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Max Planck RESEARCH

The Science Magazine of the Max Planck Society 3.2018

The Origin of Life

CITIZENS' RIGHTS
Russian roulette with mental health

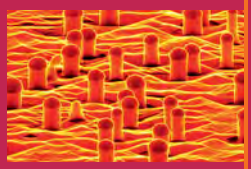
QUANTUM PHYSICS
Diamond – a flawless sensor

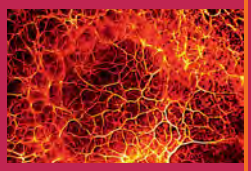
EXTREME WEATHER
Quirks in the computer

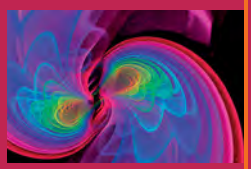
URBAN DEVELOPMENT
Creating space for existential awareness

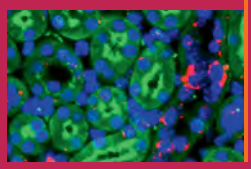
Max-Planck-**Innovation**

Connecting **Science and Business.**









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Connecting Science and Business

www.max-planck-innovation.de

Photo: Jan Banning

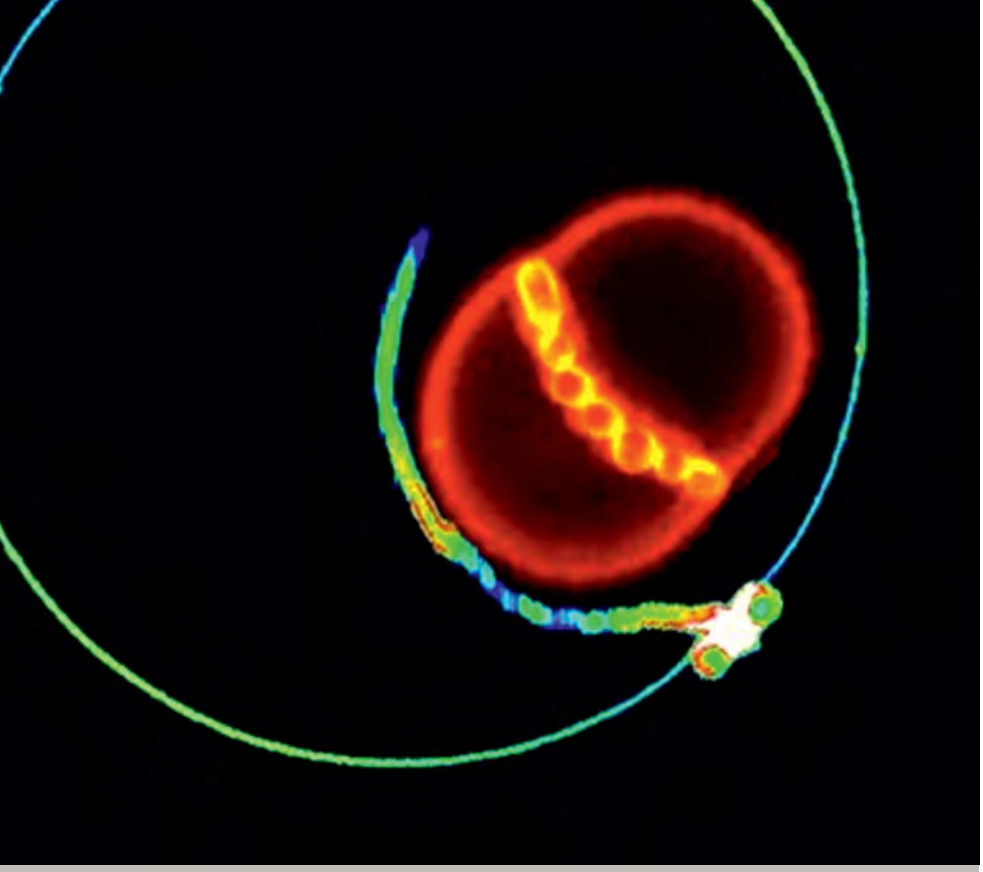
Old Bailey in East Africa

A day in May 2010: in the Ugandan capital Kampala, the high court is in session, presided over by Judge Benjamin Kabiito. Due to its colonial history as a British protectorate, Uganda is one of the nations in which justice is administered according to the common law system customary in many English-speaking countries. This system is based on precedents, i.e. on authoritative judicial decisions made in earlier cases. The judge's assessment of each case therefore plays a significantly more important role than in civil law, the system customarily used in continental Europe.

