene that's intended to wipe out mosquitoes and therefore to prevent the spread of malaria. How does that work?*
A gene of this kind causes female mosquitoes to produce sterile daughters. Their sons, on the other hand, are capable of procreation and continue to spread the gene throughout the population. However, this only works if the mother has two mutated copies of the sterility gene. In that case, she will actually only have half as many offspring, and the mosquito population will shrink – although mosquito populations are often huge, and it would take a long time for them to die out in this way. After all, two copies of the sterility gene have to meet in a mosquito for the insect to actually become sterile.

*A phenomenon known as the gene drive could accelerate this process.*
Exactly. The gene drive mechanism ensures that all offspring of a female mosquito receive two mutated versions of the sterility gene, even if she only contains one copy. The population would therefore shrink much faster than normal. However, the gene drive is nowhere near as fast as many people think. Even in an animal with generations as short as those of the mosquito, it could take the gene drive eight years or more, under ideal conditions, to make a population incapable of reproduction. Moreover, from our experiences with insecticides, we've learned how quickly insects can adapt if the selective pressure is strong enough – and if they developed resistance to a sterility gene, it would be like having six winning numbers in the lottery. I'm certain that large insect populations will adapt to a gene drive of this kind and deactivate it. Mosquito are very unlikely to be exterminated in this way.

Guy Reeves

*Are the current laws governing these kinds of experiments adequate?*
The regulatory authorities face an enormous challenge. They have to consider extremely complex mathematical models – a difficult task even for well-equipped authorities in industrial nations. But many of the prospective projects will affect emerging economies that are not equipped for this sort of thing at all – and, of course, viruses and insects don't obey national borders.

Interview: Harald Rösch

Photo: private


Getting started: the Co-Directors of the Max Planck Center in New York, Melanie Wald-Fuhrmann and Catherine Hartley, Hugh Brady, President of the University of Bristol, Max Planck President Martin Stratmann, and Klaus Blaum, Co-Director of the new Center in Tokyo (from left).

# New York, Bristol, Tokyo

Three new Max Planck Centers founded on three different continents

The Max Planck Society has further expanded its collaboration with top international partners, opening three new Max Planck Centers in spring 2019. The first of them is the Max Planck NYU Center for Language, Music and Emotion in New York. This Center combines the traditionally independent research areas of language and music on the one hand with emotion, memory, and decision-making on the other – and researchers plan to study interfaces between these areas through experimental work. At the Max Planck Bristol Center for Minimal Biology, researchers want to construct artificial cellular skeletons and develop nanoscale molecular machines. By doing so, they hope to gain more accurate insights into the building blocks needed for life. The dimensions in question are even smaller at the Max Planck-RIKEN-PTB Center for Time, Constants and Fundamental Symmetries, which is a collaboration by a total of four partners: the Max Planck Institutes for Nuclear Physics and Quantum Optics, the Japanese research institute RIKEN, and the Physikalisch-Technische Bundesanstalt (PTB). One of their objectives is to develop clocks that are even more accurate than today's atomic clocks, with a view to determining natural constants more accurately and investigating the symmetry between matter and antimatter.

# Exemplary further development

Federal prize for a highly parallel drug analysis method developed in Goettingen

Successful technology transfer: Moritz Rossner from the Max Planck Institute for Experimental Medicine.

The development of new drugs is a very laborious and expensive process. When a new substance is discovered, researchers must determine how a large number of molecules – so-called targets – react to it within the cells. This is the only way to prove that the substance has the desired medical effect and to identify its side effects. At the Max Planck Institute for Experimental Medicine in Goettingen, a suitable integrated measurement process has been developed for the first time. The method is able to analyze substances for a multitude of targets in parallel in a single measurement, allowing drugs to be developed much faster and more cost-effectively than with existing methods. The team of researchers working under Project Leader Moritz Rossner in Goettingen refined the method for use in the pharmaceutical industry and subsequently founded the company Systasy Bioscience. For this work, the scientists have now earned third place in the VIP+ innovation awards of the Federal Ministry of Education and Research (BMBF). These honors are awarded to especially successful projects, which are supported by the Ministry as part of the so-called VIP program to encourage validation.

Photos: Kahn/Courtesy of NYU Photo Bureau (top); Kate Kirkby; GSI; private (bottom)

# A river under human influence

Using the Mississippi as an example, an interdisciplinary project shows how human activity can cause permanent changes in nature

Can the transition into a new geological era dominated by humans also be illustrated at the regional level? That is precisely the aim of the project "Mississippi. An Anthropocene River", which was designed by Haus der Kulturen der Welt (HKW) and the Max Planck Institute for the History of Science. Its participants also include numerous U.S. partners and the Max Planck Institutes for Chemistry, Biogeochemistry and the Science of Human History. The project is partly sponsored by the German Foreign Office as part of the ongoing Year of German-American Friendship in the U.S. The areas around the Mississippi – which was once more of an immense floodplain than a river – evolved into a huge agricultural and industrial corridor as the river was dammed and canalized in the 20th century. Passing through complex, rapidly changing man-made ecosystems, the river acts as the catchment area for a range of cultures and is the scene of historical inequalities. As part of the Mississippi project, scientists, artists, and activists are working together to develop new methods of research and teaching that transcend the boundaries between disciplines. In collaboration with local initiatives, they are delivering insights into the local dynamics of changes taking place on a global scale.

Changeable: the motif of the Mississippi project is based on a 1940s map documenting historical changes in the riverbed.

Graphic: Meandering Mississippi. Map by Harold N. Fisk, U.S. Army Corps of Engineers, 1944 | Geological Investigation of the Alluvial Valley of the Lower Mississippi River

## On the net

**The power of emotions**
Hate and love, disgust and security – emotions not only move and control us but also wield immense power over politics and society, as demonstrated by the exhibition The Power of Emotions. Germany 19 | 19. The concept was developed by Ute Frevert, Director at the Max Planck Institute for Human Development, together with her daughter Bettina Frevert, who works in historical-political education. The 22 A1-sized posters are intended for display in schools, city halls, libraries, and other public places. Through individual emotions, they explore key events in German history from the founding of the Weimar Republic in 1919 to the Peaceful Revolution of 1989. Among other things, the website allows users to order the set of posters and offers an overview of where the exhibition is currently being shown.
**https://machtdergefuehle.de/?lang=en**

**Ethnological research in three minutes**
What does field research look like? What methods do you work with? In these videos, scientists from the Max Planck Institute for Social Anthropology in Halle provide an insight into their work. For example, Imad Alsoos speaks about mobilization strategies of Islamic groups in Palestine and Tunisia, Charlotte Bruckermann presents her field research on $CO_2$ emissions trading in China, and Brian Campbell gives an outline of everyday life in the multireligious city of Ceuta, a Spanish enclave in Morocco. The charming thing about these three-minute videos is that they are not only in English but also in the mother tongues of the various researchers – in Arabic, German, and Maltese.
**https://www.eth.mpg.de/4811217/conference_videos**

**Identifying plants via smartphone**
While out walking, you spot a plant that you'd like to know more about. What's the plant called, is it poisonous, or might it be a protected species? If you don't have a plant identification book to hand, your mobile phone will be able to help in the future – thanks to the app *Flora incognita*. This identification software was developed with the help of scientists at the Max Planck Institute for Biogeochemistry in Jena. Flowers and leaves can be photographed using the smartphone's camera – and, in a matter of seconds, you receive a suggestion for the name of the plant as well as further information. The free app, which is now available in seven languages, allows plants to be identified by anyone, anywhere.
**https://floraincognita.com/?noredirect=en_US**

# Digital **humanism**

From nursing care robots to language assistants such as Alexa and Siri or electronic control systems in your car, digitization is literally drawing closer to our everyday lives. For a long time, the issue of ethics has been on the table in order to keep the use of artificial intelligence within reasonable limits. Our author advocates reviving humanistic ideals for the digital world. His main concern is that people should take center stage.

TEXT **JULIAN NIDA-RÜMELIN**

For many historians, the greatest innovation in human history is the invention of arable farming and livestock farming. The ancient hunter-gatherer culture that still exists to some small degree today was replaced by settled farmers and livestock breeders. However, in terms of its most important features, the human species was still designed to cope with the old, outmoded way of living. While arable farming and livestock breeding enabled many more people to live in a certain area than before, at the same time, general health deteriorated and epidemics developed, as did myopia, tooth decay and flat feet.

> The big data economy is casting a pall over the beautiful new world of the Internet

Industrial technologies played a huge part in shaping our current way of living. The steam engines of the early industrial period, the electrification process at its most intense, as well as the continuous shift from industrial production to service provision in recent decades, have created a standard of living in the most highly economically developed regions of the world that has never existed before in the history of humankind. Average life expectancy is increasing all the time, even though the way of life of the late industrial period is not always conducive to good health.

Possibly, digitization will turn out to be the fourth great technological, even disruptive, innovation. Certainly, both its convinced proponents and equally convinced critics alike agree that the human way of life will again be subject to fundamental change as a result of digitization. However, the euphoric chorus that accompanied the early digital period – such as the expectation that with the establishment of the Internet, the age of individual freedom and global democracy would find its highest form on the net – is now turning into an anxious swan song mourning the passing of constitutional democracy, with electoral manipulation by Cambridge Analytica and Russian bots. A kind of hangover has taken hold. Leading representatives of the Internet ideology of anarchic freedom, such as Jaron Lanier, are revising the assessments for which they

Photo: Alamy

Human or machine? In the age of artificial intelligence, the boundaries appear to be becoming more fluid.

became famous decades ago, and which shaped an entire generation of Silicon Valley employees. The projection of hippie visions onto the Internet age, which spread right up to CEO level at Google, Microsoft, Amazon and Facebook, now already appears

According to the logic of AI, there is no freedom of will

to be a thing of the past. The beautiful new world where everyone is connected to everyone else, all have the same access to information, where dictators cannot survive and the American way of life dominates the global village, has palled. In the era of the big data economy, commercialization has become all too obvious.

One feature is now becoming clear that used to apply to other technological innovations in the past, namely that technologies are always ambivalent; they can be used to both good and bad purpose. There is no mechanism inherent to technology that guarantees to provide the perfect way of human life. The assumption that in each case, it is technical progress – the development of human productive forces and the conversion of natural assets into consumer goods that leads to advances in human history – that can be regarded as the real driver of progress, is a Marxist legacy that we should abandon. People decide on how to use technological options; they decide whether digital opportunities contribute to a humanization of the world and to economic and social progress, or whether they lead to a loss of political control, dependence on the media and the atomization of society. Digital humanism counters both the IT and Internet enthusiasts and the apocalypticists with its message that technical progress is shaped by humans.

From antiquity through to present-day Hollywood, the relationship between human and machine has inspired many myths. Computers are algorithmic machines or Turing machines (named after the mathematician Alan Turing). People and other highly developed life forms are not machines. Nature as a whole is not a machine. Digital humanism does not transform people into machines, nor does it interpret machines as being people. It adheres to the particular nature of human beings and their abilities, and uses digital technologies to expand, rather than to limit them.

If people were to act with the same degree of predetermination as Turing machines, all our behavior could in principle be predicted in advance. Since our behavior depends on our convictions, it should in principle also be possible to forecast the convictions that we will have in the future. However, this would mean that we would also be able to forecast the knowledge held by future societies, which however is incompatible with the genuine progress of knowledge and also raises logical problems to which Karl Popper pointed in the past. He argued that the assumption that all future knowledge can be predicted on the basis of what we currently know leads to a logical contradiction, since this knowledge is already contained in our current knowledge; therefore, there is no knowledge in existence that has not yet been realized today. However, one precondition of a real knowledge revolution is that the later knowledge is not already covered by what is currently known. With this assumption, comprehensive determinism finds itself in an unresolvable conflict.

According to the logic of AI, there is no freedom of will. Machines do what they are programmed to do. They behave in the way they should. If they don't, this is due to anomalies in the system, in other words, random irregularities or damage. Additionally, some software-controlled systems have probabilistic functions, which assign a probability distribution of successor states to a state, rather than a fixed successor state. They make it possible to construct "learning" robots and more complex software systems. The transition from deterministic to probabilistic machines not only leads to a suspension of the categorial difference between human and machine. The alternative is not a choice between determinism and probabilism, but between determination and freedom.

Humans reflect on their actions, and are in a position to tailor their actions to a certain rationale. This ability to make decisions that accord with the best rationale is what constitutes human freedom and responsibility, and what separates us from animals and machines. If the action in question were already determined every time before any consideration or deliberation is made (or even just the distribution of probability of the potential actions), the actor would not be free, and also not responsible. In fact, strictly speaking, there wouldn't be an actor at all. Then there would not be an action, but simply pure behavior.

Another topic that is frequently the subject of discussion in the Internet era is "virtual communication". However, the term is misleading, since in the so-called "virtual world", communication is generally real. Every item of communication uses different media. The oldest medium came in the form of signs and soundwaves, while later cultural techniques such as reading and writing used lettering as a medium, and the invention of the printing press at the dawn of the modern age made this medium available to the mass population. In contrast to what some postmodern theoreticians say, digitization will not bring about an end to the rationality of the Gutenberg era, neither will a new world of images be created without a logical structure; to a far greater extent, the medial spectrum of acts of communication will be expanded by a further dimension. There is nothing virtual about this.

However, the same rules apply for communication on the Internet as for communication in general. Philosophers of language agree that successful communication practice is only made possible when those involved in the communication stick to certain constitutive rules. These include the rule of truthfulness. This requires that if I make a claim, I am also convinced that it is true. Equally, we can expect our communication partners to trust us, in other words, that they assume that the claims that I make are in line with my own convictions. These rules are only trivial on the surface. After all, they subject the communication partners to the obligation to orient themselves on what they regard as good rationale in the way they express themselves, rather than on their own individual interests. In many cases, purely individual interests would contradict the requirement to observe the rules of truthfulness and trust. If we were always to be untruthful when this was in our interest, the act of communication would immediately lose its value.

In the same way as overall everyday communication is based on the observance of certain norms and rules, such as truthfulness, trust and reliability, and these rules must be generally accepted as general limitations in order to enable us to treat each other humanely, it is also true of the Internet that communication is eroded without functioning ethos norms. At times, the anonymity of Internet communication, the lack of a face-to-face situation and the possibility of communicating under a false name enable manipulative practices that fail to conform to the rules of truth, trust and reliability.

Fortunately, the practice of targeted deception can only function on a parasitic basis, in other words, only when the majority of the communication partners adhere to the rules of truth, trust and reliability. It appears that this is still the case. Most social media groups, whether closed or open, are noticeably characterized by honesty, stability and reliability. An indication of this is the positively excessive use of rules of behavior and the rigid sanctioning of shitstorms and individual expressions of displeasure. When fewer legally sanctioned norms apply, cultural practice takes on greater importance.

> Access to the World Wide Web should be a basic human right

For many people throughout the world today, sending e-mails, presenting themselves on the Internet, communicating and accessing all kinds of information is a part of everyday life. However, not everyone has the same access to the Internet everywhere in the world. This is known as the digital divide, or the gap between so-called "onliners" and "offliners".

Even if the number of offliners is declining year by year, there are plenty of reasons why access to the

Photo: Alamy

Internet should be declared a basic human right – today and certainly in the future. The basic underlying principle of human rights has not changed: the right to self-esteem is inviolable. This is the core of human dignity, as expressed for example in the ethics of Immanuel Kant or, in the present day, in the ethics of Avishai Margalit in systemic form. The conditions of human society change with the times and cultures, however. The definition of exclusion and discrimination practices is not set in stone, but depends on cultural and economic conditions. Human rights apply in traditional cultures as well as modern ones, although a general education guaranteed by the state only recently became a human right in the modern age, since the conditions for this were not provided in traditional societies. Participation in communication, the free expression of opinion and information freedom are a human right; the media of communication and information change with the times.

The more digital technologies are used in everyday life, the louder the call will become for digital education. For example, in 2014, the head of studies of the International Conference of the Learning Sciences, Birgit Eickelmann, complained in an interview with the Frankfurter Allgemeine Zeitung newspaper that too many children are not able to work independently on the computer, to create presentations and documents, and that for this reason, we "in Germany have lost access internationally in many areas." She demanded better digital education, which in general means teaching media skills and how to handle the new technologies. With this in mind, in 2016, the German Federal Ministry of Education started the "Education campaign for the digital knowledge society", which is designed to promote learning with digital media and the teaching of digital skills. The aim is to make increasing use of new learning apps, virtual libraries and virtual reality glasses in classrooms, lecture theaters and companies.

However, the problem with these forms of digital education campaign is that their goals remain too vague, and they focus only on the ability to handle technologies, something that is already taken for granted by the younger generations. The grotesque consequence of this is that *digital immigrants* teach *digital natives* a language that they have painstakingly learned, while the pupils, who have learned it since childhood, can speak it with ease.

In the case of digital technologies, products are also changing so fast that knowledge of how to use them must constantly be updated, making it not particularly suitable as school learning material. If the characterization of Wilhelm von Humboldt still applies today, i.e. that school knowledge is of a canonical nature – in contrast to scientific, research-oriented knowledge – then practicing how to handle digital end devices cannot be classified as a useful classroom subject. What, therefore, could digital education be like?

> The ability to make independent judgments – a humanistic ideal – is becoming more important

Digitalization changes the availability and archiving of data stocks. Broad areas of the humanities, historical and philosophical research (sources, texts, interpretations) are becoming generally available to an increasing degree. Today, research and travel that used to take up so much time, as well as hours spent in specialist libraries, is often no longer required. The full digitization of museum stocks currently in progress, along with mandatory digital documentation in the sciences, will further improve this situation. Since the amount of time and money involved in acquiring data is decreasing, this form of accumulated knowledge is losing value. As a result, methodological skills are becoming more important than data skills. This is already reflected in study programs, where entire areas of knowledge are regarded as non-essential and are being replaced by methodology training.

As a result of the digitization of data provision, numerous "gatekeepers" such as librarians, publish-

Photo: Alamy

ing editors, journal reviewers, and newspaper, TV or radio editorial boards are no longer required. This means that there is an increasing demand for the ability to make an independent judgment. Data provision does not replace the ability to evaluate and examine data as to whether it is reliable and what arguments can be based on it.

The World Wide Web is confronting us with a far greater variety of interpretations, theses, theories and ideologies, making it more difficult to form an opinion. As a result, the old humanistic education ideal formulated in Plato's *Theaitetos* dialog 2,500 years ago, which places the independent power of judgment, the ability for theoretical and practical common sense at the forefront, has gained enormously in value. People who tend to follow suggestively formulated convictions, or who screen themselves off from unpalatable facts, quickly lose their bearings in the new, digital data universe. They enclose themselves in "bubbles", such as those provided by the social media in particular, or they lurch about through the data world, pulled in different directions by different influences. As a consequence of digitization, we are not living in a knowledge society, but rather in a data society, or better, in a data economy.

Ultimately, many aspects of digitalization point to a further key goal of humanism, namely the formation of personality. Today, this topic is of greater importance than ever before, and its significance will further increase as our methods of communication become digitized and during the course of interactions, transfers of data and services and digitalized production (key word: Industry 4.0). The reason for this is quite simple: the more varied, volatile and complex personal connections, community networks and ways of living become, the greater the need for the individual ability to be the author of one's own decisions, convictions and projects. Digital opportunities create new personal freedoms and trigger an enormous impetus for change, both culturally and economically. They therefore also strengthen the potential for autonomy among individuals, while at the same time exposing them to the stress of an increasing need for orientation. ◀

Photo: Andreas Müller

## THE AUTHOR

**Julian Nida-Rümelin** teaches philosophy and political theory at the Ludwig-Maximilians-Universität in Munich. He is responsible for the field of culture at the Zentrum Digitalisierung.Bayern, and is a member of the Board of Directors of the newly-founded Bavarian Research Institute for Digital Transformation.


## THE BOOK

Julian Nida-Rümelin
Nathalie Weidenfeld
**Digitaler Humanismus**
Eine Ethik für das Zeitalter der Künstlichen Intelligenz
Piper Verlag, Munich 2018
Hardback, 224 pages, EUR 24

McMurdo Station
Antarctic

# A paradise in white and blue

Max Planck scientists cooperate with partners in around 120 countries all over the world. Here they write about their personal experiences and impressions. Konrad Meister from the Max Planck Institute for Polymer Research in Mainz spent four months in the Antarctic conducting research in cooperation with the Universities of Oregon and Illinois (U.S.). He tells of long working days, explains the connection between his research and ice cream, and why the Antarctic is a place full of contradictions.

It was the moment when the first fish took the bait and I thought, "That can't be true. All around you, there's nothing but ice and snow. And you're sitting there, fishing," that I realized that now I really was in the Antarctic. The southernmost continent on Earth, and 16,796 kilometers away from Mainz.

I had undertaken an arduous journey to get here. From Frankfurt, the first stop was Christchurch in New Zealand. From there, I flew with an LC-130 U.S. Air Force plane to the Antarctic, to the McMurdo Station, an old navy base which at certain times of the year houses several hundred scientists, depending on the season.

I can best describe everyday life there as "eat, sleep, science." Since it never gets dark, it's by no means unusual to work from 8 in the morning until 11 at night. The daily routine is pretty much the same: load up the PistenBully, drive to the fishing spot, and drill a hole through the ice, which is several meters thick. Then the first task is to catch fish! Once my colleagues and I have caught enough fish, we drive back to the station. There, we take a small amount of blood from the fish and place them in special aquaria in order to prepare further tests.

The focus of my research is on why fish don't freeze in the Antarctic. The American Arthur DeVries is considered a pioneer in this field. In the 1960s, he discovered that these fish have special proteins that act as a type of natural anti-freeze, which is why DeVries called them anti-freeze pro-

Graphic: iStockphoto

Dr. Konrad Meister, 36, studied biochemistry at the Ruhr-Universität Bochum and gained his doctorate in physical chemistry. Following a stint as a postdoc at the AMOLF research Institute in Amsterdam, supported by a Marie-Curie scholarship, he has been a Group Leader at the Max Planck Institute for Polymer Research in Mainz since summer 2018. In his work, he focuses on proteins with unusual properties.

teins. Since then, quite a lot has been learned about how they function. If a fish absorbs small ice crystals, anti-freeze proteins dock onto them and prevent the ice from further increasing in size. Here, I am particularly interested in the molecular mechanisms. How do these proteins bond with the ice crystals? Do they change their structure during the process?

For this reason, I moved to the Department for Molecular Spectroscopy at the Max Planck Institute for Molecular Research, which with its state of the art spectroscopy methods and outstanding ice laboratory offers ideal conditions for my research. Now the only thing that was missing were the proteins, and I am grateful that Director Mischa Bonn gave permission for me to go on this expedition for several months.

One important area of application for my research is cryopreservation, with the aim of freezing organs and other tissue. However, anti-freeze proteins are also used in the food industry, where they ensure, for example, that ice cream stays creamy. They are also of interest as a very powerful anti-freeze for a large number of industrial surfaces, such as the blades of large wind turbines.

The Antarctic is a place full of contradictions: the endless expanse of the ice often gave me a feeling of boundless freedom, while at the same time, you are a prisoner on this continent and are reliant on the base station. Although the Antarctic is one of the most remote regions in the world, you are constantly surrounded by people at the station. There isn't any such thing as your own private space.

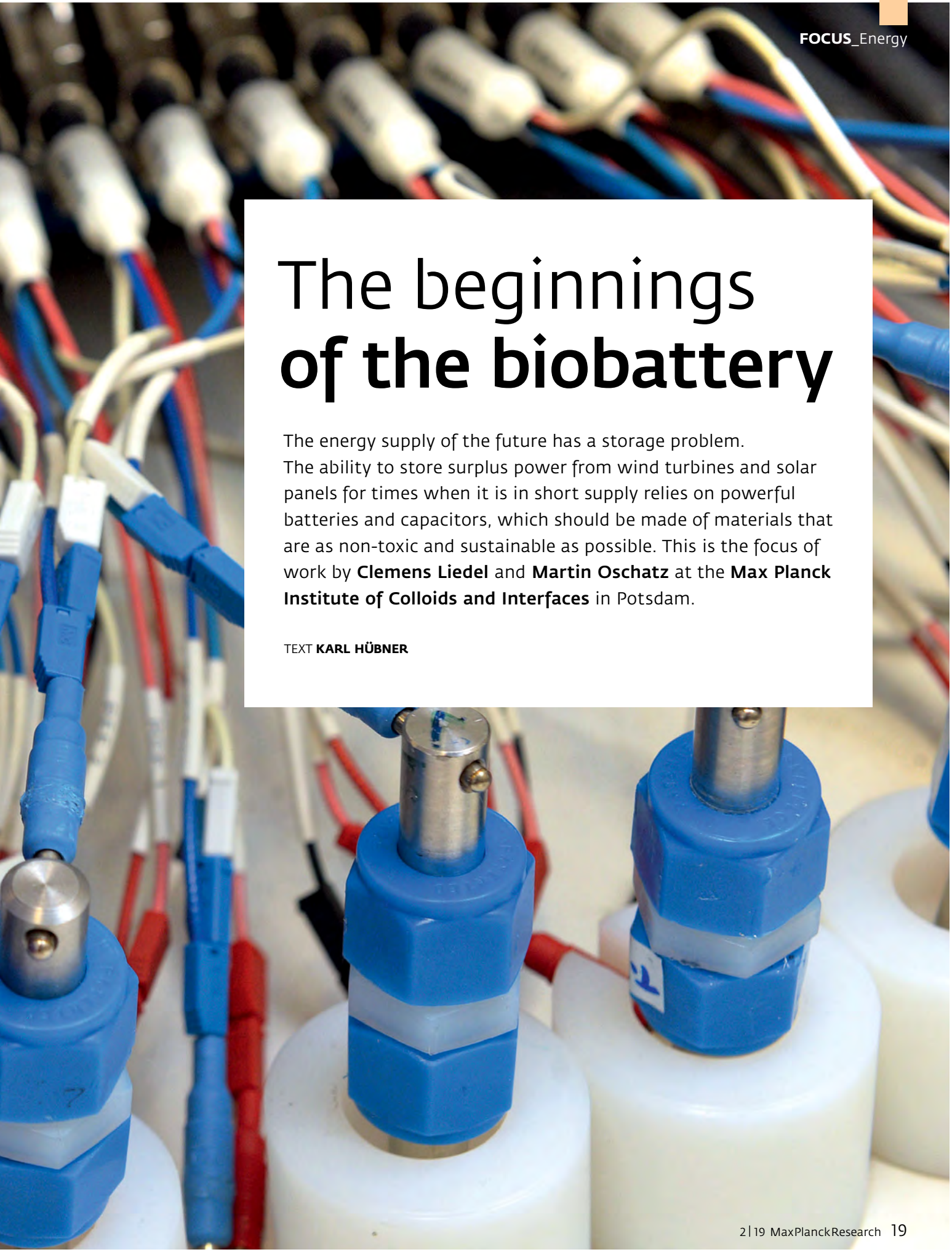
Also, life in the Antarctic is very monotonous. For a start, there's the everyday fishing expeditions; then there's the constant brightness and the fact that you can hardly smell or hear anything. Also, I spent months on end living with the same people, who are also all approximately the same age. Under those conditions, you long to see someone different once in a while.

However, there are some routines that I never tired of. Who wouldn't love to see whales, seals or penguins right up close on a regular basis? And with time, I began to pick out increasingly subtle differences in the landscape, which at first sight seems to consist of nothing but ice and snow. For that reason, I will always remember the Antarctic as a special place: a paradise in white and blue.

Photo: private

Testing sustainable battery components: researchers in Potsdam use a potentiostat to test how well the cells work with, for example, electrodes or an electrolyte made from renewable raw materials. To do this, they charge and discharge the test systems multiple times, taking measurements of the current and voltage between the poles.

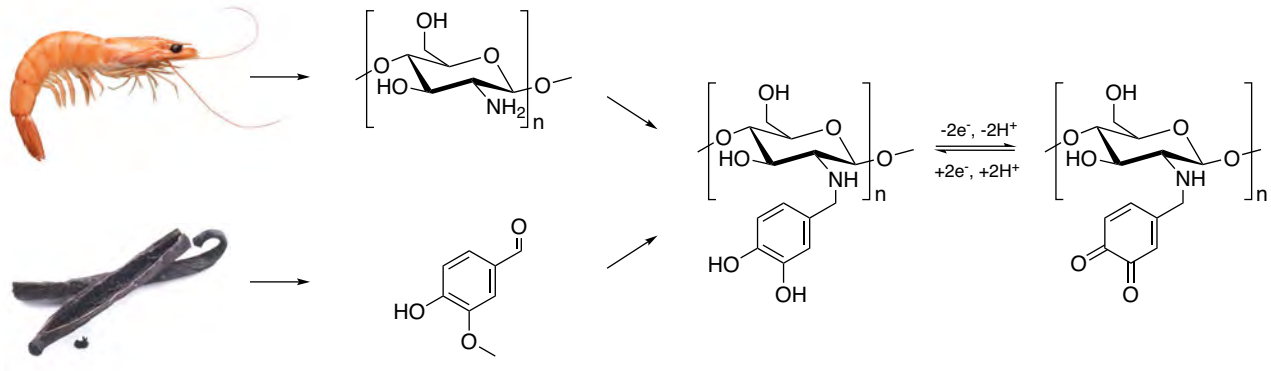
Photo: Bettina Ausserhofer



# The beginnings **of the biobattery**

The energy supply of the future has a storage problem. The ability to store surplus power from wind turbines and solar panels for times when it is in short supply relies on powerful batteries and capacitors, which should be made of materials that are as non-toxic and sustainable as possible. This is the focus of work by **Clemens Liedel** and **Martin Oschatz** at the **Max Planck Institute of Colloids and Interfaces** in Potsdam.

TEXT **KARL HÜBNER**




A recipe for an organic cathode: Max Planck chemists combine chitosan from shrimp shells with vanillin, the aroma of vanilla, which can also be produced from wood. By doing so, they hope to be able to replace substances such as lithium cobalt oxide, which is currently used for the cathodes in lithium batteries and whose use is questionable for political and environmental reasons.

There's a hint of vanilla in the air. It's not necessarily what you expect to encounter in a chemistry lab, let alone in one used for research in the field of battery materials. "That's from the vanillin," smiles Clemens Liedel. But anyone looking forward to some leftover Christmas cookies or freshly baked birthday cake is in for a disappointment. There are no baked goods anywhere to be seen. In Liedel's lab, vanillin is currently being used as a starting material for a potential electrode material of the future.

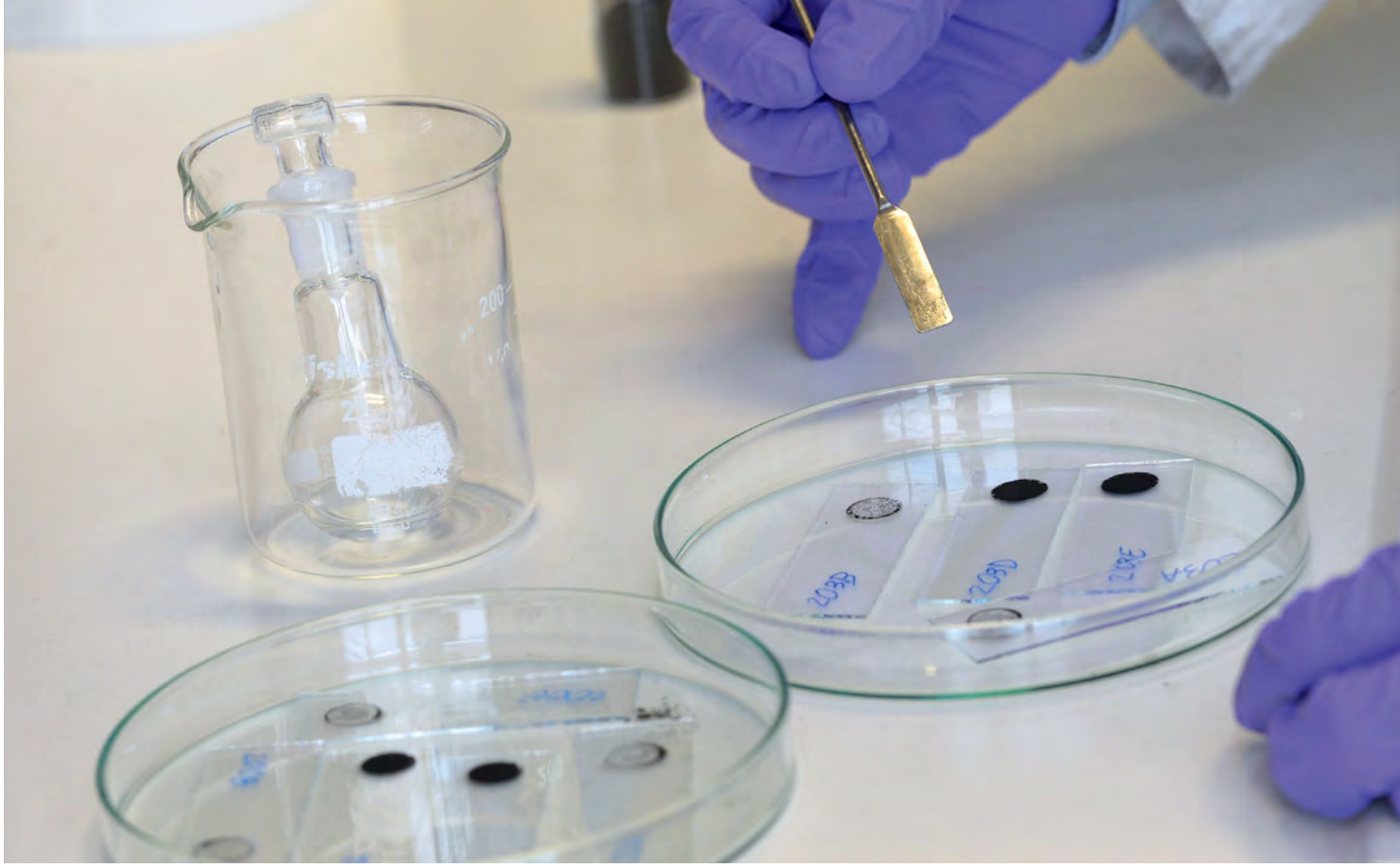
Clemens Liedel is a researcher at the Max Planck Institute of Colloids and Interfaces in Potsdam, where he leads the "Sustainable Energy Storage Materials" working group. The name says it all: ideally, the new battery materials should be made from renewable raw materials and thus ensure almost unlimited availability. That is certainly not the case with today's lithium batteries. Lithium itself is quite a rare metal and is found in only a limited number of deposits around the world. Some two-thirds of lithium batteries also contain cobalt, a metal whose extraction is often accompanied by social and environmental problems in the exporting countries. Other components include electrolytes, which are sometimes toxic or even flammable. Given the rapidly rising demand for storage capacity, these conditions are still anything but ideal.

Clemens Liedel believes that the approach using vanillin could offer a significantly more sustainable alternative, as this substance can be prepared from one of the most common materials of all – from lignin, a principal component of wood. Every year, nature produces many billions of tonnes of lignin.

But how can an organic molecule be used as a material for batteries? After all,

A good mixture: working in glass flasks, the Potsdam-based chemists convert chitosan and vanillin into a sustainable electrode material.

Photos: istockphoto, shutterstock, Bettina Ausserhofer (from top to bottom); graphic: MPI of Colloids and Interfaces



Getting an overview: to investigate the properties of sustainable electrode materials, the researchers apply them to microscope slides with carbon paper.

Photo: Bettina Ausserhofer

when it comes to batteries, we typically think of metals such as lead, cadmium, or indeed lithium. "In very general terms, what you need are substances that can release electrons and then absorb them again," explains Liedel. "These might be metals, which are then converted into metal ions, but they can also be organic substances."

Specifically, the researchers in Potsdam envisage using vanillin for the cathode – that is, for the positive pole of lithium batteries – instead of substances containing heavy metals, such as lithium cobalt oxide. But that's easier said than done – a brittle powder like oxidized vanillin cannot readily be used as an electrode material. "Normally, you mix the substance with a binding agent to create a compact paste and make it conductive by adding carbon," explains Liedel. Although this approach proved successful, it was not sustainable enough for the chemist – he was still concerned about the binder, a fluorinated polymer.

At present, therefore, the researchers in Potsdam chemically bond their vanillin to the biobased polymer chitosan before mixing the combined substance with particles of soot – completely without binders. Chitosan is a sugar-like polymer that can be obtained from the shells of shrimp, for example. Soot is still obtained from petrochemical resources, but could also be produced from biomass. At present, the Potsdam-based researchers are testing a pure vanillin/carbon mixture that works without a binder or chitosan, provided the vanillin first undergoes a chemical modification.

## A MORE SUSTAINABLE SOLUTION FOR ELECTROLYTES

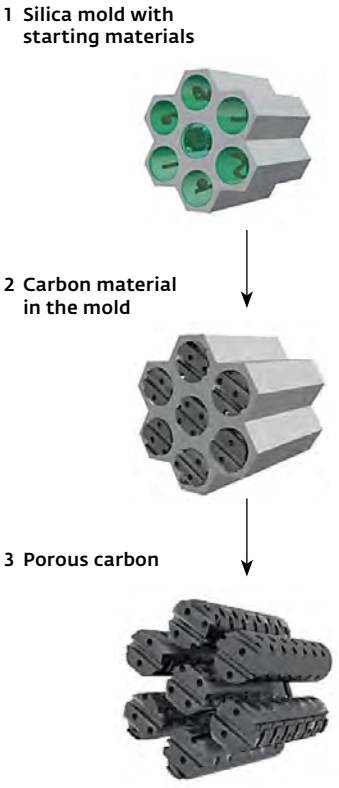
To test the electrode material, a member of the team applies an extremely thin layer of the mixture of substances to a sheet of carbon paper, from which they punch out a small, circular section. This is then inserted into a plastic housing, followed by a separating membrane, an electrolyte, and a counter-electrode – and the battery is complete. It is now possible to measure the battery's voltage between two stainless-steel cylinders protruding from the plastic housing. Today, it is 3.1 volts.

But that's not the only thing the scientists test. "In addition, we always carry out long-term tests involving a series of alternating charging and discharging processes," says Liedel. "In this way, we can see whether our electrode is actually suitable for frequent charging cycles." That, of course, is an essential prerequisite for rechargeable batteries – and the researchers say that the latest vanillin-based approach has already proven successful.

However, Clemens Liedel's group is also putting a great deal of thought into future electrolytes. The electrolyte is the component in a battery that contains the mobile charge carriers (the ions), which are responsible for balancing out the electrical charge between the two poles. Electrolytes usually consist of a conductive salt that is adapted to the electrodes, as well as a solvent. "Currently, these are typically solutions of toxic lithium salts in flammable organic carbonates," explains Liedel. But the chemist has a more sustainable – and safer – solution in mind.

Here, too, the team has enjoyed some initial successes. Clemens Liedel walks into another of his labs, reaches for a round-bottomed flask, and briefly swirls it around in the air. A colorless mixture can be seen sloshing around inside. "That's an ionic liquid," says Liedel. The term is used to describe salts

that are liquid at temperatures below 100 degrees centigrade. Like all salts, the liquid is made up of positively charged cations and negatively charged anions. The researcher explains why this group of substances makes good solvents for electrolytes: "As well as being good conductors of other ions, ionic liquids are barely volatile and therefore offer excellent fire resistance."




Baked storage battery: to create a material for powerful supercapacitors, the Potsdam-based chemists fill a mold made of quartz (silica, 1) with a highly concentrated aqueous solution of the starting materials sugar and salt. Heating this in the absence of air converts the sugar into carbon, which contains pores left behind by the evaporating salt (2). The researchers etch away the silica mold so that only the porous carbon material remains (3).

Moreover, some ionic liquids are also purely organic and, ideally, can therefore be derived from renewable raw materials. For Liedel, they also have another important feature: "It's easy to fine-tune their chemical properties." For example, researchers can readily configure not only the ion conductivity of the molecules, but also the temperature range in which they are liquids. His group has now identified a suitable ionic liquid for which half of the raw materials are already renewable.

## A MARRIAGE BETWEEN BATTERY COMPONENTS

In commercial batteries, the two poles are usually very close together and separated by a fine-pored membrane to avoid an electrical short-circuit. This separator is typically made of an oil-based plastic and is permeable to the ions of the electrolyte in order to allow charge balancing, which is necessary when electrons migrate from the negative to the positive pole through an electrical load or while the battery is being charged. Here too, Liedel's group can already offer an alternative – one which they stumbled across entirely by accident during their work involving chitosan. The researchers simply linked up the chitosan chains by adding additional substances to create a network of macromolecules with small pores. Experiments with this material have reportedly been successful. "The anions in particular migrate readily through the pores," says Liedel.

After extensive basic research into individual battery components, the group is now looking to the next big step. "We now want to experiment with bringing all of these approaches together," says Liedel – in other words, combining the organic cathode material with the ionic liquid, the chitosan membrane, and a sodium- or magnesium-based anode. "But we still have a few details to clear up." One such question is how chemically compatible the ionic liquid is with a biobased electrode material, such as oxidized vanillin.

The fact that polymer-based battery materials are currently seen as a promising and sustainable alternative is also demonstrated by the launch of a Priority Program by the German Research Foundation (DFG) in April 2019. Over a six-year period, the DFG will provide a total of EUR 12 million for a corresponding research network that also includes Clemens Liedel's group.

So far, the only battery component for which Liedel doesn't do his own materials research is the negative pole. At present, this anode usually comprises a combination of lithium and graphite. Although other metals such as sodium or magnesium are already being discussed and would offer significantly better availability, as well as being more sustainable, a number of technical questions must still be resolved before they can be put to practical use.

Another of the researchers working on this is Martin Oschatz, a colleague of Liedel's at the Institute. Oschatz has his laboratories just a few steps away from those of Liedel's team. He leads the working group on "Energy and Environmental Utilization of Carbon Nanomaterials," which studies applications including the use of such materials in storage batteries. Oschatz experiments with carbon materials featuring pores of a precisely defined size. In principle, the aim is to provide the largest possible surface area with the maximum number of binding sites for metal atoms. This would also be instrumental in improving the specific energy of anodes.

While a battery is discharging, it is the anode that supplies the electrons. These are typically released by a metal,

Graphic: MPI of Colloids and Interfaces

which then becomes a positively charged ion – that is, a cation. The simplest thing would therefore be to make the electrodes from that metal, but that is hard to do with certain metals. Lithium is therefore usually combined with graphite, intercalating the lithium atoms between the graphene layers.

## POROUS CARBON FOR SUPERCAPACITORS

Martin Oschatz is working on a similar solution for sodium. "The method involving intercalation in graphite doesn't work with sodium," he says. But the carbon chemist has already found another solution in the form of a carbon-based polymer with two important special features: the flat macromolecule forms sieve-like pores of its own accord, and the chemists have carefully selected the parent compounds in order to incorporate nitrogen atoms at the edge of the pores. "These ensure the stable storage of metal atoms," Oschatz explains.

However, the researchers first had another obstacle to overcome. Although the high nitrogen content increases the binding strength for sodium, it also reduces the conductivity for the electrons released by the sodium during the discharging process. Echoing Liedel's approach with his organic cathode materials, Oschatz therefore had to combine his polymer with soot in order to obtain a suitable electrode material. Specifically, the researchers in Potsdam do this by coating extremely thin carbon threads with their carbon/nitrogen polymer. Following initial testing, Oschatz says that the storage capacity of their material is already relatively good for sodium.

Unlike Liedel, however, Oschatz doesn't just have batteries in his sights. The porous, nitrogen-rich carbon polymer has apparently also proven to be an effective catalyst material for the energy-efficient synthesis of ammonia. With regard to other environmental applications, Oschatz says that, because the pores are good at capturing carbon dioxide molecules in particular, the material also makes an effective $CO_2$ filter for processes such as flue gas scrubbing.

Even in terms of electricity storage, biobatteries are not the only application that the chemist envisages. Oschatz also wants to use highly porous carbon as an electrode material in supercapacitors, which provide very fast access to

***Top*** No superficial matter: Milena Perovic and Martin Oschatz prepare for a measuring procedure that allows them to determine the surface area of carbon materials. The device determines how much gas can be absorbed by four samples held in cooling vessels.

***Above*** A tidy job: before the surface area is measured, the samples are heated in a vacuum to remove volatile substances that would distort the analysis results.

Photos: Bettina Ausserhofer (2)

Food for thought: Clemens Liedel and Martin Oschatz discuss new ideas with a view to developing more sustainable materials for energy storage devices.

the energy they store. In addition, capacitors generally have a much longer service life than batteries, although the amount of energy they can store was also much smaller until now. Supercapacitors are already found in applications where large quantities of electricity are required at short notice – for example, when starting up a streetcar. Some automobiles also use supercapacitors for energy recovery during braking.

The capacitors that Martin Oschatz deals with store electrical energy in the form of an electric field – that is, by loading up two electrodes with opposite charges. To balance out the charge, oppositely charged ions from an electrolyte accumulate at the respective electrodes. How much charge a capacitor stores, and how quickly it charges or discharges, depends on how many ions the electrodes adsorb and release and how quickly they can do so.

The activated carbon typically used in many current supercapacitors already has plenty of contact with the outside world, providing a specific surface area of around 1,500 square meters per gram. But Oschatz wasn't going to settle for that. "Because of the manufacturing process, the porosity of activated carbon is quite random and completely disordered," says the chemist. He wants a material whose surface structure is clearly defined down to the nanometer level – that is, to within a few millionths of a millimeter. Moreover, this structure should ensure that, when a voltage is applied, the material can adsorb and release as many ions as possible, as quickly as possible.

## A PARKING GARAGE FOR IONS

Martin Oschatz therefore uses an almost pure carbon material with a large surface area and an ingenious pore structure. This proves to be a particularly effective electrode material for energy storage devices. The material can bind to many more ions – and release them again – faster than the nitrogen-containing carbon that Oschatz's group developed for sodium batteries.

The reason why the electrode material is so effective is that it has enough pores along its contact surfaces with the electrolyte to adsorb ions without subsequently blocking others. Oschatz likes to think of it as a sort of parking garage: "We need lots of streets that serve as access roads, which need to be lined with a sufficient number of parking bays."

To build these nanoscale parking garages, Martin Oschatz's team first uses a special silicate material to create a sort of tiny baking tin with cavities precisely matching the desired structure of the parking garage. The model essentially consists of countless parallel tubes separated from one another by a gap of a few nanometers. The researchers fill the baking tins with a mixture of sugar and salt and then put the whole thing in the oven at about 800 degrees centigrade.

In the absence of air, the sugar is pyrolyzed to leave behind a carbon material, whereas the salt evaporates in the oven to leave behind cavities – that is, the parking bays for the ions. By varying the quantity of salt, the chemists can control the pore size and create parking spaces with dimensions in the order of one nanometer or less. The researchers then chemically dissolve the baking tin, leaving behind a vast number of carbon rods connected to one another by small bridges. "The empty

Photo: Bettina Ausserhofer

spaces between the rods are then our streets," says Oschatz. It is through these streets that the ions reach their parking spaces.

## LOWER COSTS PER STORED KILOWATT HOUR

With this specially designed porous structure, the researchers can now achieve specific surface areas of up to 3,000 square meters per gram – the equivalent of half a football field in a few granules of carbon. To determine the surface area, they use an instrument that measures how many particles of a gas bind to a specific quantity of their materials. From this, they can derive the specific surface area of their substances.

Of course, they have already taken measurements to determine how quickly their material charges and discharges again. "We've had some samples that we could charge and discharge ten times faster than activated carbon," says Oschatz, adding that the storage capacity also exceeded that of previous electrode materials.

Sebastian Pohlmann is also observing these attempts with interest. Pohlmann is in charge of material and cell development at Skeleton Technologies, the only manufacturer of supercapacitors in Europe, and is working on electrodes with improved properties at the company's Grossroehrsdorf location. "In this context, it's very important to bring greater order to the structure of the porosity," he says.

And what about sustainability? On first inspection, sucrose – one of the essential starting materials – appears to offer a similar degree of renewability to the lignin that Clemens Liedel used to prepare vanillin. "Of course, sucrose is a foodstuff first and foremost," Oschatz admits, but he is keen to emphasize that, "as a raw material for electrodes, the substance is still much more sustainable than, say, lithium or cobalt." He believes that the environment also stands to benefit from the development of materials with especially high specific energy and long service lives.

Markus Antonietti is also enthusiastic about the results obtained so far. He leads the Department of Colloid Chemistry – where Clemens Liedel and Martin Oschatz are also researchers – at the Max Planck Institute of Colloids and Interfaces in Potsdam. Antonietti believes that the new materials for supercapacitors will one day pave the way for a significant reduction in the cost per stored kilowatt hour of electricity. In his view, the objective must now be to boost the storage capacity to the extent that these energy storage devices might one day take on the role of existing batteries.

Antonietti also has another vision: "At some point, every household will need a storage battery of its own, and each summer they'll charge it up with the energy they need for the next winter." This would involve quantities of energy that simply couldn't be stored sustainably with today's batteries. "We therefore need materials that are free of metals – and ideally renewable," says Antonietti. He's therefore also pleased to detect a hint of vanilla drifting over from Liedel's labs from time to time. Of course, future users of these storage batteries wouldn't get the chance to enjoy this aroma. Once incorporated into a battery, the vanillin would be chemically bound – and therefore odorless. ◀

www.mpg.de/podcasts/energie (in German)


## SUMMARY

- **Current battery systems are based on raw materials that are incompatible with the sustainable expansion of storage capacities.**
- **Max Planck researchers are therefore investigating battery components – such as electrodes, electrolytes, or separators – made from renewable raw materials like vanillin, chitosan, and appropriate ionic liquids.**
- **They are also attempting to increase the specific energy and charging and discharging speed of supercapacitors by developing corresponding electrode materials with a larger surface area and a structure that is as precisely defined as possible.**


## GLOSSARY

**Anode:** Together with the cathode, this is one of the electrodes at which electrical energy is stored as chemical energy and converted back into electrical energy within a battery or an electrolytic or fuel cell. When a battery is discharged, anions – that is, negatively charged particles from the electrolytes – or neutral metal atoms of the electrode material release electrons, which flow to the cathode via an external circuit.

**Electrolyte:** The conductive medium between two electrodes. It contains ions that ensure the flow of current between the electrodes and that are also involved in the electrochemical processes taking place at the electrodes, such as in batteries.

**Cathode:** This takes up electrons from the external circuit and transfers them to the electrolyte. It is where metal cations, for example, are converted into uncharged metal atoms.

**Separator:** A membrane, usually made of a porous plastic, that separates the anode and cathode compartments. It prevents short-circuiting between the two electrodes but is permeable to ions so that a current can flow through the electrolyte.


A labyrinth of technology: the plasma chamber of Wendelstein 7-X sits deep within a maze of pipework, nozzles, and gangways.

Photo: Jan Michael Hosan/IPP

# Solar fire in the **stellarator**

Nuclear fusion aims to recreate the sun's power on Earth and would represent a completely new source of energy. At the Wendelstein 7-X facility, researchers led by **Thomas Klinger**, Director at the **Max Planck Institute for Plasma Physics** in Greifswald, are exploring one approach to this form of energy generation.

TEXT **ROLAND WENGENMAYR**

"You can barely make out the torus itself," says Matthias Hirsch as he surveys Wendelstein 7-X. The "torus" that the plasma physicist is referring to is the ring-shaped centerpiece of the gigantic 725-tonne metal object filling the several-story shed in front of us. The ring is hidden within a multitude of over 250 pipe connections and nozzles – a truly bewildering sight for the lay person. In turn, all of this is surrounded by scaffolding made up of staircases, balconies, and access bridges interspersed with pipelines, cable strands, and equipment cupboards.

We're at the Max Planck Institute for Plasma Physics (IPP) in Greifswald, and Hirsch is expertly guiding us through this labyrinth – although there's one

piece of equipment whose purpose even he can't fathom. You can't blame him. After all, we're climbing through the external scaffolding of an enormously complex machine that is now used for research by over 200 scientists from across Europe, Australia, Japan, and the U.S. Even for an expert like Hirsch, it's impossible to get to grips with every last detail.

Researchers from Germany – and above all from the Max Planck Society – have taken a leading role in the construction of Wendelstein 7-X. The project aims to support an important scientific objective: harnessing the solar fire as an almost inexhaustible source of energy for applications such as power generation. Deep within the sun, temperatures of 15 million degrees cause hydrogen nuclei – protons – to fuse, forming nuclei of the element helium and releasing vast quantities of energy in the process. Without this furnace running on solar fusion, Earth would be a cold, dead planet.

However, the light hydrogen atoms only fuse when exposed to the crushing gravitational force of the sun. There, they experience unimaginable pressures of some 200 billion atmospheres, which no solid material could even come close to withstanding here on Earth. Exploiting solar energy in this way therefore seemed like an unattainable dream – until ingenious physicists came up with an alternative. In the mid-20th century, they discovered that nuclei of the heavy hydrogen isotope deuterium, which contains a neutron in addition to its proton, and tritium, a superheavy hydrogen isotope with two neutrons, can also fuse to form helium.

## NUCLEAR FUSION – A NEW FORM OF ENERGY GENERATION

This fusion reaction takes place in an extremely thin, hot gas, and is easier to implement from a technical perspective due to the low pressures involved. That being said, it also requires temperatures even higher than those present in the sun – well in excess of 100 million degrees. In a high-temperature plasma of this kind, electrons and atomic nuclei are completely separated from one another. As both of them are electrically charged, they can be confined by a strong magnetic field. This acts like a virtual thermos flask and is the trick on which fusion research relies.

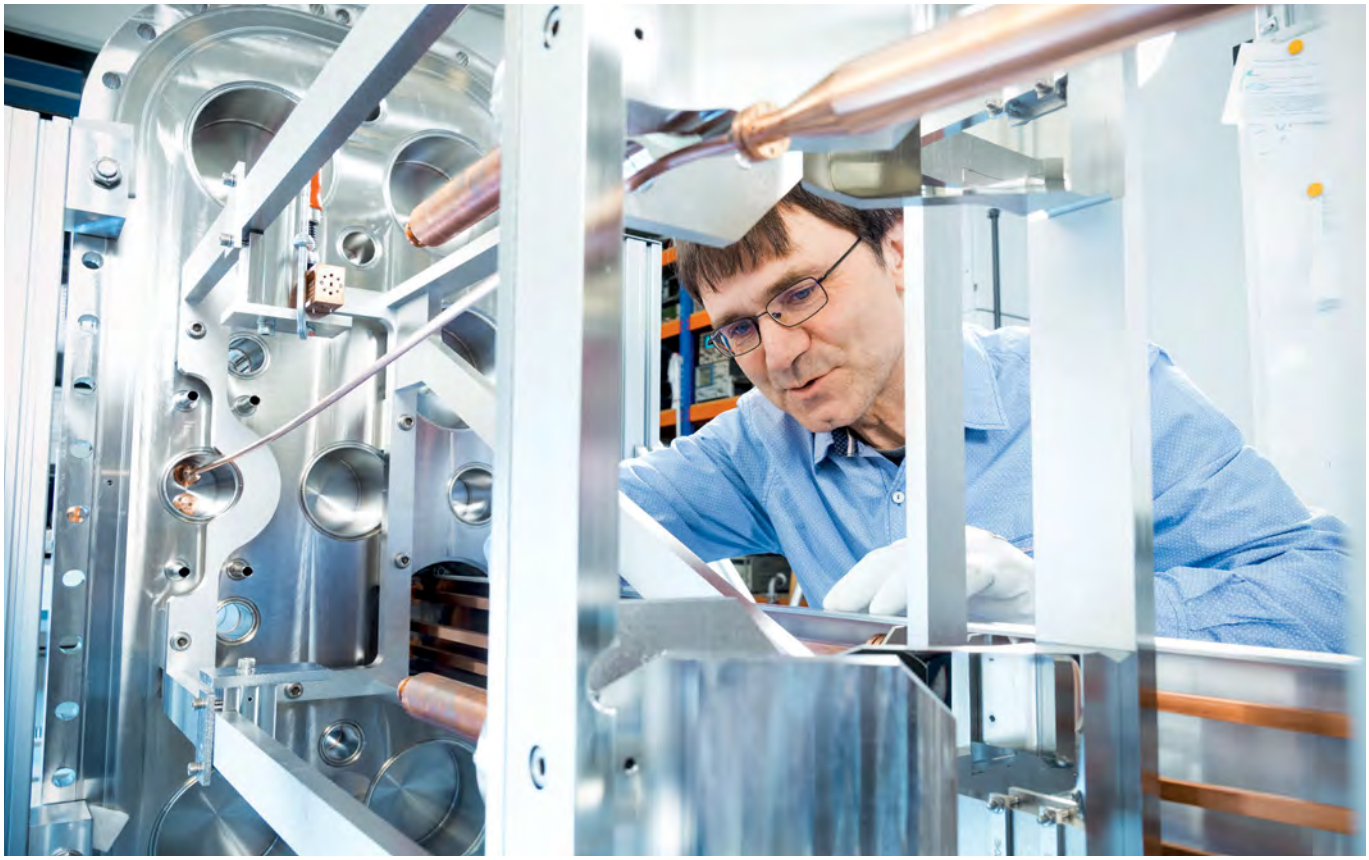
In a future fusion power plant, the plasma vessel would only contain about one gram of the helium/tritium mixture. This almost non-existent quantity of fuel could produce 90,000 kilowatt hours of thermal energy – equivalent to the heat of combustion of 11 tonnes of coal. However, burning that amount of coal would release over 30 tonnes of carbon dioxide into the atmosphere. By contrast, fusion power plants would operate on a carbon-neutral basis. This, together with their extremely low fuel consumption, is what makes them such a promising idea in a century in which our lives will increasingly be shaped by climate change.