The judicial system in Uganda is largely independent. However, people in poor and rural regions in particular often have little or no access to the organs of the state judiciary. The court, police and prison infrastructure is inadequate; the prisons are extremely overcrowded. While Uganda still has the death penalty, it is very rarely implemented within the civilian justice system. The second most severe penalty is a life sentence – which then actually means imprisonment for the natural life term of the convict. A person sentenced to imprisonment for a specific period cannot be released before two-thirds of this sentence have been served.

The image is part of the exhibition "Law & Order – The World of Criminal Justice" by Dutch photographer Jan Banning, which was created in cooperation with the Max Planck Institute for Foreign and International Criminal Law in Freiburg. It includes pictures from prisons, courtrooms and police stations in Uganda, Colombia, France and the U.S.

"Law & Order" will be on display in the Max-Planck-Haus at Hofgarten in Munich for Max Planck Day on 14 September 2018. The exhibition catalog is available at www.janbanning.com/books/law-order.



18 THE ORIGIN OF LIFE

ON THE COVER No satisfactory conclusion has yet been drawn about where life first emerged. It could have happened in thermal springs such as the Champagne Pool in New Zealand. These warm, saline environments provide conditions that are important for the evolution of lifeforms.

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Photos: University of Stuttgart, Tom Pingel, dpa/Holger Hollemann (left to right)

Landmarks in science

Max Planck President looks ahead to future research topics at the annual meeting

100 years after the Nobel Prize was awarded to Max Planck, Martin Stratmann believes that science is once again experiencing epochal change. As the Max Planck President emphasized in his speech at the close of the 69th annual meeting in Heidelberg, data-driven research has joined experimentation, theory and simulation as a "fourth paradigm". In addition to big data, the life sciences in particular are seeing further revolutionary innovations such as the CRISPR-Cas9 genetic scissors and organoids, i.e. organ-like cell tissue grown in Petri dishes. Stratmann also mentioned public concern at recent developments in science. The Max Planck Society takes both these fears and its responsibility very seriously. Other speakers at the Plenary Assembly included Baden-Wuerttemberg's Minister of Science Theresia Bauer. The ceremonial address was given by Stephen Mann of the University of Bristol, a pioneer in the newly forming research field "Origin of Life". The Directors of the Max Planck Institutes and the research organization's central decision-making bodies came together for this two-day annual meeting. Prizes were also awarded to 36 outstanding young scientists, including the Otto Hahn Medal for outstanding doctoral research.

Past and future: at the annual meeting for 2018, Max Planck President Stratmann paid tribute to Max Planck on the 100th anniversary of his being awarded the Nobel Prize and looked ahead to innovative new research topics.

The size of raindrops

First prize in the Physics category at the national finals of "Jugend forscht" goes to Max von Wolff from the Megina Gymnasium in Mayen

A measuring device for raindrops – this invention won Max von Wolff, a pupil at the Megina Gymnasium in Mayen in the Rhineland-Palatinate, first prize in the Physics category of the "Jugend forscht" contest for young researchers. The prize, which is worth EUR 2,500, was presented by Martin Stratmann at the national finals in Darmstadt. The Max Planck President was visibly impressed by the "deep interest in physics" shown by the pupil. The 18-year-old's project addressed the question of how to record the size of raindrops. He constructed an apparatus in which raindrops fall on a synthetic membrane and make it oscillate. Sensitive sensors register the membrane's fine vibrations and send the measurements to a computer that uses them to calculate the size of the raindrops. This would enable meteorologists to better predict the course of a hurricane, for example, based on the size of the raindrops. More than 12,000 pupils from all over Germany took part in the 53rd "Jugend forscht" contest. The Max Planck Society has been funding this contest for many years; since 2012, it has provided all the physics prizes for all levels from the regional competitions to the national finals.