The prospect of developing a climate-friendly source of energy may well be the reason why Robert Habeck, co-leader of Alliance 90/The Greens, expressed his positive attitude to the research during a recent visit to Wendelstein 7-X. When the foundation stone for the facility was laid in 1997, his party's supporters protested against it. "Today, we take a less ideological line on nuclear fusion," Habeck explained. In his view, the basic research is fascinating and should be promoted. "Exploring alternative energy supplies is fundamentally the right thing to do."

Thomas Klinger points out that fusion energy is the only new form of primary power generation that humanity is currently researching: "It's the last unopened barrel of energy, so to speak." As if to highlight this statement, a burst of warming sunlight illuminates the office of the Max Plank Director, who leads the Greifswald location of the Max Planck Institute for Plasma Physics. With his wiry build, the physics professor looks as if he might jump up and reach for a wrench at any moment.

### THE ROAD TO NUCLEAR FUSION

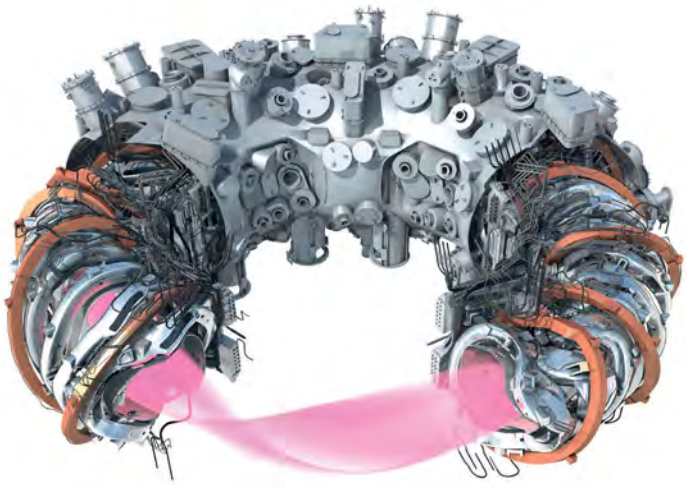
The fusion of deuterium and tritium to form helium ought to be performed in a very thin, hot plasma. Even with a relatively small number of collisions, the heavy hydrogen nuclei release sufficient energy to maintain the fusion reaction. Although any fusion plant of the future will therefore constitute a nuclear facility, it also offers some key advantages over today's nuclear power stations. In the event of an accident, there is no risk of a core meltdown, as the sensitive plasma simply goes out. The radioactive tritium is also bred and consumed directly within the self-contained fusion power plant. Moreover, as only a few grams of fuel are needed, there are none of the disposal problems associated with nuclear power plants. Likewise, fusion doesn't produce tonnes of radioactive waste that then need to be stored for many thousands of years. When a plasma vessel is dismantled at the end of a fusion plant's useful life, only internal components are radioactive. These must then be stored securely for a few decades – a manageable period of time for human civilizations.



Access for researchers: Matthias Hirsch prepares a nozzle through which the sensors of various analytical devices transmit data about the properties of the plasma.

Indeed, the researcher has temporarily found himself in the role of site supervisor – and on a very complex construction site. Little by little, the Greifswald researchers need to forge their way into uncharted technical territory.

But Wendelstein 7-X itself is not a nuclear facility and is not designed for nuclear fusion. Rather, the experiment is an opportunity for physicists to study the behavior of a hot plasma in a stellarator using light hydrogen. A stellarator is one of two types of fusion devices that are currently being researched. As the biggest stellarator experiment to date, the machine in Greifswald is intended to demonstrate that facilities of this kind are fundamentally capable of confining a hot plasma for long enough and with the requisite efficiency. That, in turn, would pave the way for a fusion power plant based on this technical principle.

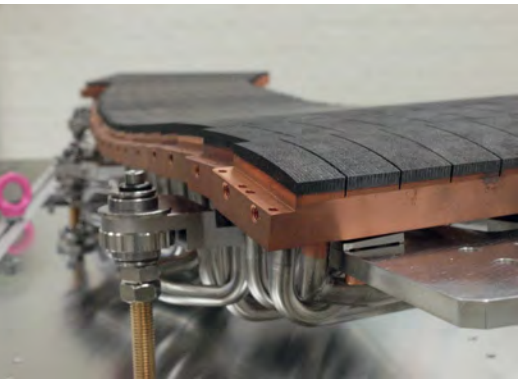


Construction diagram for a magnetic cage: the plasma (pink) is forced to adopt a convoluted path by 70 magnetic coils threaded together around the chamber. Countless openings in the system's casing provide access to the interior.

Wendelstein 7-X is currently being adapted for the next series of measurements after completing three previous series, each of which ran for 15 weeks. On 10 December 2015, the first plasma was fired up to a temperature of one million degrees. It consisted of a thousandth of a gram of helium, which was intended to act as a cleaning agent in order to remove contamination from the plasma vessel. This is an important step because hydrogen plasmas are highly sensitive. On 3 February 2016, the researchers in Greifswald then generated a hydrogen plasma for the first time – in the presence of German Chancellor Angela Merkel.

The plasma can be heated using various techniques. The electrons can be set in motion using a beam of microwave radiation – a high temperature simply means that particles are moving

Photo: Jan Michael Hosan/IPP (top), graphic: IPP (bottom)



Cooling system and filter: the entire plasma chamber is clad in more or less square-shaped graphite tiles. Much smaller, rectangular graphite plates cover the divertor, which runs through the chamber like a ribbon (large image). Passing through its baffle plates are water pipes (small image) that are intended to carry heat from the plasma to the generators in a fusion power plant. However, the divertor not only cools the plasma but also contains cooling coils in its wall in order to freeze out impurities.

around quickly. As the electron soup in the plasma mixes with the hydrogen nuclei, it also warms them up. In addition, the scientists in Greifswald are testing a second heating method that involves firing fast-moving hydrogen atoms into the plasma. In the future, there are also plans to heat the protons directly using powerful radio waves.

Wendelstein 7-X has already broken a number of records set by other stellarator-type plasma experiments. These include discharges lasting for almost half a minute with a plasma temperature of well over 40 million degrees centigrade. In other low-density discharges, the electrons have reached temperatures of as much as 100 million degrees. This also represented the technical maximum at the current stage of completion, for the walls of the plasma experiment were not yet actively cooled. As a result, the interior of Wendelstein 7-X heated up not only due to radiant heat from the plasma but also due to hot particles escaping from the magnetic cage and colliding with the vessel wall. After longer discharges, the plasma vessel therefore had to cool down for about a quarter of an hour before the next shot.

The system is currently out of action for about two years while the team in Greifswald installs an active water-cooling system. This should allow Wendelstein 7-X to cope with plasma discharges lasting for half an hour at very high temperatures. "A water-cooling system may sound trivial," says Klinger, "but for us it means performing plumbing work to an extremely high standard." Every part of the plasma vessel that is exposed to heat must be connected to the cooling system, and this work will therefore involve a total of four kilometers of water pipes. "It's a huge branched-water system," says Klinger.

## THE DIVERTOR DRAWS FUSION HEAT OUT OF THE PLASMA

In this regard, one particular challenge is that a high vacuum must be present in the plasma chamber during operation. What the researchers fear most are tiny leaks in the water pipes, as these are very difficult to detect. A "dripping nose", as Klinger puts it, could be enough to destroy the vacuum by allowing water to evaporate.

Photos: Bernhard Ludewig/IPP (top), IPP (bottom)

Strict standards therefore apply during the modification work.

However, the greatest technical demands must be met by the divertor. This sits on the inner wall of the ring and consists of a series of consecutive high-tech plates that protrude into the edge of the hot plasma during operation. Accordingly, the plates must be able to withstand extremely high temperatures. In a future power plant, the plan is for similar plates to extract a proportion of the fusion heat from the plasma. This will then drive steam turbines by heating water in a circuit leading out of the vessel.

During operation, the baffle plates of the divertor are exposed to a powerful heat flux of around 10 megawatts per square meter – approximately equivalent to the heat output of 4,000 typical microwave kitchen appliances. "That's about the most that known materials can withstand," explains Klinger. It resembles the conditions experienced by a spacecraft during re-entry into the Earth's atmosphere, which also creates a hot, glowing plasma. The baffle plates of the divertor are therefore made of the same material as the heat shield tiles on the bottom of earlier American space shuttles: a carbon composite material reinforced with carbon fibers.

The carbon fibers not only provide the composite material with mechanical stability but also transport heat toward the vessel wall. Unlike the space shuttle during re-entry, however, these plates need to hold out not just for a few minutes but for almost half an hour. The new divertor – which is currently being installed – must therefore be extremely good at conducting heat between the baffle plates and the water-cooled wall. With this in mind, the Greifswald-based researchers have worked with industry partners to develop a completely new bonding technique.

However, heat dissipation is just one of the divertor's several functions. It is also intended to keep the plasma clean, acting as a vacuum cleaner for impurities arising from unavoidable contact between the plasma's thin outer region and the wall. Charged impurities force plasma electrons to change their trajectories, leading to the emission of X-rays. Moreover, the impurities themselves are excited by the collisions with plasma particles, resulting in greater radiative energy losses from thin plasma, which experiences significant cooling due to these two effects.

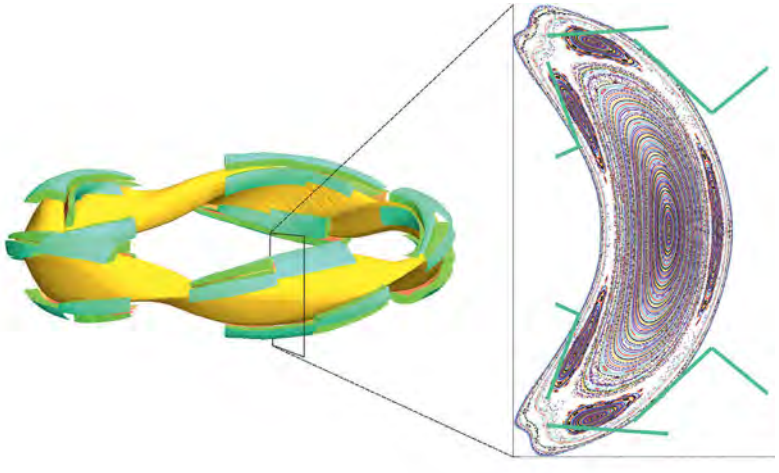
## THE CONSTRUCTION PROCESS – A GIGANTIC 3D PUZZLE

Moreover, the divertor helps to keep the number of hydrogen particles under control. For this reason, a cryogenic pump is incorporated into the wall beneath the baffle plates of the divertor. In principle, these "cryopumps" work like a cold beverage can that mists up with condensation when you take it out of the refrigerator in summer – except that the pump in Greifswald is cooled using liquid helium at a temperature of -269 degrees centigrade. "As a result, all of the small particles get stuck there," says Klinger. However, the cryopump requires the team in Greifswald to accommodate additional pipes for liquid helium between the water pipes.

Liquid helium is also used to cool the large superconducting coils, which generate the powerful magnetic field for plasma confinement. In total, 70 of these coils are strung together around the plasma chamber like bracelets on a wrist. Most of the coils have a convoluted geometry and therefore generate a magnetic field with multiple twists and turns. This field acts on the hydrogen nuclei and electrons as they speed past, forcing as many as possible onto magnetic roller coasters that repeatedly hurl them back into the hot plasma. After all, the aim is to minimize the number of hot particles that escape.

The individually shaped coils were just one reason why the construction of Wendelstein 7-X resembled a gigantic three-dimensional puzzle, in which components weighing several tonnes had to be joined together with the utmost precision. First, the team in Greifswald worked with partners to build five 120-tonne modules. Then, the fitters used the shed's overhead cranes to piece these together to form the torus of the plasma vessel. The number of modules depends on the shape of the plasma. "If we could look down from above, we would see a pentagon with rounded corners," Matthias Hirsch explains during his tour.

It is the complex magnetic field that makes the stellarator concept more complicated than the competing tokamak



Anatomy of a plasma: the divertor plates (green) protrude into the convoluted path of the ribbon (yellow). A cross section (right) shows the inner structure of the hot, electrically charged gas.

Graphic: IPP

principle, which is being used to build the large ITER system in Cadarache, France. With their significantly simpler design, tokamaks have already reached a more advanced stage of development. In 1991, the Joint European Torus (Jet) research reactor in the British village of Culham successfully ran the first short, controlled nuclear fusion experiment in a plasma made of deuterium and tritium. For the first time, the fusion experiment at ITER is expected to deliver more power than is needed to heat the plasma. This net gain in energy would represent a preliminary stage in the development of the first demonstration power plant.

## THE TWO CONCEPTS OF NUCLEAR FUSION COMPARED

Compared to stellarators, tokamaks have a much more symmetrical, ring-like plasma shape that – besides its technical simplicity – helps to reduce the impact of potential energy-loss mechanisms. However, this must also carry a powerful toroidal current that holds the plasma together within its tubular magnetic field. This toroidal current leads to additional plasma turbulence, which must be kept under control. In addition, a tokamak works like a large transformer, with the plasma representing one of the coils. As the plasma current only arises in response to changes in the coil's current, a voltage is applied to the coil in pulses. Accordingly, a tokamak can only produce pulsed plasma discharges, and so the system is exposed to constantly changing loads.

"We want to avoid the constant cyclical loads on the material and the cyclical forces during startup and shutdown," explains Sibylle Günter, Director at the Max Planck Institute for Plasma Physics. For this reason, international research is underway into con-

Physicists are sometimes also site supervisors: Thomas Klinger is responsible for plasma research in Greifswald and supervised the construction of Wendelstein 7-X.

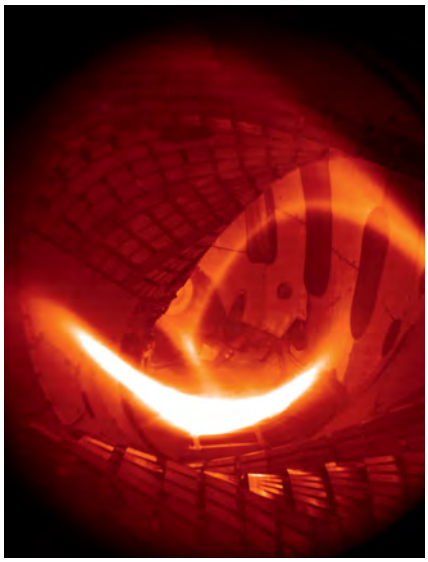
cepts that can extend these pulses to several hours or even bring about constant – that is, steady-state – operation. In 2016, for example, a team from the IPP in Garching used the site's Asdex Upgrade tokamak to demonstrate that it is possible to do this by driving the plasma flow from the outside. "In the second operating period, ITER is intended to test scenarios such as this with a view to achieving steady-state tokamak operation," says Günter.

A stellarator, on the other hand, operates as a purely magnetic cage without the ring current, and is suitable for continuous operation from the outset. That's what makes stellarators such an interesting idea. However, in the first few decades of research into these devices, the complex shape of their magnetic field represented an insurmountable obstacle: for a long time, the systems simply couldn't confine enough hot plasma particles. That changed in the 1980s, when theoretical scientists from the Max Planck Institute for Plasma Physics in Garching developed the concept of the advanced stellarator, whose modular coils featured complex shapes. Advanced stellarators can now reach the temperatures needed to initiate a nuclear fusion reaction. Part of the reason for this breakthrough was that increased computing power made it possible to calculate the complicated magnetic field geometry accurately for the first time.

Wendelstein 7-X has already produced so much new data in the initial runs that the physicists have plenty of analysis to be getting on with during the modification work. If the experiment with the new water-cooling system succeeds in achieving half-hour plasma discharges, that raises the question of when we might see the first fusion power plant based on the stellarator principle. "Give Wendelstein until the mid-twenties," says Klinger. "Subsequent development will also depend on the results delivered by ITER."

One of the main objectives of ITER is to achieve a net energy gain from fusion, says Sibylle Günter. However, she also raises another key question that ITER is meant to resolve: how will the plasma be affected by the resulting fusion product – that is, by extremely fast-moving helium nuclei? "For example, these fast helium nuclei could also trigger instability in the plasma," she says. "It's a completely new area of physics to explore, and I personally find that very exciting." At any rate, researchers and engineers still have a lot of work to do before fusion energy can be exploited commercially. It remains to be seen whether the stellarator or the tokamak will emerge victorious from this marathon effort, but – even at this early stage – the scientists in Greifswald have made considerable progress with the stellarator concept. ◀

www.mpg.de/podcasts/energie (in German)



The first hydrogen plasma: ignited by German Chancellor Angela Merkel on 3 February 2016, it burned for a quarter of a second and reached a temperature of 80 million degrees.


## SUMMARY

- **Nuclear fusion could offer a completely new way of generating energy in the form of heat or electricity. Researchers at the Max Planck Institute for Plasma Physics are attempting to recreate the intense heat of the sun on Earth using the Wendelstein 7-X stellarator.**
- **Inside the stellarator, hot plasma at a temperature of over 100 million degrees must be permanently confined in a magnetic field cage – the experiment is aiming for half an hour. At the current stage of completion, Wendelstein 7-X has succeeded in generating hot plasmas at temperatures of over 40 million degrees for half a minute at a time.**
- **Unlike the competing tokamak principle, which is easier to implement and has already reached a more advanced stage of development, the stellarator allows continuous operation right from the outset. Its technical exploitation would therefore be more straightforward.**

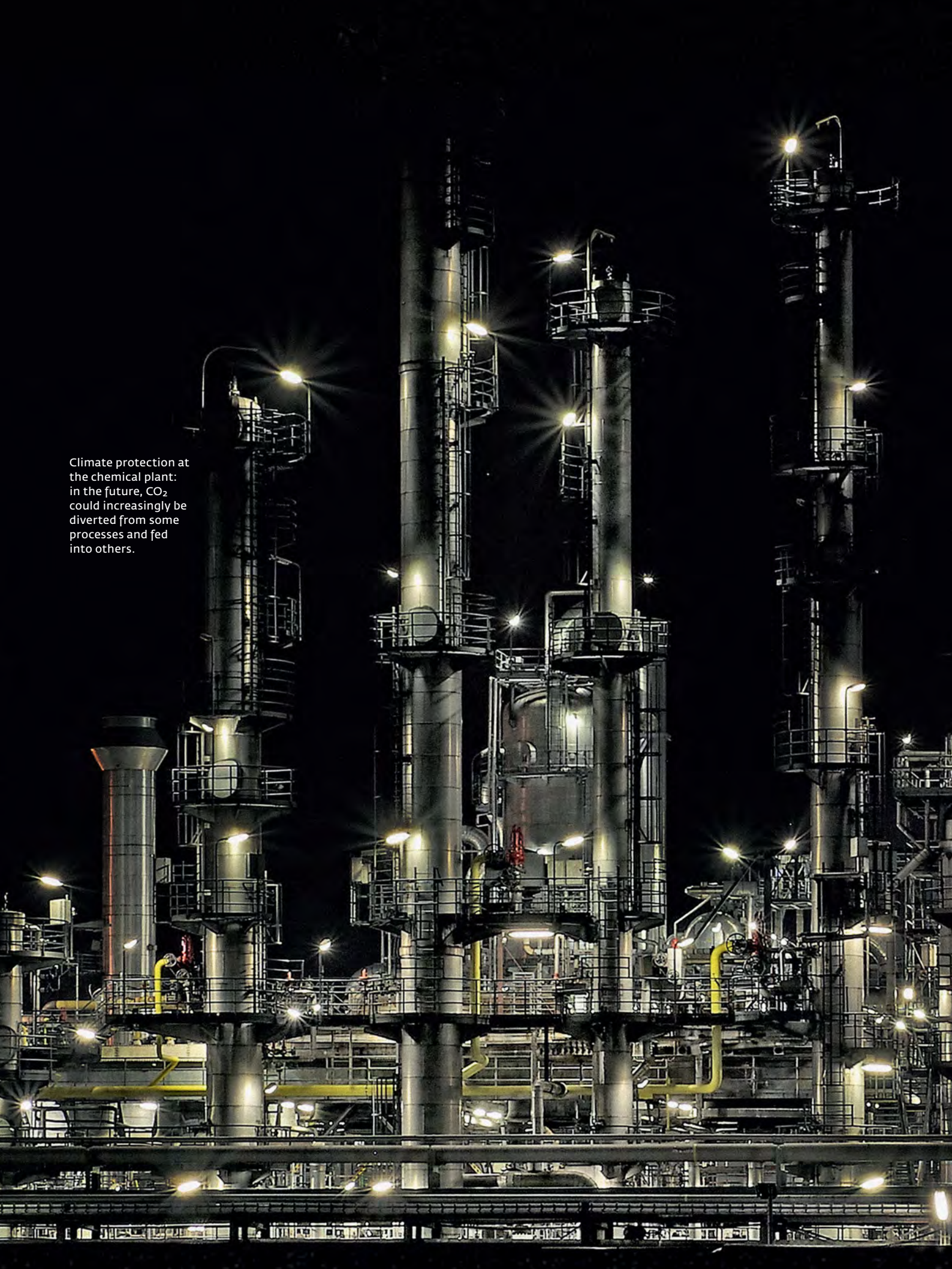

## GLOSSARY

**Plasma:** A gas whose atoms or molecules are wholly or partially ionized – in other words, they have had some or all of their electrons removed. A plasma is formed at very high temperatures.

**Stellarator:** In a nuclear fusion facility of this type, a twisted plasma would be confined solely by an external magnetic field with a complex shape. Constructing the coils to generate this field is therefore an extremely challenging task.

**Tokamak:** In this type of facility, the plasma forms a perfect ring confined by a magnetic field, which is in turn partly generated by a ring current in the plasma itself. Without additional technical measures, which are yet to be fully developed, a tokamak can only be operated on a pulsed basis.

Photos: Matthias Otte/IPP; Achim Multhaupt (left)



Climate protection at the chemical plant: in the future, $CO_2$ could increasingly be diverted from some processes and fed into others.

# A greenhouse gas to fuel the chemical industry

Carbon dioxide, of all substances, could help the chemical industry reduce its climate footprint. Using energy from renewable sources, it could be incorporated into the building blocks of plastics and other products – if suitable catalysts and production processes can be found. That is the task of researchers led by **Walter Leitner** at the **Max Planck Institute for Chemical Energy Conversion** in Muelheim an der Ruhr.

TEXT **PETER HERGERSBERG**

A conversation with Walter Leitner can change the way you see the world. Afterwards, when you look around, you may well see one thing in particular: carbon. That's hardly surprising – as an element of life, carbon forms the chemical backbone of every living organism and is an integral component of organic matter that nature provides, including wood, starch, and cotton.

But carbon is also omnipresent in plastics, in the dyes for our clothes, in medications, and in fuels. Even if we consider these products to be artificial, they wouldn't exist without nature's input. "Through photosynthesis, plants that were alive millions of years ago absorbed the carbon we use today in the form of coal, oil, and natural gas – both as an energy vector and as a raw material for chemical production," says Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion in Muelheim an der Ruhr and Professor of Technical Chemistry at RWTH Aachen University.

However, if we humans want to preserve the Earth in its current form, we can no longer rely on this fossil-based form of economic activity. Sooner or later, all carbon-containing raw materials end up as $CO_2$, most of which is released into the atmosphere, where it causes an imbalance in the natural carbon cycle. Many national economies are taking action with the goal to reduce their carbon footprint. In Germany and around the world, an increasing proportion of our electricity is now derived from renewable sources – especially wind and solar power. In this way, we could gradually eliminate our energy supply's reliance on fossil resources – and, indeed, on carbon itself.

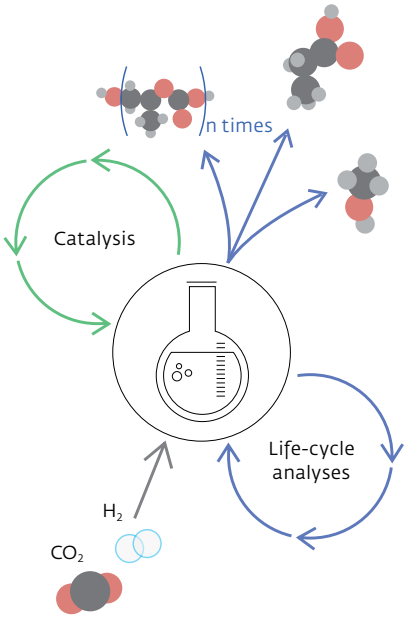
"But we will always need carbon in the chemical value chain," says the chemist. If nothing else, therefore, he wants to contribute to ending the reliance on fossil sources of carbon in chemical production and has set his sights on $CO_2$ of all substances – the waste product that does the greatest harm to the reputation of fossil raw materials. Above all, Walter Leitner and his team want to use $CO_2$ to replace oil where appropriate and thereby pave the way for the adoption of a circular carbon economy.

## REDUCING THE CHEMICAL INDUSTRY'S CARBON FOOTPRINT

"In principle, we could even recover $CO_2$ from the atmosphere. But even in a non-fossil energy system, large quantities of $CO_2$ are available from numerous industrial processes. If we could tap into these sources to exploit them as raw materials, we could significantly reduce the carbon footprint of the chemical industry," says the Max Planck researcher.

Turning the greenhouse gas $CO_2$ into a raw material sounds like an elegant way to make the chemical industry less dependent on fossil feedstocks, but it's tricky to implement. That's because $CO_2$ is chemically very lazy – if not to say completely apathetic. In technical terms, the carbon is extremely reluctant to give up the oxygen. Indeed, it's for good reason that fire ex-

Photo: C. Dietl




***Above*** Greenhouse gas as a raw material: $CO_2$ can react with hydrogen ($H_2$) and other substances to form a variety of products. Catalysis steers these reactions toward the desired substance, and life-cycle analyses ensure that the entire process is more sustainable than a method based on fossil raw materials.

***Below*** $CO_2$ extraction: in principle, it's possible to filter the gas from ambient air and put it to practical use, as Climeworks has shown with this demonstration device.


tinguishers are filled with $CO_2$ in order to fight flames.

At the same time, there's no shortage of substances that bind with oxygen even more readily than carbon – hydrogen being one example. However, you first need to break the carbon-oxygen bond, which takes a considerable amount of energy. "From a climate protection perspective, that's why it makes sense to use $CO_2$ in chemical production particularly if this energy comes from renewable sources," says Walter Leitner. "We're now developing the scientific and technology basis for these new interfaces between energy and chemistry – for example, in the Power-to-X initiative." With Leitner as one of the coordinators, this project is funded by the Federal Ministry of Education and Research (BMBF) and includes partners from academia, industry, and other parts of society.

## TWO AIMS: HIGH-VOLUME AND HIGH-QUALITY PRODUCTS

One approach to chemical production using $CO_2$ begins with the electrolysis of water to produce hydrogen – using sustainable electricity. In future, this could also allow electrical energy to be stored in times of excess supply from wind turbines and solar panels. Then, chemists use catalysts to arrange for a molecular marriage between hydrogen and $CO_2$.

The researchers in Muelheim envisage using this method for synthesis of methanol, formaldehyde, and formic acid – relatively simple substances that are formed when one $CO_2$ molecule reacts with different numbers of hydrogen molecules in each instance. The substances are used on a massive scale in industry as raw materials for a whole host of products, such as plastics, solvents, agrochemicals, or even pharmaceuticals. Methanol is also of interest as a fuel. But Walter Leitner and his team want to go also a step further than that. They want to combine the greenhouse gas and hydrogen with other chemical building blocks to produce polymers or components of drugs directly. "These higher-value products are more competitive than simple building block chemicals in the early stages of a circular carbon economy and are easier to introduce on the market," says Leitner.

Caroline Gebauer is another researcher who believes that this form of $CO_2$ recycling could have a sustainable future in the chemical industry. Gebauer participates in Power-to-X on behalf of BUND (Friends of the Earth Germany) and advises the project with regard to environmental and climate protection. From this perspective, she currently takes a critical view of synthetic fuels, however, when produced from renewable electricity and $CO_2$.

"Using electrical energy to produce hydrogen and then converting that into a synthetic fuel consumes several times more energy than direct electrical use," says Gebauer. "In our view, therefore, it's only feasible in applications such as shipping and aviation, where there is – as yet – no direct electrical alternative." However, Walter Leitner believes there is a promising future also for fuels produced from wind, solar power, and the greenhouse gas $CO_2$. "Such chemical energy vectors allow renewable energies to be transported over large distances and distributed using existing infrastructure," says the researcher. "That will form an essential part of a sustainable global energy system."

Whether it's for a fuel or a plastic, the chemical use of $CO_2$ relies on catalysts that give the mixture of gases a helping hand – and Walter Leitner's team specializes in this area.

Presumably, everyone knows about the catalytic converter in cars, which converts pollutants into harmless substances. In very general terms, catalysts act as the matchmakers in the world of chemistry: they reduce the amount of energy needed for a chemical reaction, steer it in the right direction, and are often instrumental in making a trans-

Graphic: designergold based on a draft from the MPG; photo: Project Management Jülich/Carola Sonnet

Catalysis research for sustainable chemistry: Christophe Werlé (left) and Alexis Bordet are searching for molecular matchmakers that selectively bring $CO_2$ together with other substances, such as hydrogen.

formation possible in the first place. When it comes to using $CO_2$ as a raw material, the catalysts must perform all three of these tasks.

## IT ALL BEGAN WITH A CATALYST FOR FORMIC ACID

Walter Leitner and his team have been researching suitable catalysts for some time – for example, for the production of formic acid. This molecule is formed by combining a $CO_2$ molecule with precisely one hydrogen molecule. Leitner's interest in this reaction did not come about by chance – it was with formic acid that he began his journey into the world of $CO_2$ chemistry while studying for his doctorate at the University of Regensburg. At that time, he was using formic acid as a source of hydrogen for chemical reactions, producing $CO_2$ as a by-product. "I asked myself, purely out of curiosity, whether this process could also be reversed," says the chemist. It turns out that it could – with a molecular catalyst containing the precious metal rhodium as its active center.

The metal center in this type of catalyst increases the chemical reactivity of one or both reaction partners – and the type of metal determines not only the size of this increase but also how much hydrogen the $CO_2$ takes in and what additional partners it incorporates. However, what comes out of this process is also determined by the so-called ligands, which are often complex organic molecules containing phosphorus or nitrogen as points of contact with the metal. The ligands form a defined envelop around the metal center so that, in many cases, the reaction partners can only attach themselves at certain positions relative to one another. Ideally, this leaves them with only one way of reacting – the one the leads to the desired product.

Christophe Werlé, who leads his own working group in Walter Leitner's Department, is searching for catalysts that bring $CO_2$ and hydrogen together in this way. Sometimes his work also involves optimizing an existing catalyst. Here, his first question is always why a catalyst does what it does. In this way, he hopes to identify starting points for improving these chemical facilitators – for example, in order to boost the yield of the desired product and reduce the amount of by-products. But Christophe Werlé also wants to use catalysts as matchmakers in particularly difficult partnerships, such as that of $CO_2$ and hydrogen in formaldehyde.

In practice, this requires a great deal of creativity and, especially, hard work. After all, Christophe Werlé and his team have set their sights on the intermediate products in which the catalyst, as a mediator between the starting materials, forms itself only weak bonds

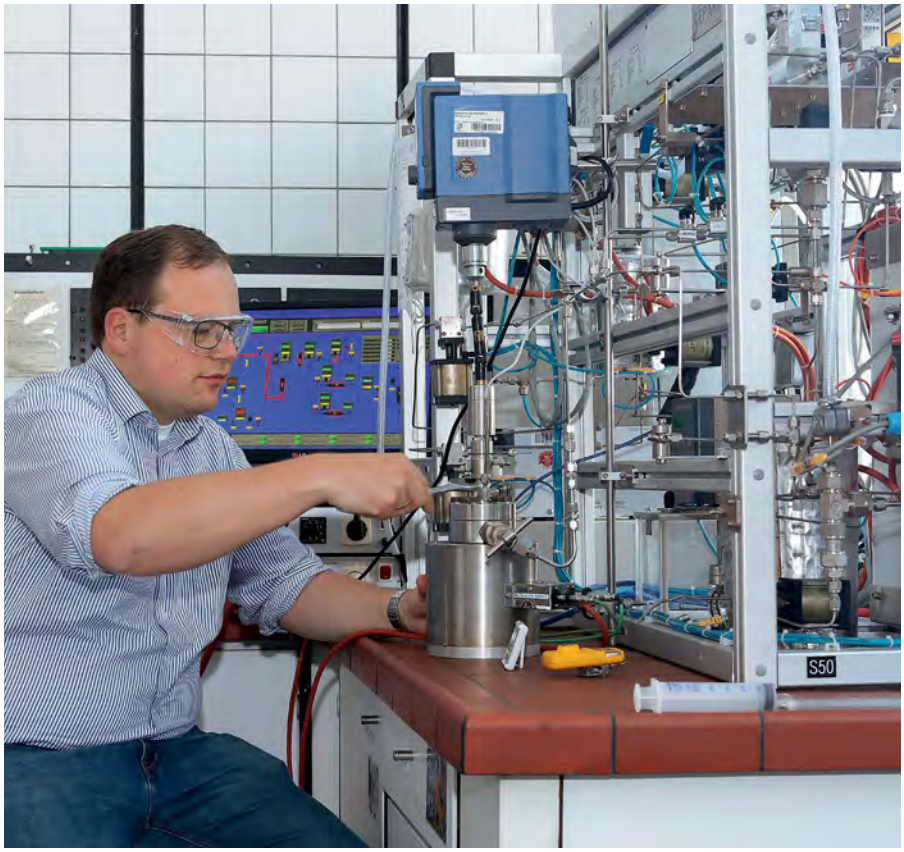
Photo: Thomas Hobirk

with the partners to be. Based on these short-lived constructs, the scientists can identify the reaction pathways and potential alternative routes. However, the problem with the short lifespan is that the contacts have no sooner formed than they change again. "To allow us to analyze them, we try to stabilize potential intermediate structures by varying the ligands," says Christophe Werlé.

Experiments like these give the chemists in Muelheim hints as to how $CO_2$ can be turned into the desired products. Recently, a team made up of Leitner's colleagues in Aachen and Muelheim identified a catalyst that, for the first time, contains the cheap and abundant metal manganese instead of a precious metal and can be used to convert $CO_2$ into methanol.

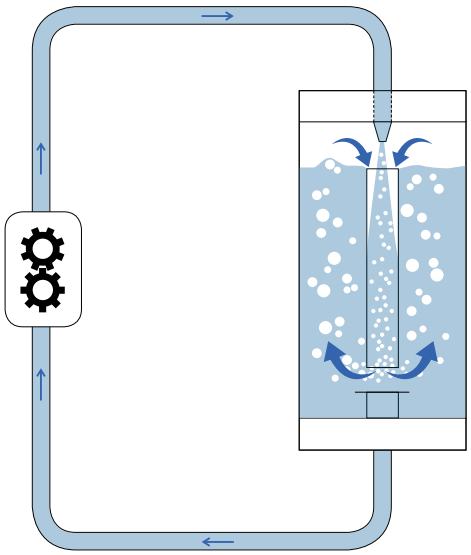
## PRECIOUS METAL CATALYSTS ARE AS YET MORE EFFICIENT

Although Walter Leitner is pleased with this achievement, he is confident that catalysts containing a precious metal can also be used in chemical production. After all, he says, the ligands in catalysts for $CO_2$ conversion are often at least as expensive as the metal – and precious metal catalysts are still in many cases much more efficient than the alternatives containing cheaper metals such as manganese, iron, or




Chemical plant in the lab: using a high-pressure reactor, the researchers in Muelheim study reactions involving gases such as $CO_2$ or hydrogen (left). In this miniature version of an industrial plant, Andreas Vorholt is preparing an experiment to test the long-term stability of a catalyst (right).

Photos: Thomas Hobirk (2)



All mixed up: if the starting materials and catalyst are dissolved in two immiscible liquids, the chemists in Muelheim use a nozzle loop reactor to achieve the closest possible contact between them. Here, part of the reaction medium is drawn off at the base of the reactor and injected back in under high pressure at the top of the vessel. One of the liquids is therefore dispersed in the other as a multitude of small droplets.

nickel. "Even if that only means you can use five percent less of the raw materials in an industrial process, the resulting cost advantage often outweighs that of using a cheaper metal in the catalyst," says Walter Leitner. What's more, another property of catalysts ought to compensate for the downside of using rare and expensive metals: theoretically speaking, they are not used up in the reaction.

## NANOPARTICLES IN A MOLECULAR CARPET

In practice, however, catalysts do wear out over time. This can happen because unwanted substances attach to them, forming persistent impurities, or because the ligands, which are often fragile, become damaged. Molecular catalysts such as those being investigated by the researchers in Muelheim also dissolve in the reaction medium – in what chemists call homogeneous catalysis – and must therefore be laboriously separated out once their job is done.

For this reason, the chemical industry typically prefers heterogeneous catalysis, in which liquid or gaseous starting materials react on the surface of solid catalysts – eliminating the need for a separation process. However, these solid matchmakers are harder to systematically optimize for a chosen reaction. "We're therefore working with scientists from all Departments of our Institute to identify the fundamental common ground between these two areas so that we can enjoy the best of both worlds," Leitner explains.

Alexis Bordet and his team work at the boundary between those two worlds. Instead of individual metal atoms in soluble catalysts, the chemists use metallic nanoparticles and ionic liquids. These substances consist of two charged components, one of which is an organic molecule in the form of a short thread. The scientists in Muelheim chemically attach these molecular threads to a material such as silicon dioxide, producing a charged molecular carpet that attracts the metallic nanoparticles like velour attracts dust. The reaction partners then flow across the chemical pile, which is interspersed with metal atoms, and are paired off while traveling through the reactor.

Here, the team wants the molecular carpet fibers to do more than just hold the nanoparticles in place. "The ionic liquids interact strongly with the nanoparticles and can act as a catalyst themselves," explains Alexis Bordet. "We exploit this behavior to combine different functions of the two components into tailor-made catalysts, which then allow us to transfer the hydrogen to substances from biomass with a high degree of selectivity or to $CO_2$ directly."

While Alexis Bordet is working on catalyst recycling using his "catalytic carpet", Andreas Vorholt is conducting research into engineering solutions with a view to helping industry use dissolved molecular catalysts that have proven effective in the research lab. The chemist, who leads a research group of his own at the Institute in Muelheim, also studied business administration and has previously worked as an advisor to industry. But it wasn't the first time that he realized: "There's a big gap between what academic research makes possible and what industry goes on to implement. That's why we want to provide practical data, so that industry says: that's really good – why don't we try it too?"

## THOROUGH MIXING FOLLOWED BY PERFECT SEPARATION

With this in mind, Andreas Vorholt is focusing on reactions in mixtures of liquids that separate from one another, like oil and vinegar in a salad dressing. In these situations, the catalyst may find itself in an organic liquid, for example, while the product collects in an aqueous solution – or vice versa. But this concept presents chemists with a dilemma: during the reaction, all of the components are supposed to mix thoroughly – and, in the case of $CO_2$ and hydrogen, the process even involves gaseous starting materials. At the same time, the catalyst and the product are supposed to go their strictly separate ways once the reaction is complete. "It's like in real life: you always want exactly what you don't have," says Vorholt. Indeed, it's hard to come by a for-

Graphic: designergold based on a draft by the MPG

***Above*** Distilled ideas: Sheetal Sisodiya, Walter Leitner, Christophe Werlé, and Christina Erken (from left) discuss new experiments that can put $CO_2$ to use.

***Below*** More climate-friendly in the future: the greenhouse gas can be used as a raw material for foams.

mula in which the reaction partners are fully dissolved in the catalyst solution but the product then fully migrates into the other liquid.

One way out of this awkward situation is for the starting materials and the catalyst to be present separately in the two liquids and for one liquid to then be dispersed throughout the other in the form of extremely small droplets. This provides the future partners with a large contact surface where they can meet the catalyst and react. Andreas Vorholt's team implements this concept using a nozzle loop reactor, in which part of the cocktail is drawn off at the base of the reaction vessel and injected back in under pressure through a nozzle at the top. "This produces fine droplets, and the reaction proceeds much faster than in conventional reactors – even though the catalyst is left totally separate from the product at the end of the process," explains Vorholt.

In order to gain a better understanding of what goes on in their reactors, and to influence the process, the chemists are setting up lab-scale copies of industrial systems and incorporating a whole host of analytical instruments. "We're integrating a working section for online monitoring – because how cool would it be if I knew that the catalyst isn't doing what it's supposed to do right now, and I could then counteract that," says Vorholt.

## $CO_2$ AS RAW MATERIAL FOR MATTRESSES AND SPORTS FLOORS

One current example serves as proof that catalysts and chemical processes can actually be adapted to allow the industrial conversion of $CO_2$. At the CAT Catalytic Center, a joint research center of the company Convestro and Leitner's group at RWTH Aachen University researchers have helped develop a process that can incorporate $CO_2$ into a polyol – a key component of foams and adhesives.

The company aquires the necessary $CO_2$ from other chemical processes, where it arises as a by-product, and uses it to replace a proportion of the starting material for polyol production – which used to be obtained exclusively from petrochemistry. Covestro is now producing the first polyols with a $CO_2$ content of up to 20 percent on the scale of a several thousand tonnes. The process therefore preserves resources and reduces $CO_2$ emissions accordingly, as demonstrated in comprehensive life-cycle analyses conducted by André Bardow, a professor at RWTH Aachen University. Foam whose molecular framework incorporates $CO_2$ is already being used to make mattresses and recently even sports facilities were equipped with flooring based on these materials that contain $CO_2$.

For Walter Leitner, the $CO_2$ mattresses are a perfect showcase – and are therefore just the beginning of some-

Photos: Thomas Hobirk (top), shutterstock (bottom)

thing much bigger. Whether the chemical industry ultimately uses this greenhouse gas as a raw material for other products will, however, also depend on factors over which he has no influence with his catalysis research. One example is how efficiently and economically $CO_2$ can be captured when it's formed in large quantities. Moreover, sufficient electricity must be available from renewable sources to produce hydrogen sustainably if it is to partner up with $CO_2$ – and the gases must be made available at the same site before being processed by the chemical industry.

In Caroline Gebauer's view, $CO_2$-based chemical production should receive a bit of help to get started: "$CO_2$ emissions should carry a far higher price – one that takes account of the climate damage associated with it," says the Power-to-X expert from BUND. "A carbon tax would certainly help." Regardless of this, Walter Leitner believes there are good opportunities to put $CO_2$ to use. "Even today, converting $CO_2$ with hydrogen can be beneficial from an environmental and economic perspective, particularly where the existing processes are costly and energy-intensive," says the chemist. But of course, the sustainable processes would be more competitive if the economic assessment took account of the carbon footprint. "In addition to the chemical catalyst, this would then provide the economic catalyst." ◀

www.mpg.de/podcasts/energie (in German)


## SUMMARY

- **With a view to using $CO_2$ as a raw material in the chemical industry, Max Planck researchers are searching for suitable molecular catalysts and production processes.**
- **They have already identified chemical matchmakers that combine the greenhouse gas with hydrogen to produce methanol and formic acid.**
- **To avoid the need to laboriously separate dissolved catalysts from the products after a reaction is complete, chemists use metallic nanoparticles, which they attach to a base material with ionic liquids, or a reactor in which the catalyst and the products are held in different liquids.**


## GLOSSARY

**Catalyst:** A substance that reduces the energy needed for a chemical reaction, steers it in a chosen direction, and is often instrumental in making a transformation possible in the first place. The catalyst is not used up in the reaction. In homogeneous catalysis, the starting materials, the product, and the molecular catalysts are all dissolved in one liquid. In heterogeneous catalysis, liquid or gaseous starting materials flow across a solid catalyst instead.

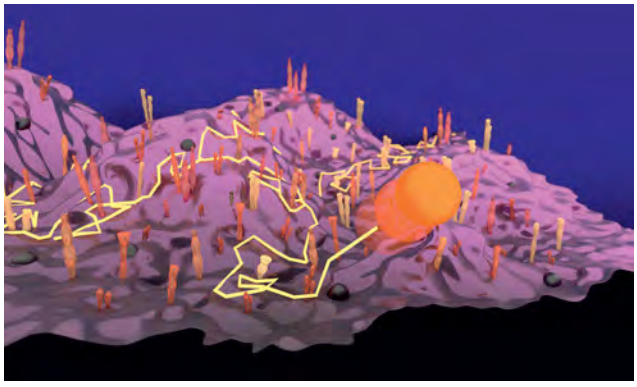
**Ligand:** The building blocks of a molecular catalyst arrange themselves around the metal atom – the active catalytic center – in order to steer the reaction in a chosen direction.

**Power-to-X:** One of the Kopernikus projects, with which the Federal Ministry of Education and Research (BMBF) supports schemes relating to the energy transition. Among other things, Power-to-X investigates the use of energy from renewable sources to produce hydrogen, which is then combined with $CO_2$.

# 3D movies from cell membrane

A new microscopy technique is making it possible to watch membrane proteins at work

A research group from Erlangen is shedding new light on cell functioning and thus opening up new possibilities for developing therapeutic drugs. Vahid Sandoghdar and his team from the Max Planck Institute for the Science of Light and the Max-Planck-Zentrum für Physik und Medizin have developed a method known as iSCAT (short for interferometric scattering) to such an advanced level that they can now use it to film proteins in a cell membrane in 3D and nanometer resolution. To do so, the team marks the molecules with individual gold nanoparticles. The gold scatters irradiated light, thus enabling the scientists to pinpoint the proteins. Since cell membranes are involved in numerous cellular processes, studying their movements and behavior can reveal a lot about the way in which cells function. This knowledge is important in medical terms, as the proteins in cell membranes are susceptible to a considerable number of active ingredients.
(www.mpg.de/0220191/en)

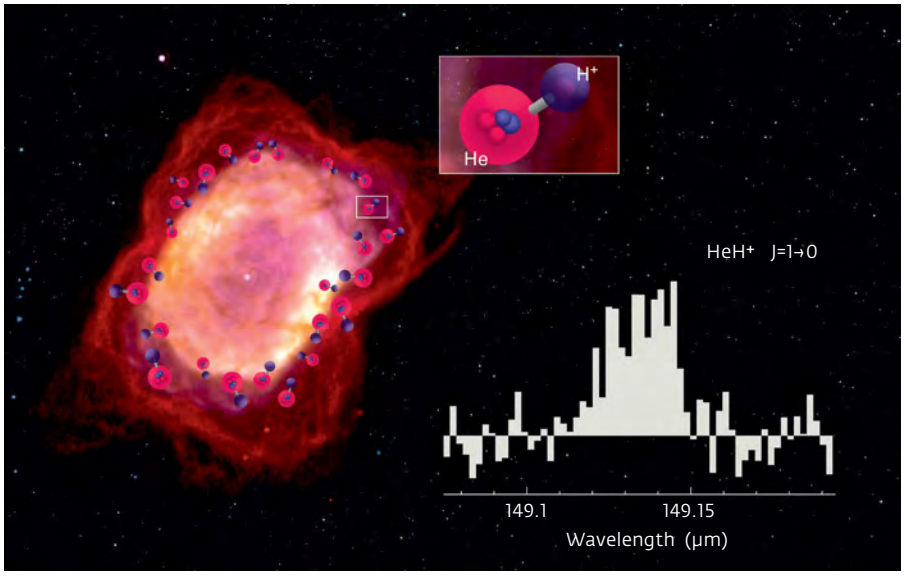


Road movie with membrane protein: a protein molecule marked with a gold particle (orange circle) can be tracked on its path across the cell surface (light yellow line) since the nanoparticle scatters light in a characteristic pattern.

# Molecule from the early universe

Astronomers find helium hydride in a planetary nebula

Immediately after the Big Bang 13.8 billion years ago, the universe was unimaginably dense and hot. It was only after a certain time that falling temperatures allowed the first chemical reactions between the newly formed light elements to take place. During this process, ionized hydrogen and neutral helium atoms combined to form the helium hydride ion ($HeH^+$) – the first molecule ever. For a long time, researchers tried in vain to find this substance in space. Using the far infrared spectrometer GREAT on board the flying observatory SOFIA, an international team led by Rolf Güsten from the Max Planck Institute for Radio Astronomy has now succeeded in detecting this molecule in the planetary nebula NGC 7027. Planetary nebulae are gas envelopes ejected by sun-like stars during the final phase of their lives. At their center sits a spent white dwarf star with a surface temperature of more than 100,000 degrees; this emits energy-rich radiation that drives ionization fronts into the ejected envelope. Model calculations predicted that this was where the $HeH^+$ molecule forms, and the astronomers did indeed strike gold. (www.mpg.de/13392365)




Early molecule: the spectrum of the helium hydride ion HeH+ seen on board the flying observatory *Sofia* in the planetary nebula NGC 7027. The underlying image was obtained using the Hubble telescope; the sharp transition zone between the hot gas (white-yellow) and the cooler envelope (red) is clearly visible. This is where $HeH^+$ is formed.

Graphics: Richard W. Taylor/MPI for the Science of Light (top); composition: NIESYTO design; image NGC 7027: William B. Latter (SIRTF Science Center/Caltech) and NASA/ESA; Spectrum: Rolf Güsten/MPIfR, Nature, April 18, 2019 (bottom)

# Diet influenced the development of languages

Changed dietary habits encouraged the development of new sounds

The phonemic inventory of human speech is incredibly diverse, ranging from common sounds such as "m" and "a" to rare click consonants. This range of sounds is generally thought to have become established with the emergence of Homo sapiens around 300,000 years ago. An international team of researchers including scientists from the Max Planck Institute for the Science of Human History and the Max Planck Institute for Psycholinguistics is now shedding new light on the evolution of verbal language. The study shows that labiodental consonants such as "f" and "w", which now occur in numerous languages, have only become widespread over the last 2,000 years – as the result of a change in dental bite. In earlier times, adult humans had edge-to-edge bites in which the incisors met exactly, thus enabling them to chew tough food. As softer food become more widespread towards the end of the Stone Age, this formation was superseded by a dental bite in which the upper incisors were positioned slightly in front of the lower ones. (www.mpg.de/13189521)

## Lower pension, shorter life

Income and social status are having an increasing impact on life expectancy

On average, men who receive small pensions die five years earlier than male pensioners who are better off. This was the conclusion drawn by scientists at the Max Planck Institute for Demographic Research from their analysis of data provided by the German Pension Fund. Between 1997 and 2016, life expectancy increased in all income brackets. However, at 1.8 years, the life expectancy of the poorest 20 percent in West Germany increased by only half the time gained by the highest income group. In the East, the lowest income group gained three years, while the highest gained 4.7 years. In addition, some of the older population of the former GDR were able to collect hardly any pension entitlement points after the reunification of Germany because they became unemployed or had to resort to marginal employment. This caused pensions in the East to shrink significantly after 1997. Lead author Georg Wenau warns against interpreting pension size as a causal factor affecting life expectancy. Small pensions are frequently the result of poorly paid jobs and periods of unemployment. Income also correlates strongly with health habits and level of education. (www.mpg.de/13326414)

# On the trail of the Denisovans

In 2010, when scientists from the Max Planck Institute for Evolutionary Anthropology in Leipzig analyzed a tiny finger bone from the Denisova cave in Russia, they hit upon a scientific sensation: the genetic material it contained was distinct from that of Neanderthals and modern humans. The bone must therefore have come from a previously unknown hominin. Known as Denisovans, these early hominins must have mixed with modern humans, as traces of their DNA are still found in Asian, Australian and Melanesian genomes even today. Analyses of the genomes of people living in Indonesia and New Guinea have shown that they inherited DNA from not one but two different Denisovan lineages. The two lineages are so divergent that these two groups may have been completely separate. Denisovans may even have lived in the region until around 30,000 years ago. This means that they may have been one of the last surviving groups of hominins.

The Denisovans must therefore have once been widespread; however, fossils of these mysterious archaic humans are still rare. After the bone from the cave in Russia from which the Denisovans got their name, researchers at the Max Planck Institute in Leipzig have now matched another fossil to a Denisovan hominin: a mandible from a cave in Tibet. This primitive man lived at least 160,000 years ago. The place where the mandible was found is located more than 3,000 meters above sea level, thus proving that the Denisovans had adapted to life in this low-oxygen atmosphere long before Homo sapiens arrived in the region. Earlier genetic studies have shown that the Denisovans passed on a gene to the people now living in the Himalayas that enables them to survive at these high altitudes.
(www.mpg.de/13386452, www.mpg.de/13329072)

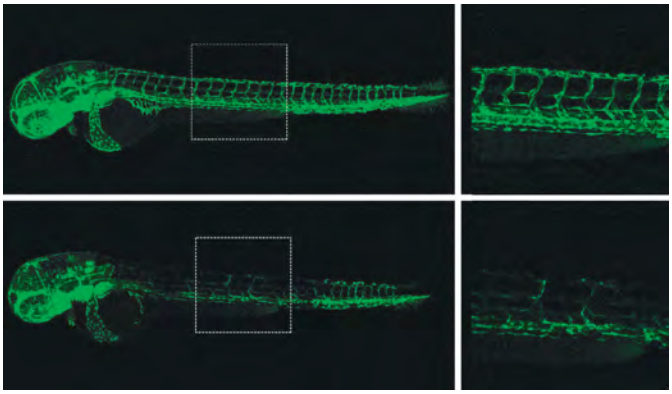

Fragment of a Denisovan's lower mandible found in the Baishiya Karst cave in Tibet. Compared to Homo sapiens, these prehistoric hominins had powerful jaws with unusually large molars.

Photo: Dongju Zhang, Lanzhou University

# Genetic defects without consequences

The messenger RNA of defective genes can ensure that other genes compensate for the defect

Defective DNA sequences are responsible for a number of serious diseases. The severity of a disease can vary from patient to patient, as related genes become more active in some of them to compensate for the defect. It appears that a key role is played by messenger RNA molecules (mRNA), which transport the information from the mutant gene out of the cell nucleus to the location where the protein is formed. With the help of genetically modified zebra fish, scientists from the Max Planck Institute for Heart and Lung Research have discovered that the mRNA of a mutant gene sends signals for related genes to take over the task. According to the researchers, these then form more mRNA to compensate for the loss. For several diseases, this could be the reason why some patients have milder symptoms. In the next phase, the researchers aim to compare patients with symptoms of varying degrees of severity. This may enable them to identify genes for new treatments. The study also makes it clear that it is extremely difficult to predict the consequences of manipulating the genome. (www.mpg.de/13336233)



The vascular system (green) of two-day-old zebra fish embryos. Absent mRNA in a defective gene prevents the vessels from developing properly (bottom).

# Are fish aware of themselves?

The animals appear to recognize themselves in a mirror

Chimpanzees, dolphins, crows and magpies perceive their reflections as images of their own bodies. Until now, passing this mirror test was seen as an indication that the species in question possess self-awareness. Scientists at the Max Planck Institute for Animal Behavior in Konstanz have now discovered that cleaner wrasse also react to their reflections. The fish attempt to remove spots painted onto their bodies when they see them in the mirror. However, the fish show no interest in invisible spots or spots on others of their species. The behavior of these fish meets all the criteria required to pass the mirror test. However, according to the researchers, it is not yet clear whether the results constitute evidence that the cleaner wrasse possess self-awareness. Instead, they are more inclined to interpret the results as an incentive to critically examine the mirror test and consider whether it should continue to be used as the standard test for verifying the existence of self-awareness in animals. (www.mpg.de/12704402)

Self-critical scrutiny: cleaner wrasse (*Labroides dimidiatus*) live in the sea and feed on parasites on the skin of other fish. They recognize in the mirror when a spot has been painted on their bodies.