Photo: Amac Garbe

"A price tag on citizenship"

Ayelet Shachar reflects on how visas for the super-wealthy are changing politics and society

Immigration policy is a highly contentious topic in many western countries. They are increasingly closing their borders to all kinds of immigration – with one exception: many governments are actually courting wealthy capital investors, not least in terms of citizenship. Ayelet Shachar, Director at the Max Planck Institute for the Studies of Religious and Ethnic Diversity, takes a closer look at the so-called golden visa programs.

Ms. Shachar, can you tell us a little bit more about these golden visa programs?
Ayelet Shachar: I would refer to this visa as a tailor-made pathway for the world's super-rich to acquire citizenship – quickly and simply without any disruption to their life. In certain cases, these new citizens do not even need to set foot in their new home country.

Don't they have to do anything in return?
The governments seem to be saying something along the following lines: "Bring us your wealthy." On civic integration, they say: "If money is the currency for access, then we are more than willing to waive or bypass the standard civic integration requirements" that are otherwise jealously enforced. Of particular note is the fact that the requirements applicable to all other migrants have become more restrictive in recent years.

How much does this kind of privileged access cost?
The American golden visa program formally requires an investment of one million dollars. In practice, that amount is typically reduced to 500,000 if you invest in specifically designated areas. In the United Kingdom, the minimum investment is two million pounds sterling, and if you invest that, you establish what is called a "leave to remain". The greater the investment, the shorter the time that the investor has to wait to establish their residency.

Do the programs actually accomplish their purported goal of bringing economic investment or providing long-term benefits to the economy?
This is interesting, because the programs for which we have more data are the ones that ran for a longer time, the investor visa programs that, say, Canada and the United States have had. In the United States, a current governmental study says – I'm quoting now: "The government cannot demonstrate that the program is improving the U.S. economy and creating jobs for U.S. citizens." In Canada, which had a very successful investor visa program for a number of years, similar conclusions were drawn and the program was canceled in 2014. The situation was such that many people actually acquired citizenship and then left; they were not active in any way either in society or in the economy. Of course, this is a generalization, but this trend was identified at least in these two countries that have a longer track record.

In your view, what are the ethical problems associated with this visa?
Visa programs for wealthy people provide preferential treatment to the global one percent. The great ethical concern here is that these programs exacerbate inequality. A second set of concerns deals with the intrusion of the market into the political sphere. Citizenship is actually about political relations, the special bond between a person and her fellow citizens and their relationship to a given government. If you put a price tag on citizenship, you are not just sending a clear message about who is wanted and who is seen as a valuable future citizen, you're really recasting something deeper: membership in the political community.

Is it fair to say that if you are very rich, you essentially get your own set of rules?
I think you're correct. We have seen this in other fields. I think it's quite new and to some extent surprising that we are also seeing it in the heart of citizenship. But these rules didn't fall from the sky, they were introduced by the respective governments. I think once we call attention to these kinds of golden visa programs, we can step back and ask questions about how citizenship is granted. Do we think these rules are fair? When we think about immigration and inclusion of newcomers, should we include some consideration for justice and equality and not just self-interest? I think de facto most countries do wish to have a blend. Perhaps we need to rebalance this kind of distribution.

Ayelet Shachar

Interview: John Krzyzaniak
Editor: Mechthild Zimmermann

An in-depth version of this interview was published on the website of the Carnegie Council for Ethics in International Affairs (www.carnegiecouncil.org).

Photo: Frank Vinken

Live videos from inside the body

Jens Frahm wins European Inventor Award for fast magnetic resonance imaging

"The European Inventor Award is a great honor and a marvelous acknowledgement of the innovative work done by the whole research team." With these words, Jens Frahm expressed his thanks for the distinguished award presented to him by the European Patent Office in recognition of his work at the Max Planck Institute for Biophysical Chemistry in Goettingen. Frahm and his group succeeded in accelerating magnetic resonance imaging (MRI) procedures by up to 10,000 times and establishing this technology in clinical practice. Back in the 1970s, the first MRI machines required patients to lie absolutely still for minutes at a time to obtain a useful image – a significant disadvantage compared to the much faster ultrasound and x-ray imaging procedures. The FLASH technology developed by the team of researchers led by Jens Frahm reduced the imaging speed to just a few seconds and made MRI one of the most important diagnostic imaging procedures. Physicians worldwide use this method for around 100 million screenings a year. With the FLASH2 method, the team from Goettingen also succeeded in taking a step towards real-time MRI, with which it has now become possible to film processes inside our bodies for the first time.