Graphics: MPI for Heart and Lung Research (top); photo: A. Jordan (bottom)

# Life-saving turnaround in energy policy

Harmful substances released when burning fossil fuels currently cost millions of human lives every year

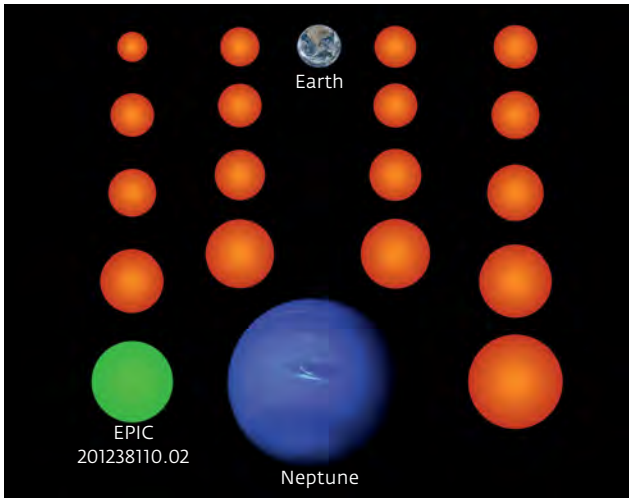
A rapid withdrawal from the fossil-fueled energy industry would not only benefit the climate, it would also prevent more than three million premature deaths caused by air pollution every year. This was the conclusion reached by an international team of researchers led by Jos Lelieveld, Director at the Max Planck Institute for Chemistry. The scientists have been investigating how air pollution from various sources affects human health. Their study utilizes epidemiological data and a model of the globe's atmospheric chemistry. These allow conclusions to be drawn as to which diseases are the result of contamination with noxious substances and how they shorten statistical life expectancy. It has accordingly been found that emissions from the global combustion of mineral oil, mineral gas and coal are responsible for around 65 percent of the premature deaths caused by air pollution. Fine dust particles are particularly harmful, as they significantly increase the risk of cardiovascular and respiratory diseases. Human health could therefore benefit significantly from switching to renewable energy sources. (www.mpg.de/13275159)

Wind power instead of coal: a shift from fossil energy sources would significantly reduce the health hazard posed by air pollution.

# 18 Earth-sized exoplanets discovered

A new method is being used to detect small celestial bodies that previous searches had overlooked

At present, astronomers are aware of a good 4000 planets orbiting stars outside our solar system. Around 96 percent of these exoplanets are significantly larger than our Earth, However, this percentage is unlikely to reflect actual conditions in space, as large planets are significantly easier to pinpoint than small ones. Yet these small worlds are also the most fascinating, as they give reason to hope that a "second Earth" may be found elsewhere in the universe. Scientists at the Max Planck Institute for Solar System Research, the Georg August University of Goettingen and the Sonneberg Observatory have now discovered 18 Earth-sized exoplanets. All these strange worlds have one thing in common: they are so small that previous searches overlooked them. One of the new exoplanets is among the smallest discovered to date, while another may turn out to have conditions that could support life. The researchers analyzed some of the data from the NASA space telescope *Kepler* using a significantly more sensitive method developed by themselves. The astronomers conjecture that their method may be able to identify more than 100 relatively small exoplanets from the entire body of data collected during the Kepler mission. (www.mpg.de/13505027)




Gallery of planets: almost all of the exoplanets known to date are larger than the Earth and are typically the size of the gas planet Neptune. The 18 newly discovered planets (here in orange and green) are significantly smaller; EPIC 201238110.02 could be hosting liquid water.

Photo: shutterstock (top); graphics: NASA/JPL (Neptune), NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring (Earth), MPS/René Heller (bottom)

# Monkey hunting ensured survival in the rainforest

Early settlers in Sri Lanka specialized in hunting small mammals

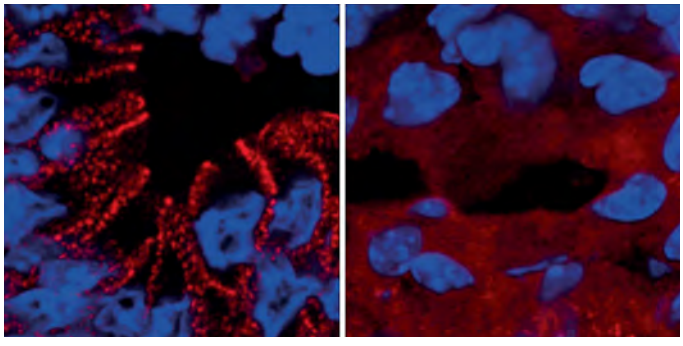
Tropical rainforests are actually a hostile environment for humans: diseases, limited resources and the indigenous animal species make the jungle less than attractive for colonization. Agile arboreal monkeys and squirrels, for example, are much more difficult to capture and provide smaller quantities of protein than large animals that live in open savannas. However, finds made in Sri Lanka prove that modern humans were already living in the local rainforest 45,000 years ago. An international team led by the Max Planck Institute for the Science of Human History has gained new insight into how Homo sapiens adapted to this environment. They have found that early settlers actually specialized in hunting small, agile mammals such as monkeys. Their hunting strategy was sustainable – only full-grown animals were killed to ensure that the natural environment was not exploited excessively. "The use of this difficult-to-catch resource is another example of the behavioral and technological flexibility of Homo sapiens," explains Michael Petraglia from the Max Planck Institute for the Science of Human History, one of the study leaders. (www.mpg.de/12746043)

At home in the rainforest: stone and bone tools used by humans 45,000 years ago have been found in the Fa-Hien cave in the Sri Lankan jungle.

# Insulin protects against colorectal cancer

Signaling pathway in the intestinal mucosa strengthens the intestinal barrier

Excess weight can stop insulin receptors reacting to the hormone. This is why overweight people commonly develop so-called "insulin resistance". They are also at greater risk of colon cancer. Scientists at the Max Planck Institute for Metabolism Research have now found out how these two diseases are linked: insulin receptors on the cells in the intestinal mucosa activate genes that are responsible for the formation of zipper-like connections between the cells and thus keep the intestine impermeable. Patients with insulin resistance have greater difficulty in reconstructing these connections following injuries to the intestinal wall. This makes it easier for bacteria to penetrate the intestinal wall and trigger inflammation in the intestine, which in turn encourages the development of colon cancer. (www.mpg.de/12791681)

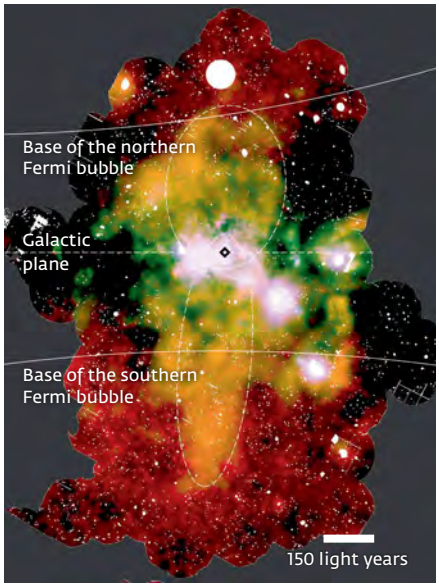


In healthy mice, connections (bright red) are formed between the intestinal cells (left). These are absent in mice with malfunctioning insulin signaling pathways (right).

Photo: O. Wedage (top); graphics: MPI for Metabolism Research/ Ostermann (bottom)

# Chimneys in the Milky Way

Researchers discover unusual structures on a new x-ray map of the Galactic Center




Our Milky Way is a comparatively tranquil galaxy. Gigantic outbursts of energy from its center, the site of a supermassive black hole, are rare. Nevertheless, astronomers have long since detected bipolar bulges close to the Galactic center. These wings or lobes show outflows from the center that only extend to distances of up to around 50 light years. Moreover, scientists have long since been familiar with the so-called Fermi bubbles, each of which stretches far beyond the galactic plane but begins some considerable distance from the center. Astronomers led by the Max Planck Institute for Extraterrestrial Physics have now discovered a new structure in x-ray images: two wide gas chimneys that connect inner regions of the center of our Milky Way north and south of the galactic plane with structures much further out. These appear to extend from the wings in the innermost regions of the Galactic Center to the base of the Fermi bubbles. The chimneys apparently blow energy and mass out of the vicinity of the black hole and transport them to the Fermi bubbles. (www.mpg.de/13261062)

A look into the heart of our galaxy: this false-color image shows the x-ray emissions from the central region of the Milky Way. Elongated structures – the recently discovered chimneys – are clearly visible north and south of the galactic plane.

# Social uncertainty also puts chimpanzees under stress

Male animals are less aggressive if social relations in their group are unstable

For species that live in groups, higher status has many advantages but also comes at a cost. An international research team from the Max Planck Institute for Evolutionary Anthropology in Leipzig observed the behavior of male chimpanzees in the Taï national park on the Ivory Coast and measured the stress hormones in their urine. The results show that the male chimpanzees' hormone levels are higher in times of social instability and increased competition. This means that the animals were more stressed than in stable periods – despite showing less aggressive behavior among themselves during these times. The stress appears to be psychological rather than physiological. The males are stressed by the social uncertainty that arises when they are competing for status within the group. As with humans, chimpanzees appear to suffer particularly when their social relationships are unstable. (www.mpg.de/13295691)

Male chimpanzees behave less aggressively in times of social instability in order to prevent the escalation of conflict and maintain the coherence within the group.

Graphics: MPE (top); photo: Anna Preis (bottom)

# Fruit bats are reforesting African woodlands

800 hectares of new forest could grow every year from the seeds scattered by the fruit bats

Intact ecosystems are not only a joy for nature lovers, they are also useful in financial terms. However, it is usually difficult to calculate how much money they actually bring in. Scientists from the Max Planck Institute for Ornithology in Radolfszell and colleagues from Sweden and Ghana have now calculated the ecological and financial benefits of straw-colored fruit bats in Africa for the first time. Every night, these bats fly long distances to their feeding grounds while scattering the seeds of the fruit they consume. According to the researchers, a colony of 150,000 bats can scatter more than 300,000 seeds in a single night. This means that 800 hectares of woodland could be reforested every year in Ghana alone – by just one colony. However, the number of straw-colored fruit bats in Africa is on the decline. The animals are at risk from hunting and the logging of large trees. Both forests and humans would benefit from better protection.
(www.mpg.de/13271542)

Straw-colored fruit bats love fruit more than anything.

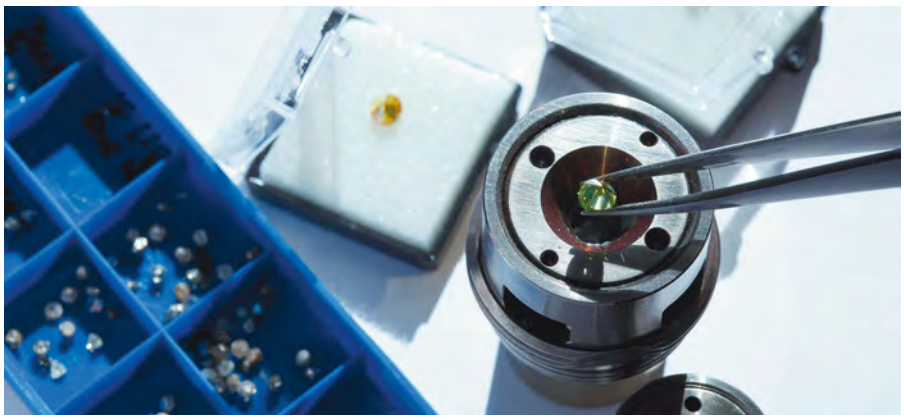
## The roots of apple trees

The history of the apple is closely linked with that of humankind. However, it seems likely that humans were not the first to make apples a big thing. As Robert Spengler from the Max Planck Institute for the Science of Human History in Jean reveals in a new study, there is fossil and genetic evidence to indicate that apple trees developed large, fleshy, sweet fruits millions of years before they were domesticated. These were an attractive food source for large mammals, which were classified as megafauna and also distributed the apples. However, most species of megafauna became extinct at the end of the last Ice Age. As a result, populations of wild apple trees became isolated until humans began transporting the fruit, particularly along the Silk Road. Thus the lineages once again came into contact and produced hybrid varieties that bore even larger fruit. Humans then reinforced this characteristic by refining and planting seedlings from the most popular trees, thus laying the foundations for the wide variety of apples available today.
(www.shh.mpg.de/1321592)

# A leap towards superconductivity at room temperature

Fewer power plants, fewer greenhouse gases and lower costs: if scientists were to discover superconductivity at room temperature, this could drastically cut electricity consumption. This is because superconductors transport electricity without loss. A team at the Max Planck Institute for Chemistry has moved one step closer to this goal. The researchers led by Mikhail Eremets have been synthesizing lanthanum hydride. This hydrogen-rich bond with the metal lanthanum loses its electrical resistance at minus 23 degrees Celsius and at pressures of less than 1.7 megabar, i.e. 1.7 million times atmospheric pressure. Until now, the record for high-temperature superconductivity was minus 70 degrees Celsius; since 2015, this has been held by hydrogen sulfide, which also has to be subjected to extremely high pressure.
(www.mpg.de/13512517)

The pressure is on: more than one million bar can be generated between two conically cut diamonds in an anvil cell not even the size of a fist. This makes lanthanum hydride superconductive at relatively high temperatures.



Photos: MPI for Ornithology/ Ziegler (top); Thomas Hartmann (bottom)

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# Künstliche Intelligenz

## Die Mitmach-Ausstellung auf dem Frachtschiff

## *MS Wissenschaft*

Künstliche Intelligenz (KI) – was ist das eigentlich genau?
Wie lernen Menschen und wie lernen Maschinen?
Wo bringt KI uns im Alltag Vorteile und welche Risiken gibt es?
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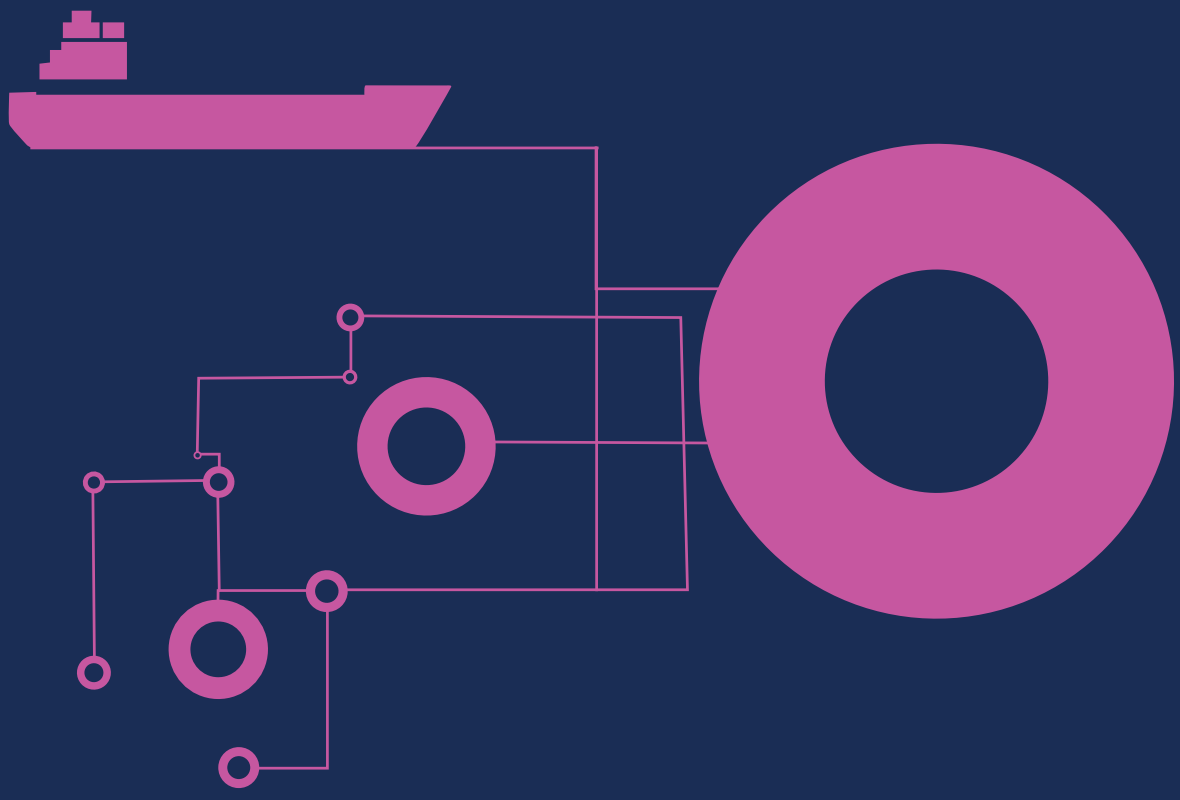

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A picture of a dark monster. The image is the first direct visual evidence of a black hole. This particularly massive specimen is at the center of the supergiant galaxy Messier 87 and was acquired by the Event Horizon Telescope (EHT), an array of eight ground-based radio telescopes distributed around the globe.

# **A portrait** of a black hole

Black holes swallow all light, making them invisible. That's what you'd think anyway, but astronomers thankfully know that this isn't quite the case. They are, in fact, surrounded by a glowing disc of gas, which makes them visible against this bright background, like a black cat on a white sofa. And that's how the Event Horizon Telescope has now succeeded in taking the first picture of a black hole. Researchers from the **Max Planck Institute for Radio Astronomy** in Bonn and the **Institute for Radio Astronomy in the Millimeter Range (IRAM)** in Grenoble, France, were among those making the observations.

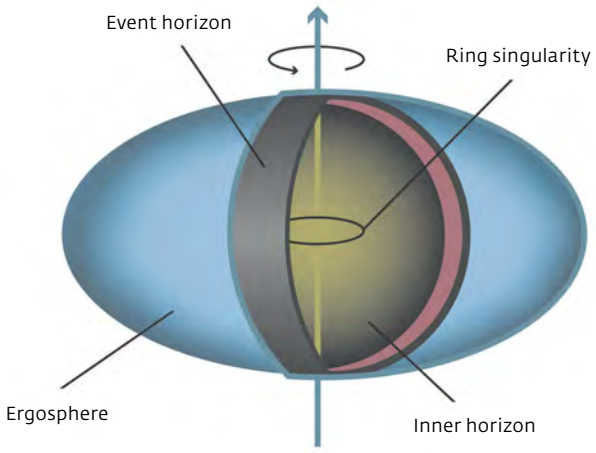
Photo: EHT Collaboration

TEXT **HELMUT HORNUNG**

In spring 2017, scientists linked up eight telescopes spread out over one face of the globe for the first time, forming a virtual telescope with an effective aperture close to the diameter of the entire planet. The technique is called Very Long Baseline Interferometry (VLBI), which combines the signals of the individual antennas into one image. This synchronization requires highly-precise atomic clocks, accurate to a billionth of a second. The technique makes it possible to resolve objects at extremely small angles of less than 20 microarcseconds. With that resolution, our eyes would see individual molecules on our own hands.

## THE DATA ARE PROCESSED IN A SUPERCOMPUTER

The Event Horizon Telescope (EHT), as the network of observatories is known, included the 30-meter IRAM dish in Spain and the APEX telescope in Chile, which is operated with the participation of the Max Planck Institute for Radio Astronomy. In the 2017 observing session alone, the telescopes recorded approximately four petabytes of data. This is such a huge volume that it was actually faster and more effective to send the data by post than via the Internet. The data were calibrated and analyzed at the Massachusetts Institute of Technology (MIT) in the U.S. and at the Max Planck Institute for Radio Astronomy using supercomputers known as correlators. >




***Left*** Beyond the horizon. The graphic depicts a rotating black hole. The ergosphere is the area in which no particles can remain at rest. The event horizon can be regarded as the surface of the black hole; anything that moves beyond it, quite literally vanishes from the world.

***Right*** Space antenna. The 30-meter IRAM dish is the most sensitive single telescope in the Event Horizon Telescope's worldwide array.

"The results have given us the first clear glimpse of a supermassive black hole. They mark an important milestone in our understanding of the fundamental processes underlying the formation and evolution of galaxies in the universe," says Anton Zensus, Director at the Max Planck Institute in Bonn and Chairman of the EHT Collaboration Board. Zensus considers it remarkable that the project's astronomical observations and theoretical interpretation were achieved faster than expected.

According to IRAM Director Karl Schuster, the success is based on "decades of European expertise" in millimeter astronomy: "Back in the 1990s, the Max Planck Institute for Radio Astronomy and our Institute with its two observatories was demonstrating technically and scientifically that our high-resolution radio observations represented a unique method for analyzing the immediate vicinity of supermassive black holes."

IRAM, a facility co-financed by the Max Planck Society, actively participated in the campaign with the 30-meter telescope. At 2800 meters above sea level on Mount Pico Veleta in the Spanish Sierra Nevada, it is the most sensitive single telescope in the EHT array. "We can adjust the antenna's surface with a precision on the scale of a human hair," says astronomer Pablo Torne.

## IDEAL WEATHER CONDITIONS AND FUNCTIONING TECHNOLOGY

Over four days in April 2017, Torne and his colleagues at IRAM simultaneously aligned their telescopes on the center of the galaxy M87 and its gigantic black hole for the first time, along with the other EHT stations located around the globe. "We couldn't have wished for better weather conditions for the time of year. Most importantly, the observatory's equipment worked perfectly, from its high-precision atomic clock and receiver systems to its data recorders," says Torne. In total, the observations recorded at the 30-meter antenna alone exceeded 500 terabytes of data.

The heart of the supergiant galaxy M87 has two particular characteristics that make it a good candidate for the project. It is both unusually massive and relatively close to Earth, which makes it easier to see. This makes it a perfect target for astronomers who, with the global telescope array, finally have an instrument capable of directly targeting such an exotic object.

The regions around supermassive black holes are subject to the most extreme conditions known in space. Black holes are fascinating cosmic objects that incorporate an incredible total mass within a tiny volume of space. Their mass and thus their gravitational pull are so great that even light can't escape them. That's what makes them black, making it impossible to directly observe them.

The only way to actually observe such cosmic gravity traps is to image their "shadow". This is caused by the extreme bending of light – shortly before it irretrievably vanishes into the black hole. By making extremely pre-

Graphic: designergold based on a draft from the MPI for Gravitational Physics

Photo: IRAM/DiVertiCimes

» The event horizon itself is not visible in the image; it is smaller and lies within the dark area.

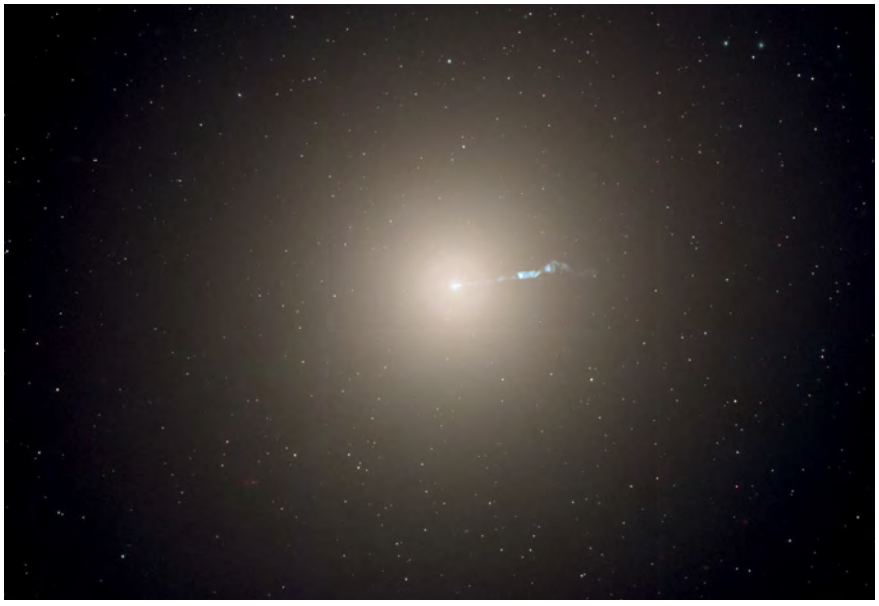
cise observations in the millimeter range, astronomers can see through the dense dust and gas clouds right through to the edges of black holes.

The image, which has now been released, was obtained at a wavelength of 1.3 millimeters (corresponding to a frequency of 230 gigahertz) and clearly shows a ring-shaped structure with a dark central region – the shadow of the black hole. A hot gas plasma is moving at high speeds around this very massive and compact object. This explains the ring-like structure in the image: the light from the strongly heated matter around the massive monster is being bent and amplified like by a lens. After a journey of around 55 million light years, it arrives at the EHT telescope array. The variations in brightness within the ring are due to a relativistic effect. As the black hole is rotating, light coming toward us appears brighter than light that moving away. The event horizon itself is not visible in the image; it is smaller and lies within the dark area.

The origin of the black hole is a supergiant elliptical galaxy known as M87, near the center of the Virgo galaxy cluster. In 1781, the French astronomer Charles Messier cataloged the object under number 87. The galaxy is also known as a strong radio source called Virgo A and is very active. Its nucleus shoots out a "jet" of matter at least 5000 light years long. This has been accelerated in the accretion disk of the black hole at its center and emitted at high velocity as a tightly focused beam perpendicular to the disk.

## A GLIMPSE INTO THE CENTRAL MACHINERY OF A GALAXY

The shadow tells the researchers a great deal about the nature of the galaxy's central machinery and allows them to accurately determine the enormous mass of the black hole in M87. This has been calculated as equivalent to 6.5 billion Suns. The figure is highly consistent with that derived from previous observations. >



A giant in the sky. The supergiant galaxy Messier 87 was one of the targets of the Event Horizon Telescope observation campaign. The jet visible in this optical image of the galactic nucleus clearly originates from the supermassive black hole in the center of the elliptical galaxy.

"For many decades, the only way to detect black holes was indirectly," says Michael Kramer, Director at the Max Planck Institute for Radio Astronomy. Then, a few years ago, scientists succeeded in detecting gravitational waves for the first time, allowing us to "hear" the effect of merging black holes on space-time.

"Now we can finally see them as well, giving us the fascinating chance to study in a unique way these exotic objects and the extreme curvature they impose on space-time," says Michael Kramer, a leading scientist in the *BlackHoleCam* project, which is part of the Event Horizon Telescope consortium totaling roughly 200 researchers.

## THE OBSERVATION REPRESENTS A WATERSHED MOMENT

The observations are ongoing. At the end of 2018, NOEMA in the French Alps joined the global array. This second IRAM observatory has twelve highly sensitive antennas, making it the most powerful in the EHT in the northern hemisphere. "NOEMA will allow us to venture into a new sensitivity range and gain even more fascinating insights," says IRAM Director Karl Schuster.

Anton Zensus considers the success to be a watershed moment in astronomy. "In the future, researchers both in and well beyond our field will clearly delineate periods before and after this discovery," says the Max Planck researcher. He believes astronomers will learn more about galactic nuclei and obtain a complete picture of how active galaxies are formed and evolve. In addition, he anticipates the discovery will allow us to test Einstein's general theory of relativity ever more rigorously. "Black holes, after all, are an ideal laboratory to test what happens in strong gravity." ◀


## SUMMARY

- **Astronomers have taken the first picture of a black hole. It resides at the center of the supergiant elliptical galaxy M87, about 55 million light years away.**
- **The discovery was made by combining observations made in April 2017 from an array of radio antennas distributed around the Earth to form a virtual telescope.**
- **This was done using very-long-baseline interferometry (VLBI), a technique that combines the signals of the individual antennas.**
- **Researchers hope that images of black holes will help them better understand galactic nuclei and provide insights into the formation and evolution of active galaxies.**


## GLOSSARY

**Accretion disc:** A disk of matter rotating and coalescing towards (accreting) a central object, for instance a black hole. It can be composed of atomic gas, plasma (ionized gas) or interstellar dust. Toward the center, the speed of rotation and temperature rise sharply.

**Arc second:** The term arc second is often employed as an expression of a telescope's resolving power, the smallest angle it can successfully resolve. An arc second corresponds to one 3600$^{th}$ of a degree. A microarcsecond is one millionth of an arcsecond.

**Charles Messier:** French astronomer (1730–1817) whose career began in the French Navy, before leading him to France's Bureau of Longitude. He discovered 20 comets and created a catalog of 103 diffuse astronomical objects, which have since been discovered to be gas nebulae, star clusters, and galaxies.

Photo: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

# "An astounding coincidence with theory"

Max Planck Director Anton Zensus on the first observation of the shadow of a black hole

What sounds paradoxical is reality: Black holes have a shadow! In the Messier 87 galaxy, astronomers were able to observe such a phenomenon for the first time with the Event Horizon Telescope (EHT). The Max Planck Institute for Radio Astronomy in Bonn had a first row seat. Anton Zensus heads the "Very-Long-Baseline Interferometry" Department. The Department deals with a technique that enabled discovery in the first place. We talked to Anton Zensus, Chairman of the EHT Collaboration Board, about how the successful observation came about and what the results mean.

*Mr Zensus, how long has the Event Horizon Telescope project been running?*

**Anton Zensus:** Officially, it started two years ago. But the preparations have been going on for a decade. And if you factor in the preparatory and pioneering work, it's actually 20 years. During this time, we have fundamentally improved the quality of our measurements and have already investigated important questions about active galaxies like M87 – such as the nature of the gigantic matter jets from their central regions. In this sense, we have now reached the peak of a long development.

*You say that EHT had only been conducting observations for two years. Were you surprised by your success after this relatively short time?*

Yes indeed! It was also astonishing that so many things worked right away. After all, the Event Horizon Telescope consists of a combination of eight different telescopes. One of these telescopes – which is called ALMA – is located at an altitude of 5000 m in the Chilean Atacama Desert and comprises 66 individual antennas. In order to be able to integrate this system into the EHT, we had to interconnect all individual antennas via software. This "phasing" was an enormous technical challenge for us and was essential for the EHT. The weather conditions also played into our hands – they were really good right from the start.

*What does an observation with eight telescopes look like?*

The key word is very long baseline interferometry (VLBI). We aim several radio telescopes, which are far away from each other, at the same celestial object at the same time. The signals collected are combined in a special computer – the correlator. In this way, a virtual telescope is created. This provides an image sharpness corresponding to

» This marks the culmination of a long period of development.

Anton Zensus, Director at the Max Planck Institute for Radio Astronomy and Chairman of the EHT Collaboration Council.

Photo: Helge Horn Photography

that of a single antenna with the diameter of the distance between the most distant antennas – in the case of the Event Horizon Telescope, this is about 8000 km. Just imagine: if your eyes were as sharp as the EHT, you could theoretically read a newspaper in New York from Bonn. However, the EHT does not see any optical light but rather radio radiation with wavelengths of just over one millimeter.

*How is your Institute involved in the Event Horizon Telescope?*
The EHT includes the 12-meter APEX telescope, which is operated by our Max Planck Institute for Radio Astronomy together with the European Southern Observatory and the Swedish Onsala Space Observatory. It is located close to the ALMA site. The Max Planck Society is also involved with the IRAM 30-meter antenna on the Pico Veleta in the Spanish Sierra Nevada and will be involved with the NOEMA telescope near Grenoble in the future. A total of thirteen partner organizations from all over the world work for EHT. Our Institute operates a supercomputer that calibrates and evaluates the data. In fact, enormous amounts of data are generated. Each of the EHT's individual telescopes deliver around 350 terabytes per day.

*You knew what you were looking for: the shadow of a black hole. I suppose theoretical considerations played an important role?*
Yes, Einstein's general theory of relativity of 1915 provides the theoretical background. Also about a hundred years ago, astronomers observed jets for the first time. These are gas flows that shoot out of the center of active galaxies and must be generated at enormously high energies. Since the 1970s, we have suspected that there are super-massive black holes behind it. The theory of relativity predicts that a massive object can deflect light. The English astronomer Arthur Eddington measured this phenomenon during a total solar eclipse when he observed a small shift of the star positions near the solar disk. By the way, that was on 29th of May 1919 – exactly one hundred years ago. This completes the circle.

*The black hole in the center of the Milky Way is much closer than that in Messier 87. Why was the EHT still successful with M87?*
Our Milky Way is a bit hesitant to disclose its deepest secrets (laughs). But joking aside, there are, of course, sound reasons. On one hand, the heart of our Milky Way is hidden in a dense fog of charged particles. This leads to a flickering of the radio radiation and thus to blurred images of the center of the Milky Way. But I am confident that we can still solve this problem. On the other hand, galaxy M87 is about 2000 times further away. However, the black hole in its center is also 1000 times more massive than the one in our Milky Way. The greater mass makes up for the greater distance. The shadow of the black hole in M87 therefore appears to us to be about half the size of the one from the gravity trap in our Milky Way.

*Just what is the shadow of a black hole?*
A black hole deflects the light even more than our sun. The theory of relativity predicts that a radiation ring should be observed around a dark spot where the black hole is located. Right where the black hole is. Some casually refer to this dark spot as the shadow of the black hole.

*But where does the light come from? Black holes are black, aren't they?*
According to the general theory of relativity, black holes have an "event horizon". It describes the region within which nothing can escape from the black hole. The event horizon – but also the area within – should therefore appear black to us. According to theory, outside the event horizon, attracted by the enormous mass, there is a huge amount of gas swirling around in a vortex-like disk structure at tremendous speeds. The gas heats up and begins to glow. Relativistic particles – those that move at almost the speed of light in a magnetic field – also release synchrotron radiation. So around a black hole, it "shines", while the hole itself, as the name suggests, appears black. It is this blackness that we've been observing.

*What did you discern from the shadow?*
To be honest, we were amazed at how well the dark spot we observed matches the structure predicted by our computer simulations. From the shadow itself, the mass, the rotation, and the magnetic field of the black hole can be derived. For this purpose, 60,000 different simulations of black holes were carried out on the computer and compared with the EHT results.

*How will this successful observation advance astronomy?*
Black holes are an ideal laboratory for measurements under strong gravity. We are at the beginning of a phase in which many new insights await us. We will soon be able to confidently exclude alternative explanations for black holes – such as boson stars or gravastars. We will better understand the galactic centers and obtain a complete picture of the formation and evolution of active galaxies. We will also be able to observe pulsars in the vicinity of the black hole in our Milky Way and thus thoroughly check the general theory of relativity.

The interview was conducted by Helmut Hornung

# The mystery of the dark bodies

Even though they have a large mass, black holes are not made of matter. Until recently, that meant that they couldn't be directly observed, only indirectly due to the gravitational effect they have on space around them. They bend space and time and exert an irresistible attraction. The Event Horizon Telescope has now allowed us to see the shadow of a black hole for the first time. It is startling that such exotic objects were first predicted more than 230 years ago.

Optical: DSS; illustration: NASA/CXC/M. Weiss

TEXT **HELMUT HORNUNG**

The story of black holes begins in the quiet little town of Thornhill in the English county of Yorkshire. For 26 years during the 18th century near the town's medieval church lived its priest, John Michell, who, as is clear from his tablet memorial in the church, was also a highly regarded scholar. Indeed, Michell had not only studied theology, Hebrew and Greek at Cambridge University; he was also a dedicated natural philosopher. His was chiefly interested in geology. In an essay published after the Lisbon earthquake in 1755, he suggested that earthquakes were propagated by waves of different types below the ground. This theory caused quite a stir in the scientific community, and it resulted in John Michell being elected a member of the Royal Society in London.

It was before the members of this august institution that he gave a lecture on the gravity of stars in 1783. In it, he reasoned in a thought experiment that a very massive star's gravity might be so strong that no light would be able to leave its surface. "If there should really exist in nature any [such] bodies ... their light could not arrive at us," he concluded.

Cosmic swirl: the Cynus X-1 black hole swallows up material from a neighboring blue massive star and emits X-rays in the process.

More than a decade after John Michell, another natural philosopher took up the subject. The French mathematician, physicist, and astronomer Pierre-Simon de Laplace suggested in his 1796

***Left*** Advanced mathematics. In 1916 the astronomer Karl Schwarzschild calculated the size and behavior of a non-rotating, electrically-charged, static black hole on the basis of general relativity.

***Right*** Thought experiments. In 1796, the French mathematician, physicist, and astronomer Pierre-Simon de Laplace suggested that their could be massive stars whose light would not be able to escape them.

work *Exposition du Système du Monde* that their could be massive stars whose light would not be able to escape them; this light, according to the generally accepted theory of Isaac Newton, consisted of corpuscles, its smallest particles. Laplace termed such an object a *corps obscur*, a "dark body."

However, the thought experiments on the physical world of John Michell and Pierre-Simon de Laplace were largely overlooked and quickly fell into obscurity. In the end, it was Albert Einstein, with his general theory of relativity, who paved the way for the entry of these "dark bodies" into science – albeit not intentionally. Based on his equations published in 1915, he did, indeed, predict the existence of point singularities in which matter and radiation would simply disappear from our world.

But in 1939 Einstein published an article in the journal Annals of Mathematics attempting to disprove the possibility of such black holes. Previously in 1916, however, the astronomer Karl Schwarzschild had calculated the size and behavior of a non-rotating, electrically-charged, static black hole on the basis of general relativity. The Schwarzschild radius of such an object, named after the astronomer, is dependent on its mass and is the boundary beyond which nothing can return. For the Earth, this radius would be approximately one centimeter, or the size of a cherry.

## EXACT SOLUTIONS OF EINSTEIN'S FIELD EQUATIONS

In his short life, Schwarzschild enjoyed rapid scientific success. Born in 1873 in Frankfurt as the oldest of six children of a German-Jewish family, Schwarzschild's talent was evident at an early age. At the age of 16 he published two papers in a renowned journal calculating the orbits of planets and binary stars. His astronomical career went on to take him via Munich, Vienna, and Goettingen to Potsdam, where he became Director of the Astrophysical Observatory in 1909. A few years later, in the middle of World War I – Schwarzschild was an artillery lieutenant on the Eastern Front in Russia – he formulated the exact solutions of Einstein's field equations. He died on 11 May 1916 of an autoimmune skin disease.

But the subject of black holes was initially disregarded by science. Indeed, after the initial hype, interest in Einstein's system of thought waned steadily. This was in the period between the mid-1920s and mid-1950s. After this, in the words of the physicist Clifford Will, "the renaissance of general relativity" occurred.

General relativity became an important means of describing objects that, initially, were the sole preserve of theoreticians, for example, white dwarfs or neutron stars in which matter is present in extreme states. Their unexpected properties could be described using new concepts derived from theory. And this led to black holes also taking center stage. Scientists who studied them became stars – like the English physicist Stephen Hawking, who died in 2018.

In the early 1970s, the satellite *Uhuru* ushered in a new era of observational astronomy. It was launched specifically to survey the sky in the extremely short wavelength X-ray spectrum. *Uhuru* discovered hundreds of sources, mostly neutron stars. Among these, one particular object in the constellation of Cygnus stood out. It was named Cygnus X-1. Astronomers discovered that the X-ray source was associated with a blue supergiant star approximately 30 times the mass of the Sun. It

Photos: akg-images (2)

» Astronomers concluded that approximately 4.5 million solar masses must be concentrated in a region the size of our planetary system.

has an orbital companion of approximately 15 solar masses, and this must be a black hole.

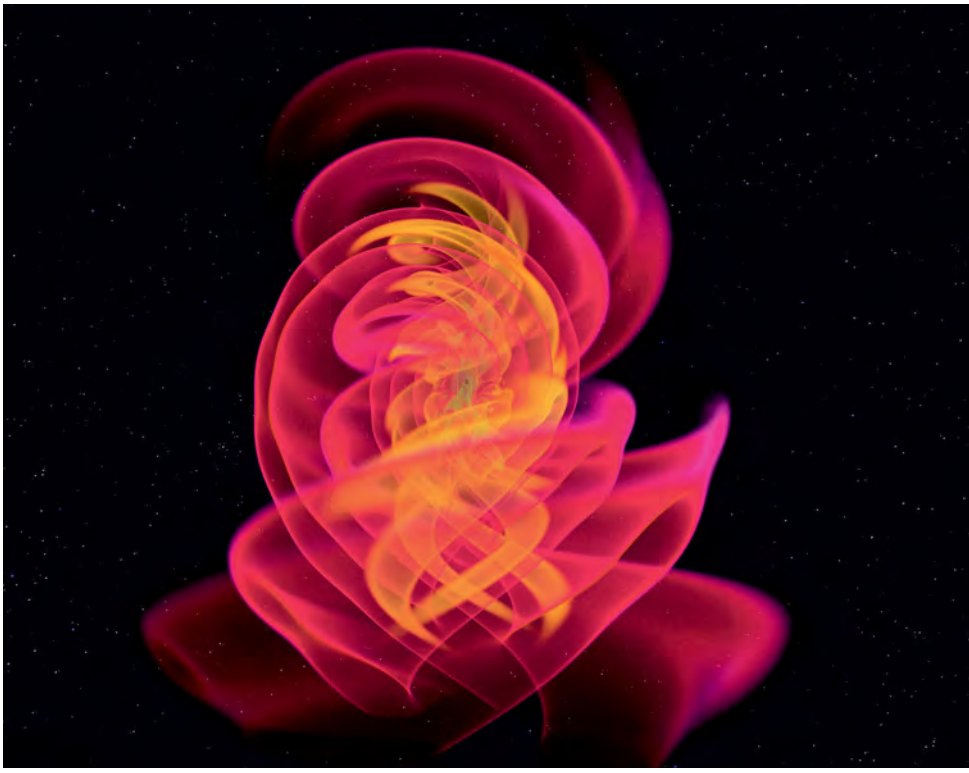
The X-ray emission can be explained by matter falling in toward the black hole due to its gravity. This forms an accretion disk around the companion due to its extreme gravity, swirling around it at unimaginably high speed and heating up to several million degrees due to friction.

Cygnus X-1 is by no means the only black hole that astronomers have indirectly detected. They now know of many, with a mass ranging from four to sixteen solar masses. One, however, is a great deal more massive. It was discovered at the end of the 1990s and resides at the heart of the Milky Way, some 26,000 light years away. In 2002, a group led by Reinhard Genzel from the Max Planck Institute for Extraterrestrial Physics made another sensational discovery. At the Very Large Telescope of the European Southern Observatory (ESO), the scientists made observations of a star that was approaching the center of our galaxy to a distance of only 17 light hours (around 18 billion kilometers).

In the following months and years, they kept track of the orbital motion of this S2 star, as it was termed. It orbits the galaxy's central region, Sagittarius A*, at an average speed of 5,000 kilometers per second and with a period of 15.2 years. The motion of S2 and other stars led astronomers to conclude that some 4.5 million solar masses must be concentrated in a region of space the size of our planetary system. A massively compact mass of that kind can only mean one thing: a gigantic black hole.

Our Milky Way is also not an exception. Scientists believe that such massive monsters lurk in the centers of most galaxies – some even more powerful than Sagittarius A*. The supergiant galaxy Messier 87 has a black hole of about 6.5 billion solar masses! Like Sagittarius A*, this star system, at a distance of approximately 55 million light years, was one of the targets of the Event Horizon Telescope. The team, indeed, have succeeded in their goal. It was announced on 10 April 2019 that they were able to take a picture of its "shadow," an observation which is considered the first direct evidence of a gravity well on a galactic scale.

But black holes had already been making headlines just a few years earlier. In September 2015, scientists confirmed Einstein's prediction of gravitational waves, with the source calculated as the merging of two black holes of 36 and 29 solar masses. The 230-year-old history of black holes is far from over. Instead, these observations mark the beginning of a new era in astronomy, which will shed light on the dark universe – and on the dark monsters that lurk in it. ◀



Ripples in space-time. In 2015, astronomers detected gravitational waves for the first time – the image is based on a "numerical relativity simulation." It depicts two black holes merging deep in space.

Photo: S. Ossokine, A. Buonanno (Max Planck Institute for Gravitational Physics), Simulating eXtreme Spacetimes project, W. Benger (Airborne Hydro Mapping GmbH)

# Fill up the bowl!

Leghold traps, limed rods, pit traps - insectivorous plants have come up with unusual strategies to obtain additional nutrients. **Axel Mithöfer** at the **Max Planck Institute for Chemical Ecology** in Jena is investigating how pitcher plants from Southeast Asia entrap and digest their victims.

TEXT **CATARINA PIETSCHMANN**

Plants that consume animals – imagine coming up with an idea like that! Evolution, though, doesn't suffer from qualms. Pitcher plants are extraordinary and have long been a source of curiosity and flights of fantasy.

Charles Darwin went as far as to dedicate an entire book to these plants, commonly referred to as carnivorous. Of the sundew's trapping mechanism, he wrote: *"It is surprising how minute a particle of any substance, … if placed in actual contact with the surface of a gland, suffices to cause the tentacle to bend. […] It is a much more remarkable fact that when an object, such as a bit of meat or an insect, is placed on the disc of a leaf, as soon as the surrounding tentacles become considerably inflected, their glands pour forth an increased amount of secretion."*

It's not just our fascination with plant carnivores that have attracted us; there are also purely practical ways of using them. In Malaysia, for example, the traps of the pitcher plant, *Nepenthes*, are filled with sticky rice, vegetables, or meat and eaten. On the island of Borneo, old pitchers that have lignified are used as storage vessels for food and drink or for steaming rice.

## FLUID WITH MEDICINAL POWERS

The plants are even said to be good for your health. Indigenous peoples, for example, treat skin inflammations and digestive disorders with the digestive liquid from the pitchers.

Axel Mithöfer also has a practical use for insectivorous plants. "In summer, I place two or three sundew plants next to the fruit bowl. That deals with any problems with fruit flies."

The additional nutrition the plants get from animals helps them to keep up in nutrient-poor environments. That's why, if you have a carnivorous plant at home, you shouldn't fertilize it. "If they can meet their needs for nutrients using their roots, they form fewer traps and instead invest more energy in leaves for photosynthesis," explains Mithöfer.

Of all the insectivorous plants, the Venus flytrap, *Dionaea muscipula*, with its traps reminiscent of leghold traps, is the most spectacular. It is native to North American bogs and is the best known active trapper. The waterwheel plant, *Aldrovanda*, indigenous in Germany but now extinct there, does possess a very similar trapping mechanism to the Venus flytrap. Its leaves, however, are only a few millimeters in size, and the plant grows under water, making it relatively unknown. With its tentacles that twist around its prey, the sundew is also an active trapper.

The Venus flytrap snaps shut on its victims at a surprising speed for a

Photo: Anna Schroll

Under UV light, the trap of a pitcher plant resembles a filigree work of art. Insects are attracted by nectar on the rim of the pitcher and slip into the belly of the trap. The lid prevents rain from diluting the digestive fluid in the trap.

» Chitin receptors signal the presence of prey to the pitcher plants – in the true sense of the word, they taste their food.

plant. Mithöfer gives me a demonstration of the trapping mechanism in the greenhouse of the Max Planck Institute in Jena. He carefully strokes a fine twig over an open trap, touching the tactile trigger hairs inside it a few times. The plant has three of these hairs, barely visible to the naked eye, on each half of the trap leaf.

## STRUGGLING IS DEADLY

The trap snaps shut in a tenth of a second. "If the fly were smart, it would stay motionless for two hours. The trap would then open, and it could fly off," explains Mithöfer. But staying standing still isn't in the nature of flies. Understanding why isn't hard. Caught between the trap leaves, it panics and struggles wildly to free itself.

Each time it touches a trigger hair, it generates a tiny electrical impulse, just like that in a nerve cell. "The plant sums the impulses to determine if it has actually caught living prey, or if only a drop of rain has landed on it," Mithöfer explains. "Two, three contacts are okay. But nine or ten means it's curtains for the fly!" A plant that can actually count!

While the trap leaves squeeze together tightly and crush the insect, the flytrap literally starts to salivate. Acid and digestive juices are secreted from glands in the trap, bathe the prey and dissolve it. The same glands then absorb what the hungry plant lacks in its nutrient-poor habitat: nitrogen and phosphate compounds.

The feast lasts several days. Then the trap unfolds again and spits out the "bones" – the indigestible chitin exoskeleton of the fly. In the wild, the next rain shower washes out the remains of the banquet.

The sundew does things entirely differently. If an insect lands on its leaves, which are covered with fine tentacles, it gets trapped by countless droplets of a sticky liquid. After this, the tentacles at the edge of the leaf first maneuver the animal into the middle of the leaf, where many of the glands that produce digestive juice are located. The leaf then slowly curls over the "meal", and the prey is digested.

There have been multiple independent instances of plants developing ways to consume animals. Depending on the expert you ask, there have been four to nine separate lines of development. The genomes of some species such as of a bladderwort, *Utricularia gibba*, and the Australian Albany pitcher plant, *Cephalotus*, have already been deciphered. In Wuerzburg, researchers are currently working on the genome of the Venus flytrap, and Mithöfer's team already possess that of one pitcher plant species of the genus *Nepenthes*.

## NEW TASKS FOR PROTEINS

From their genes, it's clear that carnivorous plants have important things in common, even if they developed the ability differently. They all use the enzymes that evolution passed them down from their ancestors. "Plants have been exposed to herbivores and pathogens, such as fungi, for 400 million years. And that's the reason why they developed enzymes like chitinases that can break down the cell walls of fungi," said Axel Mithöfer.

It's a fortunate coincidence that the carapace of insects is also made of chitin. Carnivorous plants take advantage of this fact and simply re-deploy their existing tools, turning defensive enzymes into digestive secretions.

They can now use chitinases to break down the chitin shells of insects and get at the nutrients within. The plants get the nitrogen and phosphate from the bodies of the insects using proteins and enzymes that digest nucleic acids.

Mithöfer's particular field of expertise is pitcher plants. There are just over 120 species of the genus *Nepenthes* in

Photos: Anna Schroll (3)

***Above left*** The Venus flytrap has a sophisticated capture mechanism. The leaves have been repurposed as folding traps and contain trigger hairs, which send signals to the plant when an insect is trapped. Within fractions of a second, the two leaf halves snap shut and capture the prey.

***Above right*** The various species of sundew – here the Cape sundew – in contrast rely on sticky traps. Looking like sweet nectar on red flowers glittering in the sunlight, the traps are actually covered with a sticky liquid designed to attract and hold insects.

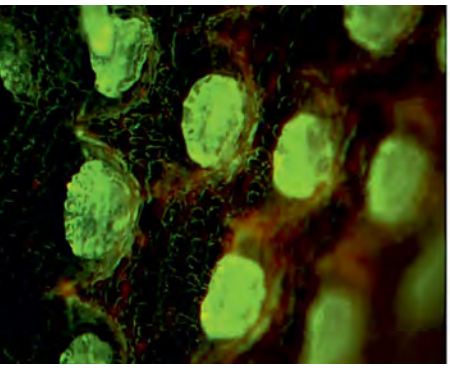
***Below*** Alberto Dávila-Lara is a doctoral student in Axel Mithöfer's research group. The photograph shows him collecting nectar from the rim of a pitcher.

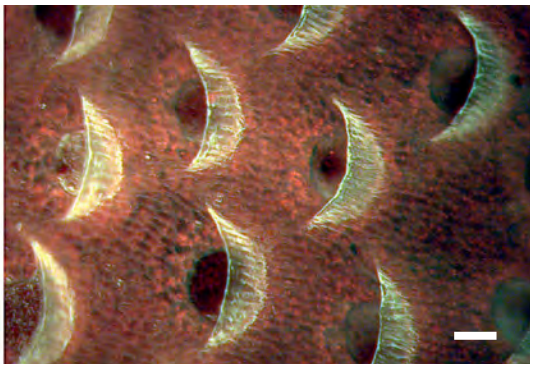
the humid tropical rain forests of Southeast Asia, most of them, climbing plants. Four species of *Nepenthes* grow in the greenhouse of Mithöfer's Institute in Jena.

Pitcher plants primarily prey on soil insects such as ants and termites. After a pitcher has matured and filled to a good quarter with fluid, the lid opens and the "hunting season" commences. At its rim, the pitcher secretes nectar, which becomes exceptionally slippery at high humidity. There's no way of gripping, even using the fine adhesive pads of insects feet. Incautious insects fall and drown in the fluid of the pitcher.

Axel Mithöfer investigates how digestive secretions are generated by feeding the pitchers with fruit flies and then placing nylon socks over them. "We do that to prevent flies from escaping or something else from falling into the pitcher."

And how do the pitchers sense that prey is near? Unlike the Venus flytrap, *Nepenthes* produces chemical rather than electrical signals. The plant's traps probably have receptors for chitin – the substance that forms the carapace of insects. While other plants use recep-



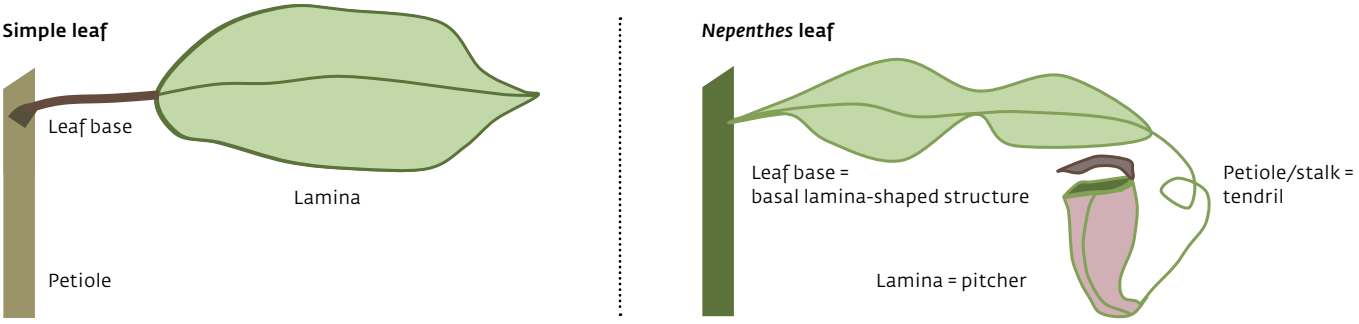


***Above*** Using a sterile syringe, Alberto Dávila-Lara extracts digestive fluid from an unopened pitcher for further analysis.

***Below left*** A fluorescence microscope reveals the glands in the pitcher wall that produce the digestive fluid.

***Below right*** The glands lie in depressions of the epidermis and are covered by protruding hoods (The bar corresponds to one-twentieth of a millimeter).

Photos: Anna Schroll (above), MPI for Chemical Ecology (below, 2)




Metamorphosis from leaf to trap: over the course of evolution, the leaf base of an ordinary leaf in *Nepenthes* has developed into a basal structure and the petiole into the tendril of the pitcher. The leaf lamina eventually developed into the actual trap.

tors to detect predators, pitcher plants use theirs to sense the presence of prey. So, in the true sense of the word, they taste their food.

## CHITIN PROMOTES DIGESTION

"As soon as the receptors detect the chitin of an insect's carapace, a signal cascade is triggered that activates the production of digestive enzymes," says Mithöfer. One of the cascade's most important signaling substances is the phytohormone jasmonic acid, which is also used to defend against predators. The digestive enzymes originate from glands in the lower third of the pitcher. These glands have two functions. "They both exude secretions and also transport the nutrients from the prey into the plant."

Typically, it's in their flowers that plants secrete nectar; *Nepenthes*, on the other hand, generates it at the rims of its pitchers. And the nectar isn't used to attract pollinators, but, instead, to catch prey. Unlike flower nectar, which can contain aromatic substances, pitcher nectar is entirely odorless. Even so, ants and beetles are tremendously attracted to it.

Mithöfer's doctoral student Alberto Dávila-Lara discovered that the rim of pitchers and the dot-like nectar glands on the body of the pitchers are not only sweet, they also glow violet under black light in the laboratory. Chemical analysis of the nectar revealed that this is probably due to a flavonoid. "Maybe it's this glow that attracts the insects," says Mithöfer.

To prove their hypothesis, Mithöfer and his team intend to test the behavior of ants by comparing how they behave presented with natural *Nepenthes* nectar and then with an artificial nectar lacking the flavonoid. To perform the experiment, they plan to fly an entire ant colony, including the queen, from Indonesia to Jena.

The pitcher fluid does already contain small amounts of enzymes before the first prey lands in it. But it can take between two and three days for enough digestive enzymes to form. "*Nepenthes* can take its time; the prey isn't going anywhere. It's a real gourmet!"

Mithöfer's team extracted the fluid from still young, unopened pitchers and discovered potassium chloride, trace elements, digestive enzymes, and naphthoquinones. As soon as the trap has caught something, it produces additional digestive enzymes and acid to activates the enzymes. The naphthoquinones have an antimicrobial effect and probably keep the juice free of germs for as long as possible. If too many insects are caught, the plant can no longer prevent bacteria from proliferating in the pitcher fluid. When this happens, the trap is broken down and discarded.

## LEAVES CONVERTED INTO TRAPS

Even if the pitchers are usually strikingly colored and patterned, they're not the flowers, but elongated, widened, and specialized leaves – a beautiful example of how plant leaves can perform a variety of tasks. They hang from the plants in all stages of development: unripe and closed, active with the lid open, and shriveled and dead. If a pitcher is incapable of consuming food, it is usually only discarded when the plant has extracted as many nutrients as possible from it. A pitcher plant, after all, doesn't have resources to spare.

Not all carnivorous plants catch their own food. Some have a "delivery service" and reward the couriers with sweet rewards. There are also *Nepenthes* species that provide shelter for ants. They live sheltered in cavities of the pitcher plant and, in return, defend their landlady against predators. They themselves are unaffected by the digestive juices, which they simply swim through. >

Graphic: MPI for Chemical Ecology

Axel Mithöfer is investigating the signal cascades used by plants to protect themselves from predators and pathogens. Insectivorous plants have modified some of the molecules in the cascades to turn themselves into predators. A bushy angelica grows in the tea room of Mithöfer's research group, but … it wouldn't harm a fly.

The plant also benefits from extracting the valuable nutrients from the waste material of the ants. In some instances, this type of nutrition can take on bizzare forms. "On the island of Borneo, tree shrews and rats sit on the rim of particularly large pitchers of certain *Nepenthes* species, lick sweet nectar from the inner surface of the lid – and simultaneously release their droppings into the pitcher. Another *Nepenthes* species provides daytime shelter for bats, whose excrement they then utilize," Mithöfer explains.

Besides carnivores and excrement feeders, pitcher plants can even be herbivores. *Nepenthes ampullaria* with its large pitcher openings, for example, waits for leaves to fall into its pitcher.

A plant that, during the course of evolution, consumes first light, then animals, and finally other plants – could there be any better way of demonstrating nature's almost infinite versatility? ◂


## SUMMARY

- **There have been multiple instances of plant species independently evolving as carnivores to consume insects.**
- **Few plants species have evolved the ability to eat insects as new inventions; instead, they have tended to repurpose existing tools.**
- **Pitcher plants do not attract insects with the smell of the nectar they secrete on the rim of their pitchers. Instead, the nectar reflects ultraviolet light, and this is probably what attracts insects.**


## GLOSSARY

**Pitcher plants:** At present about 120 *Nepenthes* species are known, and researchers are still discovering new species. Their range extends from Madagascar to New Caledonia and from China to Northern Australia. The leaves consist of a leaf base, a tendril, and the actual pitcher trap. Some species have traps up to 50 centimeters in size. Many *Nepenthes* species are threatened with extinction due to loss of habitat and illegal trade.

**Venus flytrap:** The traps of these carnivorous plants capture insects by snapping shut on them, after which they begin by exposing them to hydrochloric acid from gland cells. After a delay of a few hours, the glands also release digestive enzymes. The broken down nutrients are then absorbed by the same glands. These glands, are therefore similar in function to roots. This explains why only those genes that are typical for both leaves and roots are active in the trap cells.

Photo: Anna Schroll

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# Programming **fairness**

In the future, it will be more and more common for computers to make decisions about human beings – whether they are granting loans or assessing applicants. However, it happens occasionally that the automated systems that are already in use discriminate against certain groups of people. **Niki Kilbertus** and **Bernhard Schölkopf**, researchers at the **Max Planck Institute for Intelligent Systems** in Tuebingen, want to change this by developing fair algorithms.

TEXT **TIM SCHRÖDER**

Several blackboards are dotted around the hallways of the Max Planck Institute for Intelligent Systems in Tuebingen. Scientists walking past can use these to note down their thoughts. They are also places for researchers who happen to meet in the corridors to discuss new ideas. "It's really helpful," says Niki Kilbertus, "because I have to develop so many ideas right now." He is referring to concepts that go far beyond those he has dealt with in the past. Niki Kilbertus has degrees in mathematics and physics. He is familiar with the rigorous formal methods for solving complex matters, and he knows how to program algorithms. For his doctorate, however, he has ventured beyond the boundaries of formal languages. He is addressing a question that has been the subject of heated public debate for a while now: whether and to what extent algorithms can be fair.

Balanced calculation: algorithms must not discriminate against particular groups of people, such as women or men.

Photo: Alamy

Computers are sober machines that are incorruptible and are never wrong – or so one might think. Nevertheless, debate about computer algorithms discriminating against people flared up at the end of 2018. It had become known that a large online retailer was planning to use a computer for pre-screening applicants, and that it had emerged even in the trial phase that the computer was more likely to reject applications received from women than those from men. This led to an outcry in the media, not least because experts envisage that in the future, computers will be making decisions about human beings more and more often, using vast amounts of data that are now available. It would be scandalous if these computers favored or discriminated against particular groups of people.

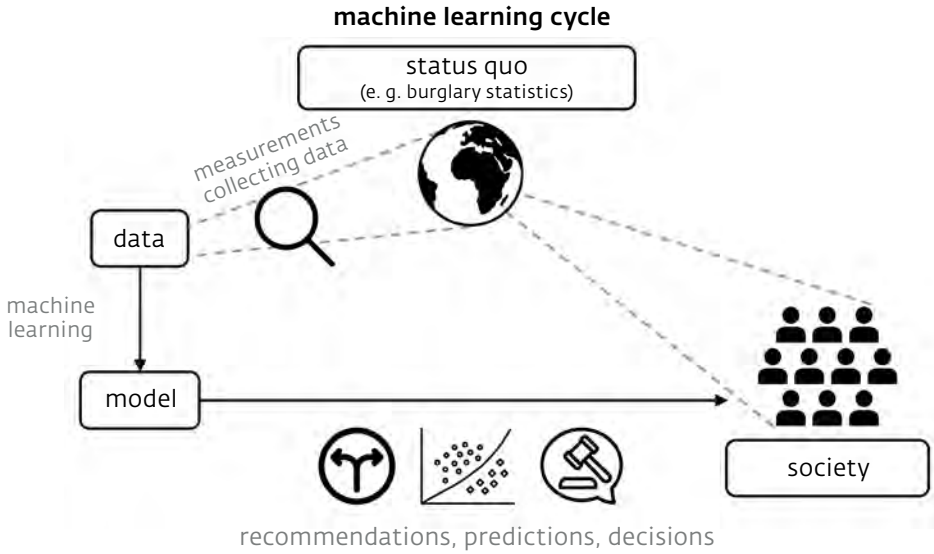
Initiatives have been formed around the world in light of such scenarios, promoting fairness in artificial intelligence. This is not their only concern, they also demand that companies must be held accountable for their algorithms, calling for responsibility and accountability. Critics also expect transparency when it comes to how and why particular decisions are made based on calculation specifications. The community is called FAT: fairness, accountability, transparency.

## ANY DISCRIMINATION MUST BE ANALYZED CAREFULLY

Niki Kilbertus is a doctoral student in the Cambridge-Tuebingen-Program run by the Max Planck Society, and works at the Max Planck Institute in Tuebingen as well as at Pembroke College in Cambridge. He and his colleagues are exploring the part of FAT that can be translated into technology: the researchers strive to teach fairness to algorithms. To do so, they rely on machine learning. This means that they enable the computer to gradually improve through learning and experience.

It is a challenging task. So far there is no technical solution that allows for fairness to be instantly realized across all applications. It is likely that this is not going to change in the future either: "There can be no solution that answers every possible question. Each situation is different, and needs to be analyzed separately," says Kilbertus. "And the second step is at least as elaborate: we need to find a mathematical description for the real-world problem."

The algorithmic analysis process always follows a clear formula: data is collected and fed into an analysis program, whose algorithms will then issue a recommendation such as "applicant not suitable". To ensure that this automated process is always fair in the future, it would need to be improved on both the data and the output side. >




"First, you need to examine which data is collected, and how, and then check which decisions are finally issued by the computer, and the reasons behind them," explains Niki Kilbertus. These analyses always touch on data protection issues as well. "This is always about sensitive personal data, after all. This means that we also need to find solutions for analyzing data without disclosing it."

The young researcher is part of the working group led by Bernhard Schölkopf, Director of the Max Planck Institute for Intelligent Systems in Tuebingen. Both researchers deal with the basic issue of causality in machine learning: the question as to what extent computers can draw meaningful conclusions between different aspects. This very question is also a central aspect when it comes to the issue of fairness.

Niki Kilbertus has an example: the granting of loans and checking of creditworthiness. Things can get critical if simple algorithms are used that are based purely on correlations "if X, then Y relationships". If residents of a particular city district were less likely in the past to pay back their loans, the algorithm could, for example, use the place of residence as an indicator for future applicants. The algorithm does not understand in this context that the place of residence is unlikely to have a direct causal impact on creditworthiness, and that there are likely to be other, more relevant factors at play.

## THE ALGORITHM WOULD NEED TO VERIFY ITS ASSUMPTIONS

Systems are often trained using historic data about credit repayment behavior. Personal data, such as the place of residence of a new applicant, are then used to calculate their creditworthiness: how likely is it that the applicant is going to pay back their loan? However, the computer may unintentionally discriminate against individuals, since a creditworthy person might live in an area to which the algorithm attributes a poor reputation.

"The algorithm would basically need to be equipped to verify its as-

***Above*** Real-life feedback: a machine learning algorithm solves a question, such as which neighborhoods are likely to experience a lot of burglaries. For this purpose it is trained using data about the status quo, for example, data regarding the economic and social situation, and crime rates. The algorithm then develops a model, based on which it issues predictions, decisions, or recommendations. If criminal acts are then prevented in a particular neighborhood due to increased police presence, society and thus the state of the world is changed. The algorithm then has to adjust the model based on new data.

***Right*** Freedom for ideas: Mateo Rojas-Carulla, Niki Kilbertus, and Nadine Rüegg (left to right) are discussing various aspects of artificial intelligence.

Graphic: MPI for Intelligent Systems

Photo: P. Junker / MPI for Intelligent Systems

sumptions on a regular basis," says Niki Kilbertus. For example, by using specific criteria to occasionally grant a loan to an individual that is initially not rated as creditworthy. Economists refer to this approach as *explore versus exploit*. To *explore* is to test new solutions in this context. To *exploit*, on the other hand, is to utilize an existing approach as effectively as possible, to avoid the effort required for a new development, for example. In the case of granting loans, the *explore* approach would provide for loans to be occasionally approved contrary to the original rules. If the person turns out to pay back the loan after all, the algorithm has to be adjusted and improved.

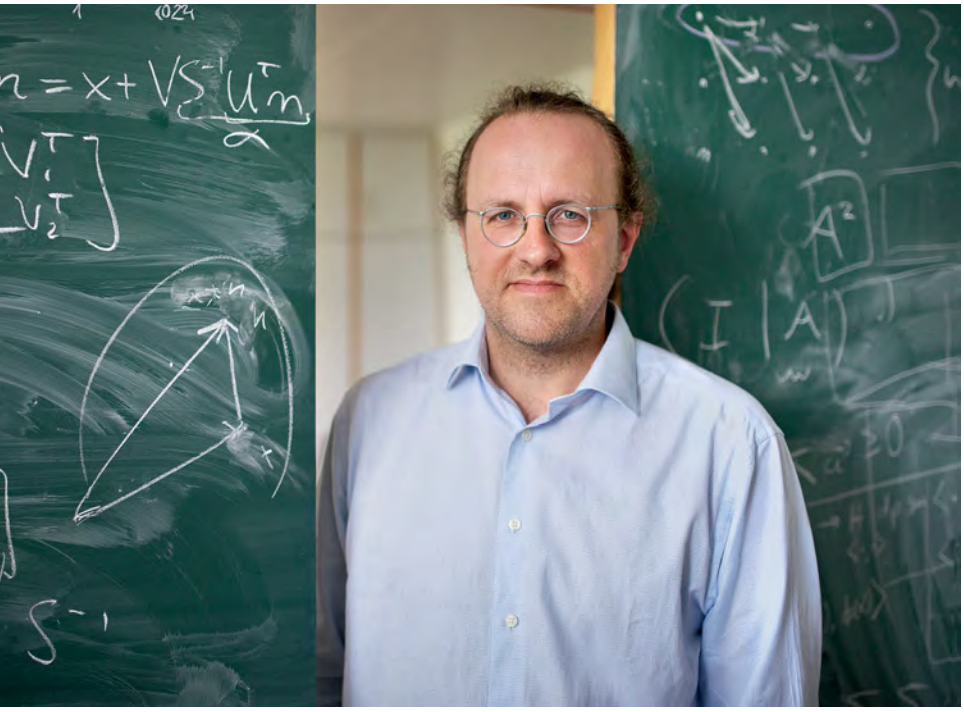
This example shows that in some cases, the data that is currently used is not sufficient in order to make fair decisions. Niki Kilbertus: "When it comes to fairness, the challenge is to discover and understand the true causal structure underlying the data as far as possible." This approach is intended to prevent an algorithm from considering data as being merely a table of figures among which it can happily establish correlations that are often likely to have nothing to do with the true causal connections.

## TRUE CAUSAL CONNECTIONS ARE KEY

Niki Kilbertus uses a far-fetched example to illustrate this point. An algorithm could detect that people who are more likely to repay their loans tend to be tidier and more likely to stick felt gliders under the chairs in their home. A calculation specification does not per se understand correlations, so it may conclude that it is a good idea to give a pack of felt gliders to new borrowers in order to increase their creditworthiness. "We need to understand the causal connections to be able to ask any meaningful questions, such as whether the individual would have repaid the loan if they had lived elsewhere," says Niki Kilbertus. By contrast, incorrect causalities such as the link between possessing felt gliders and repayment behavior could be eliminated.

Simpson's paradox is another illustration of the importance of correct identification of causal connections. It was named after the British statistician Edward H. Simpson, who demonstrated in the 1950s that a particular combination of data from different groups, such as women and men, will give rise to seemingly paradox situations. One classic example of a Simpson's paradox dates back to 1973. There was a sense of outrage at the time, when out of the women who had applied for a place at the University of California in Berkeley in the U.S., a smaller percentage had been accepted to take up studies than was the case for male applicants.

It turned out, however, that this was not a case of discrimination. An analysis of the data conducted later on showed that more women had registered for extremely popular subjects in the fields of humanities and social sciences. They were therefore on the whole rejected more often than men, who more frequently applied for less sought-after subjects such as chemistry or engineering. The paradox was that



Teaching machines: Bernhard Schölkopf teaches algorithms to recognize true causal connections among data. This also promotes fairness of decisions made by computers.

for each Department in isolation the percentage of women accepted for most courses of study was even higher than that of accepted male applicants. However, across all disciplines, the proportion of male applicants that were accepted was slightly higher. "To understand the causal connection correctly, we first need to have the right data and to know which Department the women applied for. Gender has an impact on the choice of subject. Only then are we able to correctly interpret the situation," says Kilbertus.

Bernhard Schölkopf even goes a step farther when it comes to the issue of correct causalities. He also addresses the question "where does fairness begin?" Does it begin with asking whether African-American applicants have the same opportunities in the U.S. as their white competitors? "Or do you have to go back further, and take into account the fact that colored children do not have the same educational opportunities as white children, and that this has an impact on their entire résumé and their future job prospects?" Schölkopf raises the question of whether aspects like this should also be included to create truly fair calculation specifications. An algorithm with multiple levels of fairness so to speak.

## EVEN PEOPLE ARE NOT ALWAYS FAIR

Nevertheless, he also points out that we should not get carried away too easily. "People make decisions about other people every day. It is often completely unclear why an individual makes a certain decision. At the same time, we demand that an algorithm must always make decisions that are one hundred percent correct and fair." At the end of the day, studying fairness in machines also leads to the insight that human beings are also not always fair. Quite simply, we make mistakes, for example due to a lack of information or experience. Much like machines. A dermatologist for example, who spent their entire career screening only light-skinned people for skin cancer, may be more likely to mis-diagnose dark-skinned people, and to possibly overlook a tumor. This means that dark-skinned people would not receive the same quality of treatment as light-skinned people. However, the supposed unfairness can be explained by the fact that the doctor is lacking experience in working with particular groups of patients.

Whether an algorithm is going to make fair decisions in the future also depends on how companies or people in general define or perceive fairness. "The ultimate goal is that an algorithm should always make the right decision," says Niki Kilbertus. "But first we have to clarify for each case what right even means."

There is something else that needs to be taken into account: decisions made by computers can have an active impact on the world. One example of this are modern programs that use data about cases of burglary and theft in a city to determine which neighborhoods are most likely to experience further burglaries. The algorithm's statement will then lead to increased police presence in these areas, and possibly to an increase of crimes detected. It is conceivable, however, that it was not actually the case that more criminal offenses were committed in these neighborhoods. Possibly, it was simply that more crimes were detected because the police patroled these areas more frequently.

"The decisions based on an algorithm can therefore lead to wrong conclusions. We refer to this as a feedback loop, in which the algorithm has an impact on real life." Another similar example are traffic warnings issued by navigation services. If a road is busy, the service will recommend switching to other routes, and after a short while,

Photo: Wolfram Scheible

traffic will build up on these routes. This is why Niki Kilbertus points out that it is important to keep not only fairness in mind, but also possible feedback effects.

In the context of his doctorate, he has analyzed a number of cases of discrimination and made initial attempts to describe the respective problems mathematically. "Programming takes at least as much time again as analyzing each case." And yet for the time being, he and his colleagues are focusing mostly on analysis. "Each algorithm works based on specific criteria that are used to derive a statement. We are now trying to find out where the criteria fail; to find the weak point."

An interesting question in this context is why the algorithm by the online retailer mentioned above seems to have discriminated against female applicants. It is unknown how the algorithm works in any detail, but Kilbertus has a hunch. "It is fair to assume that they set out to analyze the applications in an anonymized form." So the system would not have known the applicants' names or their gender. Nevertheless, the system failed. "Other studies have shown that women tend to mention social commitment or related activities in their applications, while men are more likely to signal dominance and to come across as more competitive," Kilbertus explains. "These aspects could be the very characteristics that the company is looking for." As Bernhard Schölkopf points out: "It is incorrect to assume that we can generally achieve fairness, by withholding certain details such as gender from the algorithm." This *fairness by unawareness* approach is far from infallible.

Whichever way fairness might be taught to algorithms, it is a rather soft criterion compared to the purely mathematic formalisms Niki Kilbertus used to deal with in the past. While he does appreciate being able to produce clear evidence for or against a statement, he also finds this new aspect very rewarding. "It is interesting to work on an issue of such social relevance," he says. He soon realized that knowledge in the fields of mathematics and computer sciences is not enough for his research work. So he decided to learn about social sciences and legal issues. He hopes that he is now well-equipped for finding truly fair algorithms. ◂


## SUMMARY

- **Algorithms make decisions about human beings more and more often. Discrimination occurs time and again in this context, not least because incorrect causal connections are established from data, such as links between an individual's place of residence and their creditworthiness.**
- **In their endeavor to teach fairness to algorithms, the researchers at the Max Planck Institute for Intelligent Systems in Tuebingen analyze the data used by the calculation specification and how decisions are made in each individual case.**
- **Based on their findings concerning true causal connections that provide answers to questions such as "Which person is going to pay back a loan?", the researchers are drafting mathematical descriptions for the respective issues at hand.**

# The art of **orientation**

Every city map, and every map in general, contains stories about the time at which it was produced. At the **Bibliotheca Hertziana, Max-Planck-Institut für Kunstgeschichte** in Rome, art historian **Tanja Michalsky** is studying how people have measured the world. Her research is expanding the area covered by her subject and even includes films by Federico Fellini and David Lynch.

TEXT **MARTIN TSCHECHNE**

From the roof of the library, the city unravels like a to-scale map. Fantastical maps of this kind have been contrived by novelists such as Umberto Eco, while others, including Jorges Luis Borges and Michael Ende, have created images that conform entirely to reality but must be understood as a paradox and nothing more than an idea. In this realm, literature enjoys almost unlimited freedom. Here, however, the observer is presented with a work of art in real life, as though spread out for study purposes: an undulating sea of roofs and gables, towers and churches protruding out from them with the cupola of Saint Peter straight ahead – a bright spot just in front of the horizon. From the right, the Palace of Justice thrusts itself like a limestone gray bar in front of an entire city district.

Tanja Michalsky steps onto the terrace of the Bibliotheca Hertziana and lets her gaze wander. To the left, in the south, the monumental column structure of the national monument to Vittorio Emanuele II towers over a former empire. It is a temple built according to the Greek model and is less than a century old. My host's extended arm picks out the Pantheon and Trajan's Column from the swirling mix of different epochs – triumphal remnants of Roman antiquity. Far below on the Via Gregoriana, the narrow street in front of the building, cars and rattling Vespas push their way between the people walking by. This is Rome, in the spring of 2019. The present day. A courtyard opens out on the opposite side, and from the vantage point of the high-up research Institute, a roof garden can also be seen, with a rusty railing running between red bricks, chairs, a rotary clothes dryer, and a few pots with sprawling green plants.

## ROME IS A JUXTAPOSITION OF ASYNCHRONICITIES

These places of retreat span the city like a cobweb. Has anyone ever recorded them on a map? Has anyone recognized them as a further layer, high above the places that have sunk and been buried, the antique, medieval and the modern, the commercial and representative levels of life? They would tell of warm evenings under the stars, of the yearning to ascend beyond long-gone eras, at least for a while.. Did this city actually exist before it was invented by Federico Fellini? Or did the great director merely create a perfect image of it with films such as "Roma" or "La dolce vita"?

"Go to the Fontana di Trevi," the art historian advises me. "Experience the crowds. And ask yourself what the idea is that makes so many people want to go there." Day and night, the police are on hand to prevent visiting couples from climbing over the edge of the baroque fountain into the light blue water kissing as passionately as Anita Ekberg and Marcello Mastroianni did in Fellini's 1960 classic, with its story of the sweet life of Rome's elite. "However," Michalsky adds, "everyone, absolutely everyone, throws a coin into the basin to make a wish for the future and to make sure they will return to this place one day."

It is precisely this juxtaposition of asynchronicities, the researcher explains, that not only determines the feel of the city, but also provides the topic and direction for her work. "Here in Rome, art didn't have to invent

Photo: Bernd Wannenmacher

Own direction:
Tanja Michalsky is taking art history research into unknown regions.

everything for the first time," she says, explaining the starting point for her research. "There was so much that was already there!" What emerges from this in relation to the structures and practices of her craft is that everyone needs to lay down paths, to follow trails, and to define contexts. And with each step on one level of time, to avoid losing sight of the others.

Tanja Michalsky grew up in Duisburg, and occasionally, you can hear that she comes from the "Ruhrpott" region. What meaning does such an accent have? Is there an intention behind it? She wears jeans and flat shoes, her light blond hair is cut short, and she has a direct manner about her. Anyone who wants to tell a story in a new and different way should refrain from allowing themselves to be easily cowed. She adds that her husband, Klaus Krüger, Professor of Art History at the Freie Universität Berlin and a specialist in Italian art from the medieval and early modern periods, is currently in town buying a new battery for their car. A Cinquecento? "No," says Michalsky, "a Toyota." Everyday life is banal, even in Rome. The traffic moves tortuously through the city, it's loud, and the garbage hasn't been collected for a long time. All this is registered by the art historian.

Three years ago, she returned to the Max-Planck-Institut für Kunstgeschichte in Rome as its Director. During the 1990s, she used Rome as a base from which to explore the tombs of the Angevin kings in Naples for her dissertation. She scratched the earth from stone plates and deciphered weathered inscriptions in order to locate a medieval French dynasty in the sheer unending chain of foreign rulers of Naples, and to identify the complex interactions between local and imported cultures.

## THIS HAD TO DO WITH POWER POLITICS, NOT PURGATORY

"How do you interpret strange artifacts from past eras?" she says, by way of describing the main focus of her project in her own casual, trenchant way. "And what makes a tomb such an important witness to a political situation?" She must have enjoyed the work. By the time she had finished her investigative detective work putting the pieces of the puzzle together, she had a solid result: "This had nothing to do with 'save me from purgatory' – that was the least of their concerns! The memorial culture of the Middle Ages focuses mainly on reinforcing and securing one's own genealogy. Pure power politics."

And what about the art? The art historian gives her routine answer. The popes, the Curia returning from Avignon in the early 15th century, who felt an urgent need to present to the world at large the beginning of a new, refined era, and the protagonists of this new dawn being heroic figures such as Leonardo, Michelangelo or Raphael, were all great material for her subject field. The successes of the researchers at the Institute, which was founded in 1913 by the patron Henriette Hertz, were spectacular – covering antiquity, the heroes of the Renaissance, the illustrious art and architecture of the Baroque period. And it isn't that long ago that her predecessor, Sybille Ebert-Schifferer, saved the world from a flood of paintings that were falsely ascribed to the great Baroque painter Caravaggio.

Yet Tanja Michalsky is steering her work in a new direction. It is a myth, she claims, that Rome lay dormant for a thousand long years, that it was a field of rubble with almost no inhabitants, a great city of years gone by waiting to be finally kissed awake again. And she refers to Erwin Panofsky, who himself is something of a hero among art historians. His groundbreaking book "The Renaissance and Renascences in Western Art", published in 1960, toppled several myths. Note the plural form! Even Charlemagne was already quoting ideas and examples from antiquity and referred to them in order to present himself as the emperor of a – nota bene – Roman Empire of the German Nation.

"There was in fact not just one Renaissance," the Director of the Institute in Rome explains. "There were several: a Carolingian Renaissance and another Renaissance during the 13th century, to name just the most important ones. Unfortunately, we are not so familiar with the names." For this reason, she talks of appropriations of antique cul-

Photo: Enrico Fontolan/Bibliotheca Hertziana

Best outlook: the roof terrace of the Bibliotheca Hertziana opens up a view over the rooftops of Rome, with the cupola of the San Carlo al Corso church (left), the national monument to Vittorio Emanuele II (white monumental building, center) and the cupola of St. Peter's cathedral (right).

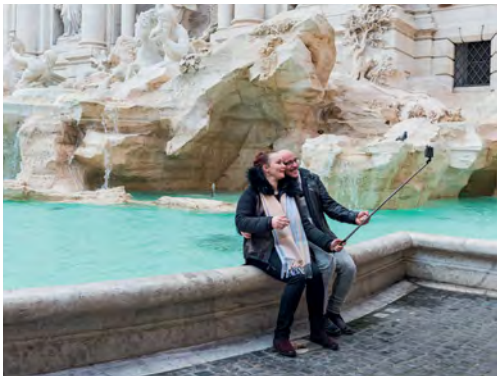
ture – and by this, she means the techniques and results of the appropriation, rather than a historical event. The statues and buildings from antiquity were already there, after all. They were part of everyday life. Anyone could observe and study them. And many people did just that.

In other words, more Middle Ages. More present-day. And a greater awareness of the migration of people and culture, of the multifaceted links between the Italian south and the rest of Europe and the world, which she experienced in such concentrated form in Naples. Anyone who wants to study the history of a city, the ultimate embodiment of urbanity, must be prepared to peel away one by one the many layers it contains, to filter all the ingredients of this amalgam and to reconstruct the way they fit together: Angevin tombstones and Greek columns, Goths, Hohenstaufen, Spanish and Bourbons, national monuments and roof gardens. She has spent long enough scraping away at these hidden, overgrown, weathered links. And the same principle applies to Rome as it does to all cities.

That's why, together with Tristan Weddigen, the second Director of the Bibliotheca Hertziana, she decided to expand the Institute's program to cover earlier eras and places beyond the south of Italy, and to connect all this with the present day. Tanja Michalsky loves taking the discussion forward to as yet unknown regions, where there are new discoveries waiting to be made.

As a result, the desk in her office is now full of medieval city maps. On the bookshelf behind it, there are DVDs with classic films by Fellini or the enigmatic levels of reality created by David Lynch, that are layered like gossamer-thin films. In "Lost Highway", the mysterious expedition into film as a medium, hunted by dark fantasies, the art historian sees a model for research in her own field of activity. From Rome, colleagues explore the face of Europe beyond Europe, reconstruct the global network of Italian art since the early modern era, and seek out the mutual exchange between directors and producers from the Cinecittà film studios. And through all this work, they come considerably closer to the complex nature of this city.

The layers of urban life, the links between eras and cultures, the open and hidden motifs of any reduction of reality... Was it not wonderfully ironic that half an hour previously, the journey to the Institute on the Pincio on the edge of the inner city already gave an indication of the complex interplay between reality and fiction? Rome is built on hills, and some roads wind uphill in



Source of longing: since Federico Fellini immortalized the Fontana di Trevi in his film "La dolce vita", with Anita Ekberg and Marcello Mastroianni, the fountain has become one of the major tourist attractions in Rome.

Photos: picture alliance/KEYSTONE (center); averess/Alamy stock photo (below)

broad curves. The helpful porter in the hotel took out one of those handy city maps designed for tourists and marked two crosses on it: this is where you are, and this is where you want to go.

However, the map did not show the many narrow streets and passages. Junctions and crossroads were incorrectly placed, even for larger roads, and the proportions were distorted. Yet on the uniform light red color depicting built-on areas, there was enough space to mark out a bar, a pizzeria or a moped hire service. The people who published the map had paid for this manipulation of reality from their advertising budget. And, as could be seen from the map, tourists were not encouraged to wander through the city without any orientation points, but to seek out shops and generate turnover. Isn't that appalling?

## EVERY MAP IS AN ABBREVIATION OF REALITY

Tanja Michalsky has to laugh. "Look," she says, and opens up the computer in her office, a few floors below the roof terrace. A map of the City of Rome by Paolino Minorita from the early 14th century appears. The representation of a constantly changing world has been a subject of interest for the art historian since she studied Dutch landscape painting as part of her extended post-doctoral qualification period, which is required for a full university professorship. And the cartographic systems of symbols are one way of documenting this world.

From the conquest of spaces, the growing ability to record and depict a place on the basis of its topographical data, progress in abstraction and earlier attempts at creating a bird's eye view through to a GPS satellite image which is accurate down to the last centimeter – all this can be read from just one map. However, at the same time, the scientist warns against systematic distortions inherent to the medium, the errors and temptations. "Every map is an abbreviation of reality," she says, in summary. "And every abbreviation is made for a reason." Sometimes, the reason is a bad one, and sometimes, it is simply bland commercialism.

An informative map: the map of Rome drawn around 700 years ago by Paolino Minorita shows among other things that at that time, the view was directed eastwards, towards the orient – hence the term "orientation".

Paolino Minorita: Cronologia magna, Venice, Biblioteca Marciana, Lat. Z. 399 (=1600), fol. 98.

This Paolino Minorita would have been an honest man. He even registered the city's hills on his map as a lateral view, since it would be another few centuries before the realization took hold that peaks and ridges look very different when viewed from above than from the familiar perspective. The method of drawing them on a map on the basis of altitude lines originated in Switzerland. Tanja Michalsky grins when she points out where it came from. She gets pleasure from such choice new items of information. Of course, the Swiss, who else! The history of cartography has its very own stories to tell.

The cartographer of Rome during the late Middle Ages drew a network of streets and aqueducts; the Pantheon is recognizable from its classical columned portal, as is the Castel Sant' Angelo and with a certain amount of imagination, the Colosseum. The scientist's finger moves swiftly over the map as though it were her present that was recorded here 700 years ago. The author presented a dramatic composition, and every place has a role to play in telling the story of the city. Paolino linked the topographical anchor to other representation levels using explanatory texts, as though he had wanted to develop a medieval computer app.

The difference between this and the road map of the present, which brazenly brings the advertising targets into focus, is not that great. It's nice to see the wide river, which is clearly the Tiber. Instead of winding its way southwards through the city in the familiar way, it runs horizontally over the map. However, she is quick to provide an explanation: "The habit of always orienting our image of the world to the north only came about much later, in the 17th century," she explains. "Before, the view was directed eastwards, towards the orient – hence the word 'orientation'."

Incidentally, it would not be at all difficult to find your way around, even with a bad map. The Institute is located at the upper end of the Spanish Steps. It's impossible to lose your way. Everyone knows where it is.

All this can be seen from above on the roof terrace. All the connections appear to be a final statement of truth.

A view of different eras: in her research, Tanja Michalsky studies medieval city maps and contemporary feature films as part of her research.

Tanja Michalsky refers to the maps over which Eco, Borges and Ende spread their fantastical, unrealizable concept of total representation. She only needs to turn around to shift her gaze from the wide horizon of the city and down into the machine rooms of art history research as though through a funnel.

## AN ATMOSPHERE OF CHEERFUL CONCENTRATION PREVAILS

Eight years ago, the Spanish architect Juan Navarro Baldeweg inserted a new building there, exactly above the garden of the legendary military commander and host Lucius Licinius Lucullus from 60 B.C., in the middle of the ensemble surrounding the 16th century Palazzo Zuccari. It cannot be seen from the road, but it is spacious enough to hold the 360,000 or so library volumes, around 870,000 carefully preserved and documented photographs from the art history collection, and 90 generous workspaces layered in a terrace structure. There are researchers there at all times. There is an atmosphere of cheerful, relaxed concentration. After all, the rule applies without exception that no book ever leaves the building. Never.

The new Director arrives when everything had been completed. Her predecessors had endured the stressful task of planning and building the library. The scholar knows how fortunate she is. She can turn her attention to the actual purpose of the Institute with almost no distractions: carefully uncovering the history of art and culture layer by layer. Expanding her horizon, promoting meetings and initiating exchange. New levels of cooperation are also emerging with the Max-Planck-Institut für Kunstgeschichte in Florence. Science and the movement of knowledge can no longer be defined by borders. Sometimes, she is worried that the generous space allotted to the depots might one day be inadequate. "We must conduct research," she says, while quietly struggling with the name of her Institute, which occasionally leads to false expectations: "We are not a library, but we do have one."

She has just re-read Stefan Zweig, with his biographical sketch of the Italian merchant and seafarer Amerigo Vespucci. The historiographer wrote that while he did not discover America, he did realize that it was America, which was something that the cartographers of his time were still only hesitantly dabbing in. As Tanja Michalsky says: "Maps create spaces. Their neutrality is a fiction." And she warns against the precision of satellite location, since their photographs, too, are still only images. And this means that they are always the means of transportation for a story. ◂

Photo: Marieke von Bernstorff

# A method that lends wings

Mathematician **Irmgard Flügge-Lotz** was one of the first female researchers in the field of aerodynamics and automatic control. While working at the **Kaiser Wilhelm Institute for Flow Research**, she succeeded in simplifying the calculations required for aircraft construction. Flügge-Lotz was later appointed the first female Professor of Engineering at Stanford University. In the U.S., her work is still held in high esteem. In Germany, however, she has been all but forgotten.

TEXT **KATJA ENGEL**

Goettingen, 1931. Leading flow researcher Ludwig Prandtl was astonished. His colleague, at 28 just half his age, had just handed him the solution to a mathematical puzzle that nobody had been able to crack for more than ten years. This conundrum was on his "menu", as he called his list of uncompleted research tasks. The result went down in the history of aerodynamic research together with the young researcher's name. The "Lotz method" makes it possible to calculate the lift on an airplane wing with comparative ease.

Prandtl soon made the woman who had so impressed him an (unofficial) Head of Department at the Aerodynamische Versuchsanstalt (AVA, now the German Aerospace Center), part of the Kaiser Wilhelm Institute for Flow Research in Goettingen. This marked the start of Irmgard Lotz's career as an internationally renowned aerodynamics expert and control engineer. Yet before 1960, when she became the first female Professor of Engineering at Stanford University, her scientific career was anything but meteoric.

A model teacher and researcher: Irmgard Flügge-Lotz was popular with colleagues and students alike.

Irmgard Lotz was born on 16 July 1903 in Hameln. This was the year in which the Wright brothers in the U.S. set a milestone in the development of aeronautics. Working in a wooden shed, the two bicycle mechanics built their "Flyer", one of the first motorized aircraft that was really capable of flying. This was another step forward in the development of the airplane, which at that time was progressing with impressive speed. However, this was still the era of inventors. There was one thing that these bold pioneers of the skies did not manage to do: they were unable to explain the mysterious forces that enable an aircraft to ascend despite being several thousand kilograms heavier than air.

While aeronautic research was also making rapid strides by the end of World War I, these advances were more theoretical in nature. Wing profiles – a major factor in aircraft construction – could only be tested by means of complex wind tunnel measurements. Ludwig Prandtl, who is generally thought to be the founder of aircraft aerodynamics, and his team in Goettingen carried out pioneering work on the theoretical description of lift. However, mathematical calculations of his wing theory turned out to be difficult. In 1919, Albert Betz, a doctoral student in Goettingen who was later to become Prandtl's successor at the Institute, finally succeeded in the describing lift by means of differential equations. However, his formulae were too complex for practical use when constructing new profiles. Expensive wind tunnel testing was still required to show the aerodynamic flow around various wing shapes and determine when turbulence would occur. Moreover, reckoners with slide rules would have to spend days solving the equations – at that time still traditionally a woman's task. In all, the procedure was unserviceable for purposes of practical aircraft design.

For more than ten years, mathematical descriptions were the biggest obstacle standing in the way of the practical application of wing theory – until Irmgard Lotz developed her method of calculation and astonished Prandtl. "An expert reckoner can calculate the necessary odd and even coefficients […] in just 2 ½ hours," she wrote in the Zeitschrift für Flugtechnik und Motorluftschiffahrt, the journal which published her method. It was the long-sought solution that closed the gap between theory and practice. Engineers were now able to calculate the requirements for better-performing wings before the construction work began.

Prandtl's appointment of Irmgard Lotz in 1929 as the only woman in his team of 25 at the AVA paid off. This was not a new situation for her. She was the only woman at the Technical University of Hanover to be awarded a doctorate in applied mathematics. She rejected a job offer from the steel industry. Irmgard

Photo: Stanford Library/Stories from the Archives

A breezy testing ground: the flow around wing profiles was tested in the wind tunnel in Goettingen – until the Lotz method made this possible with simple calculations.

Lotz had known that she wanted to help realize humankind's dreams of flight right from her childhood, when she had watched the huge zeppelins taking off from close by. She later recalled a resolution she had formed before going to university: "I wanted a life that would never be boring. That meant a life in which new things would always occur."

Shortly after her appointment to the Kaiser Wilhelm Institute, the barely 30-year-old mathematician was put in charge of a group of scientists and female mathematicians. Irmgard Lotz became one of the few female Heads of Department at the Kaiser Wilhelm Society, albeit only unofficially. After developing the "Lotz method", she worked on other mathematical solutions for the field of aerodynamics. Then in 1937, Prandtl nominated the talented woman for the post of research professor and submitted the corresponding application to the Reich Ministry of Aviation. His letter listed 13 of her publications. However, the application was rejected. The Nazi regime did not approve of women in leading positions.

In 1938, Irmgard Lotz married civil engineer Wilhelm Flügge and took the name Flügge-Lotz. Disheartened by being rejected for the post of research professor, she followed her husband to Berlin-Adlershof that same year. He accepted a position as Head of Department at the *Deutsche Versuchsanstalt für Luftfahrt* (German Aeronautical Research Laboratory – DVL). She was obliged to stay in the background and obtained a post as a "scientific advisor for aerodynamics and the dynamics of flight". Flügge-Lotz made the most of her time and did the groundwork for one of the first standard textbooks on discontinuous control. One contemporary researcher called it "a groundbreaking contribution to automatic control theory" – a subject that was still in its infancy at the time.

**THE NEW YORK TIMES of May 23, 1974**

» The author of more than 50 scientific papers, including a 1931 computation on wing lift that contributed to modern aircraft design, Professor Flügge-Lotz had been working in retirement on problems of satellite control, heat transfer and drag of fast-moving vehicles.

However, Irmgard Flügge-Lotz and Wilhelm Flügge did not stay in what was then the capital city for long. Actions taken by the Nazis led to World War II, and in 1940 the first bombs fell on Berlin. By the time of the heaviest Allied bombing raids in February 1945, the couple, along with part of the DVL, had already moved to Saulgau north of Lake Constance, an area that was less at risk. This meant that after Germany capitulated, they found themselves in French occupied territory. The French enticed many researchers away to Paris. They included Wilhelm Flügge and Irmgard Flügge-Lotz, who moved to the *Office national d'études et de recherches aérospatiales*. Here they worked on equal terms as research group leaders.

Although they were both happy in Paris, they lacked opportunities for career advancement. In 1948, they contacted Stanford University in the U.S., where Wilhelm Flügge was subsequently appointed professor. For Irmgard Flügge-Lotz, however, the move was a step backwards, as she merely received the post of lecturer – the lowest rung in the university hierarchy. The rules at Stanford only allowed one half of a married couple to work as a professor at the university.

However, this did not stop Irmgard Flügge-Lotz from carrying out a professor's tasks in the fields of teaching and research. She gave lectures and seminars, supervised doctoral students and moved ahead with her research – in both flow mechanics and automatic control. Students and colleagues alike found it more and more difficult to understand why the "lecturer" was not a "professor". The same question was asked in summer 1960 in an international setting when Flügge-Lotz became the only female delegate from the United States to attend the first congress of the International Federation of Automatic Control in Moscow. Shortly afterwards, Stanford University appointed her to the post of ordinary Professor of Engineering Mechanics, Aeronautics and Astronautics.

The remarkable scientist indefatigably continued her research and teaching activities over the years that followed. Even after she retired in 1968, she remained active in the field of research and received numerous honors. The American Institute of Aeronautics and Astronautics elected her a Fellow – the first woman ever to receive this accolade. The Society of Women Engineers presented her with their Achievement Award, and the University of Maryland awarded her an honorary doctorate. Only in Germany has she been practically forgotten.

On her death in Palo Alto, California, in 1974, a brief obituary was printed in the New York Times. And in 2014, almost 40 years later, Stanford University paid posthumous tribute to her as one of 35 "Engineering Heroes" who had been the driving forces behind the human, social and economic progress made through technology and science.

Photo: Archive of the Max Planck Society, Berlin-Dahlem

# Joining the Square Kilometre Array

Max Planck Society becomes newest member of SKA Organization

The Max Planck Society has become the 13th member of the SKA Organization, following an unanimous vote by the SKA Board of Directors. The decision to accept the application for membership was taken at the 29th Board meeting at the SKA Organization Global Headquarters in the UK.

The Max Planck Society joins the final phase of the SKA Organization, which is overseeing the telescope design phase, until the process of transitioning into the SKA Observatory, an intergovernmental organization (IGO) established by treaty to manage the construction and operation of the SKA, is completed. Any further German involvement through participation in the SKA Observatory remains to be decided and will be the subject of future discussions.

"I am delighted to welcome the Max Planck Society to the SKA Organization as our 13th member, a deserved recognition of the significant contributions Germany has made to the SKA project over the years, and particularly in this crucial pre-construction phase," the Chairwoman of the SKA Board of Directors, Dr. Catherine Cesarsky, explained.

German research institutions and industry have been an intrinsic part of SKA-related projects since its earliest days, and make a significant contribution to ongoing SKA design activities. In particular, the Max Planck Society provides instrumentation in the form of detectors, data acquisition and analysis systems for South Africa's world-class MeerKAT telescope, an SKA precursor facility which will become part of SKA-Mid.

"I am extremely pleased to see our German colleagues consolidating their long-lasting involvement in SKA-related activities both at a scientific and industrial level," added Prof. Philip Diamond, SKA Director-General. "Germany's great wealth of expertise in radio astronomy, both in science and engineering, will continue to be invaluable as we move ever closer to SKA construction and operations."

The Max Planck Society has funded a second SKA prototype dish, SKA-MPI, currently being constructed on site in South Africa, bringing together Chinese, Italian and German components.

Photo: South African Radio Astronomy Observatory (SARAO)

The Max Planck Society is a non-profit organization with 84 Institutes and research facilities. In collaboration with other German institutions and industry, it has been involved across many areas of SKA design work, including within the Mid Frequency Dish Array, Low Frequency Aperture Array, Central Signal Processor, Science Data Processor, Telescope Manager, Signal and Data Transport consortia, and research and development work within the Phased Array Feeds and Wideband Single Pixel Feeds consortia.

One of the Max Planck Society's Institutes is the Max Planck Institute for Radio Astronomy (MPIfR), a key player in the SKA's Dish engineering consortium. Together with German industry partners, such as the telescope antenna specialists MT Mechatronics (MTM), and international partners, the Dish consortium is responsible for designing the SKA's mid-frequency array (SKA-Mid), to be deployed in South Africa, The Dish consortium has already delivered two prototype SKA dishes: SKA-P, which is currently being tested in China, and SKA-MPI, funded by the Max Planck Society, which is under construction on the SKA site in South Africa's Karoo region.

"The SKA is a great opportunity for astronomers, engineers, physicists and data scientists. Besides becoming an amazing discovery machine, SKA pushes the boundaries of what is technically possible, especially in the handling and analysis of huge amounts of data. The Max Planck Society is at the center of all these exciting science and technology developments, and we are pleased to now be able to contribute officially to the SKAO efforts," says Prof. Michael Kramer, Director at the MPIfR.

# Remembering Suzanne Eaton

The Max Planck Society mourns the death of an exceptional scientist

The Max Planck Society mourns the death of Suzanne Eaton, whose life came to a tragic end in Crete on July 2, 2019. In a personal letter to her husband, Tony Hyman, Max Planck President Martin Stratmann paid tribute to Suzanne Eaton as an outstanding scientist and a wonderful human being, saying that Eaton had been a key person, an essential pillar of the Institute in Dresden right from its very beginning.

Suzanne Eaton

Suzanne Eaton was Senior Research Group Leader at the Max Planck Institute of Molecular Cell Biology and Genetics, and a Professor at the Biotechnology Center of the Technical University of Dresden. In 2001, she started linking seemingly distant areas of research in her own laboratory in order to find deeper explanations for the pattern formation in the development of the fruit fly. The focus of her research was the question "How do cells form tissues?"

"Suzanne had a huge impact on the development of our Institute in that she bridged different disciplines – biology, physics and mathematics – and as such inspired the interdisciplinarity that has characterized the research at the MPI-CBG since its conception," writes the Board of Directors in their statement following with "Suzanne was in her own league." Thanks to her insatiable curiosity and creativity, she discovered new and groundbreaking approaches to understanding how cells communicate with each other to form tissue. Through the discovery of signaling molecules, the morphogens, and their physical properties and interactions, Suzanne's team was able to explain how signals are spread over long distances in tissues. Most recently, Suzanne's research focused on the interaction of signaling and metabolic pathways.

Her studies uncovered fundamental biological mechanisms, her publications in high-ranking journals speak for themselves: Suzanne Eaton was a key player in her field of research, and her scientific work had an immense international impact in the wider scientific community. She played a big part in making the Max Planck Institute of Molecular Cell Biology and Genetics, and the city of Dresden, known throughout the world as a beacon of science and an excellent environment for early career researchers.

She was instrumental in shaping the development of the Dresden Institute. Suzanne Eaton had a decisive influence on this community as a family-friendly, international, intellectual environment with plenty of room for innovative ideas. For her, there seemed to be no doubt that it was possible to balance a life lived to the full with a career in science. She found the perfect balance to combine her many roles of scientist, mother, athlete, and enthusiastic piano player. With her calm and steady personality, she made the first generation of young group leaders feel welcome coming to Dresden from top universities to develop their own research, giving them the feeling of having come to the right place and of being able to succeed.

We miss a wonderful, creative, lively, enthusiastic colleague and friend, and a brilliant scientist.

The Max Planck Institute of Molecular Cell Biology and Genetics has collected tributes to the life and legacy of Suzanne Eaton from family, friends and colleagues:
www.mpi-cbg.de/institute/remembering-suzanne

Photo: MPI of Molecular Cell Biology and Genetics

# Max Planck survey on work culture and atmosphere

The findings show that the principles of scientific action must be complemented by the principles of cooperation

In February 2019, the President of the Max Planck Society, Martin Stratmann, commissioned a science-based Max-Planck-wide survey on working culture and working atmosphere. The findings are now in. "We wanted to get an idea of the mood across the whole organization and create transparency for cooperation and leadership culture at the Max Planck Society," Martin Stratmann explains. "The results show how important it is to continue to build a performance-oriented but also a respectful and appreciative working culture and atmosphere at our Institutes and to introduce measures for changes at the relevant locations."

The study was implemented by a research team from the Fraunhofer Institute for Work Organization headed by Prof. Dr. Martina Schraudner. More than 9,000 employees of the Max Planck Society, which represents 38 percent of the entire workforce, took part in the survey. The study is unique in this form, because for the first time, the questionnaires was not only sent to doctoral candidates and postdocs, but also to all scientific and non-scientific staff. The topic of bullying was also investigated, after public reports in 2018 had referred to allegations at two Max Planck Institutes.

## THE FINDINGS AT A GLANCE

The uniqueness of the data set provides a benchmark in the generally poorly researched environment of the work conditions in cutting-edge research.

- The staff members of the Max Planck Society demonstrate a high level of commitment to the organization, i.e. they are willing to display a high degree of individual commitment and within their respective work units are bound by a strong shared vision and collegiality.

- About 80 percent of the respondents say that individuals with leadership functions have a high employee focus and are willing to support a dynamic change culture. This is particularly the case for scientific staff members. Non-scientific staff view the change culture slightly more critically. In particular, they are less likely to confirm that they feel respected by their superiors.

- In the last 12 months, around 10 percent of respondents stated that they had experienced bullying at the workplace based on their own understanding. This is an average result compared to recent international studies. During the same period, 3.9 percent of all respondents stated that they had at least occasionally experienced sexual discrimination, which is below the international average. The current report by the U.S. National Academies of Sciences, Engineering and Medicine, for example, gives a figure of 20 percent in this area.

- Deficits are identified in relation to mentoring by direct superiors. Women in particular feel that they receive less support in their careers. Among the main target groups of mentoring, doctoral candidates and postdocs, only one in two respondents agreed with the statements in the survey regarding career development support.

- Based on their own estimates, non-scientific staff (11.8%) were subjected to bullying significantly more often during the 12 months of the survey than scientific staff (7.5%).

## CARRYING OUT THE STUDY

In order to guarantee the neutrality, data protection and especially the scientific quality of the project, a research team was set up at the Center for Responsible Research and Innovation at the Fraunhofer Institute for Industrial Engineering IAO (CeRRI) under the direction of Martina Schraudner. The survey's sample size is the largest, in absolute terms, of any investigation of a single scientific organization.

The survey is highly representative because the sample size makes up a very good proportion of the total. "Compared to researched studies, a globally unique data set regarding sample size, details and thematic scope was collected on work conditions in cutting-edge research," Martina Schraudner emphasizes.


Graphic: Shutterstock

# Wolfgang Baumeister wins the 2019 Stifterverband prize

The biophysicist has revolutionized molecular structural biology with the help of cryo-electron tomography

In contrast to our knowledge of our planet, there are still many unexplored regions in the cellular nanocosmos. The fragile architecture of large protein complexes composed of numerous subunits is particularly difficult to decipher. This is because attempting to isolate and purify the proteins also rips them out of their functional context. Wolfgang Baumeister has been pursuing a completely new approach for more than three decades.

The Director at the Max Planck Institute of Biochemistry has developed a method that opens up entirely new possibilities and numerous fields of application for structural research: cryo-electron tomography. He is now being recognized with the Wissenschaftspreis des Stifterverbands 2019 (Science Award of the Donors' Association) for his pioneering work. The prize, which is endowed with € 50,000.00, was awarded by the Max-Planck-Gesellschaft (MPG) and the Stifterverband at the annual MPG meeting in Hamburg on 25 June.

Wolfgang Baumeister receives the prize in recognition of his outstanding achievements in the field of cryo-electron tomography. What is particularly notable here is his examination of molecular and supramolecular structures within the context of intact cells at high spatial resolutions. The jury explained that it was awarding the prize because of the method's great economic relevance, which is evident in important areas of high technology, such as electronics, materials technology and pharmaceuticals. The cryo method allows larger spatial structures from cells to electronic components to be tomographically captured at very high resolutions and analyzed.

"We are developing methods to make the molecular architecture of cells visible," said Wolfgang Baumeister, summarizing his research focus. The cryo-electron tomography method that he has developed in conjunction with his team opens up completely new opportunities for structural research: entire cells or cell organelles are "shock-frozen" in liquid nitrogen in the blink of an eye. The fragile cell architecture remains unchanged while it is embedded in the glassy ice. Two-dimensional images of the samples to be examined are taken from different angles. A three-dimensional image is then built from these images. This method has already made it possible to understand the architecture of many proteins in their cellular environments.

"It is only possible to understand the various functions for which the molecular machines are responsible by examining their structures," explained Baumeister. Using cryo-electron tomography, he and his team have been able to decipher the structure of the 26S proteasomes, which are highly complex molecular shredders for proteins that are made up of 66 individual proteins. He and his team have also been able to reveal the superior organization of the ribosomes in cells, the so-called polysomes.

Wolfgang Baumeister is awarded the 2019 Stifterverband prize for his cryo-electron tomography. The method opens up numerous application possibilities, including in electronics, materials technology and pharmacy.

The researchers have now turned their attention to other cellular structures and are investigating the blueprints of pores in nuclear membranes, contact points between nerve cells (synapses) and protein complexes in membranes and cell walls. It is possible to use cryo-electron tomography to image these macromolecular structures in the intact cellular environment. Pathological changes, such as toxic protein aggregates that are mainly associated with such neurodegenerative diseases as Alzheimer's and Parkinson's, may also be investigated in this way. This method, which has been developed in basic research, is potentially able to open up new prospects for therapies by providing insights into cell architectures.

Photo: MPG / David Ausserhofer

# United with one voice

The Max Planck Society celebrates the inauguration of PostdocNet at Harnack House

The newly elected spokesperson of the PostdocNet initiative, Yu-xuan Lu, MPI for Biology of Ageing, at the inaugural event at Harnack House in Berlin at the end of April. The purpose of PostdocNet is to help forge links between all Max Planck postdocs.

PostdocNet was set up at the end of April by postdocs from various Max Planck Institutes. This initiative will in future serve to improve links between all the Max Planck Society's postdocs. Its primary goals are to provide postdocs with support during their critical professional orientation phase and create a network for dialog.

In April, another element was integrated into the structure of the postdoc phase: PostdocNet. This is a grass roots process that has already been attempted several times at the MPG but is only now bearing fruit, due not least to the high fluctuation in postdocs and the intensity of the postdoc phase. "Staff at our Administrative Headquarters were already giving us hints and tips on organizing the start-up back in October 2017, and last year the President officially gave us the green light, also with regard to financial support for our inaugural event. We are very grateful for the help that PostdocNet has received, not only from the MPG, but also from PhD and other postdoc organizations," explains Yu-xuan Lu from the MPI for Biology of Ageing, who was recently elected as the PostdocNet spokesperson.

The structure and statutes of PostdocNet are oriented on those of partner organizations. As with PhDNet, it encompasses the following working groups: *General Meeting, Secretary, Web/Media, Seminar, Survey and Equal Opportunities*. PostdocNet will also continue engaging with working groups on the topics of "Social Requirements", "Scientific Requirements", "Legal" and "Postdoc Definition"; this last group has the status of an interim committee.

Even though PostdocNet has made great strides since the beginning of 2019, there are still obstacles to overcome. Around half of all MPIs are currently represented, and PostdocNet aims to forge links with postdocs at all MPIs over the next year. All postdocs who are interested in becoming part of PostdocNet – as ordinary members or as part of a working group – are encouraged to contact the group through the website or Twitter.

Spokesperson Yu-xuan Lu takes a positive view of the work to be done: "We are delighted to have finally built a bridge between PhDnet and LeadNet, and the Max Planck Society will also benefit from PostdocNet as soon as it becomes easier to exchange questions and ideas."

The postdoc phase sets the course for a future career: while researchers enjoy increasing independence when planning, conducting and presenting their research and undergoing advanced training, they also have to assume more responsibility for supervising junior scientists and obtaining research resources. Moreover, this is the phase in which important career decisions are often made – for example whether to remain in academic science and research or to switch to business and industry.

In order to help postdocs deal with the complexity of this career phase, the Max Planck Society, with Christiane Haupt (Human Resources Development & Opportunities Department) as the Project Leader, has put together a postdoc package that includes structured guidelines and an extensive advanced training program. A conference with the title "CareerSteps for Postdocs" will also be held on June 6, 2019 at the Max Planck Institute for Brain Research in Frankfurt.

Photo: Bettina Ausserhofer / MPG

# Research Establishments

- Institute / research center
- Sub-institute / external branch
- Other research establishments
- Associated research organizations

**The Netherlands**
- Nijmegen

**Italy**
- Rome
- Florence

**USA**
- Jupiter, Florida

**Brazil**
- Manaus

**Luxembourg**
- Luxembourg


MAX PLANCK GESELLSCHAFT

## Publisher's Information


**MaxPlanckResearch** is published by the Science and Corporate Communication Office of the Max Planck Society for the Advancement of Science. Legal headquarters of the Association: Berlin.
ISSN 1616-4172

**Publisher's mailing address**
Hofgartenstraße 8, D-80539 Munich
Tel. +49 89 2108-1719 / -1276 (in the mornings)
e-mail: mpf@gv.mpg.de
The magazine as ePaper: www.mpg.de/mpresearch
App for free download: www.mpg.de/mpr-mobile

**Content Authority**
Dr. Christina Beck (-1276)

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**Photo Editor**
Susanne Schauer (-1562)

**Translation**
Proverb oHG
Marktplatz 12
70173 Stuttgart
Tel. +49 711 164090-0
e-mail: proverb@proverb.de

**Art Direction**
Julia Kessler, Sandra Koch
Voßstraße 9, 81543 Munich
Tel. +49 89 27818770
e-mail: projekte@designergold.de

**Lithography**
KSA Media GmbH
Zeuggasse 7, 86150 Augsburg

**Printing & Distribution**
Vogel Druck- & Medienservice GmbH
Leibnizstraße 5, 97204 Höchberg

**Advertising**
Beatrice Rieck
Vogel Druck und Medienservice GmbH
Leibnizstraße 5, 97204 Höchberg
Tel.: +49 931 4600-2721 (Fax: -2145)
e-mail: beatrice.rieck@vogel-druck.de


**MaxPlanckResearch** seeks to keep partners and friends of the **Max Planck Society** up to date on the latest research conducted at the Max Planck Institutes. Four editions of the magazine are published in German each year, all of which are translated into English. At present, the English version has a circulation of 10,000 copies (**MaxPlanckForschung**: 85,000 copies). It is free of charge. None of the views and opinions expressed in **MaxPlanckResearch** may be interpreted as representing the official views of the **Max Planck Society** and its associated bodies. Reprint of texts is permitted only with the prior approval of the publisher. Photographic rights may be granted by agreement.

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