Luminary in MRI technology: Jens Frahm from the Max Planck Institute for Biophysical Chemistry.

Tracking animal movements

New research center set up with Yale University to promote biodiversity protection

From butterflies to whales – animals are constantly on the move. At the same time, living conditions on our planet are changing rapidly. The Max Planck Society and Yale University in the U.S. aim to forge ahead with the study of animal movements in changing habitats and have established a joint research center for this purpose. The goal of the Max Planck - Yale Center for Biodiversity Movement and Global Change is to improve the analysis of habitat-related and environmental data, animal movements and the distribution of species. Biologists, statisticians, computer scientists and geoscientists will be collaborating closely at the center with this aim in mind. The two partners, the Max Planck Institute for Ornithology in Radolfzell and the Yale Biodiversity and Global Change Center, complement each other perfectly in this area. "The Max Planck - Yale Center will not only make significant advances in ecology and biodiversity research," emphasizes Max Planck President Martin Stratmann. With animals as sensors of environmental changes, it will also create a new public awareness of the threats to our natural resources. The Max Planck Society and Yale University are investing five million euros in the center, which is planned to run for a period of five years.

Joint project: Martin Wikelski, Director at the Max Planck Institute for Ornithology, Max Planck President Martin Stratmann, Yale President Peter Salovey, Walter Jetz, Co-Director of the Center, and Peter Schiffer from Yale University (from left).

Photos: Frank Vinken (top); Yale University (bottom)

Quality control deters predators

Economic success attracts fraud – even in the marketing of research results like in scientific publishing. Worldwide, the annual turnover of scientific articles alone amounts to 8 billion in euros. Unfortunately, big money like this attracts fraudulent, so-called predatory publishers, conference organizers or online journals, who want to cut in on the action. These players fake high-quality publishing business processes and a competitive pricing structure. However, they tend to provide no quality assurance like peer reviewing or an editorial board and little to no editorial oversight, while fees for publication are excessive.

Compared to the total amount of scientific articles published in recognized journals only a small number of papers appears in predatory magazines. For instance in 2017 the reputable Web Of Science database listed 1.7 million articles, whereas the number of articles distributed by OMICS, an example of a predatory publisher, is less than 0.9 percent (as of 2017) of the number of trustworthy articles. The journals of OMICS are currently not listed in Web Of Science.

In the Max Planck Society the fraction is as a matter of fact negligible: of the 120,000 scientific articles produced with the participation of Max Planck authors in the years 2007-2017 only nine articles, a share of 0.01 percent, appeared in OMICS magazines – which does not mean that these articles are automatically spurious.

The scientific publication system not least serves to bring theories, hypotheses, observations, and indications of knowledge which still need to be examined, to the scientific discourse. However, it is part of the normal working procedure of a scientist to categorize every scientific publication before use according to the criteria of "fact vs. scientific speculation vs. non-scientific nonsense". Brands and names of journals can serve as a supporting aid, but ultimately only a critical scientific examination of the content of the article can be decisive.

In order to combat practices such as predatory publishing, regardless of whether in connection with the traditional subscription model or Open Acces, it is primarily important to become as informed about this threat as possible and to continue to raise awareness for high quality and serious practices.

On the net

International law in focus
Unlike medicine, sciences and many of the humanities and social sciences, there are hardly any research prizes for outstanding scholars in the field of law. The Max Planck Institute for Comparative Public Law and International Law and the University of Cambridge's Lauterpacht Center for International Law have therefore established the Max Planck Cambridge Prize for International Law to honor an outstanding scholar for their academic work and function as a role model for aspiring young law specialists. The prize, which is worth EUR 20,000, is sponsored by Supporting Members of the Max Planck Society.
www.mpg.de/11810198/Donation_project_2018

Color game in black and white
A new free games app – The Color Game – is helping Olivier Morin from the Max Planck Institute for the Science of Human History in Jena take a new approach to researching the development of language. The goal of the game is to inform another person of a randomly allocated color. Instead of words, players can only use a fixed selection of black and white symbols that have no obvious connection with any of the colors. As difficult as this sounds, previous lab experiments have shown the researcher that the test subjects get the right answer more frequently than might be expected. Moreover, the players improve over time. Could this be a way of breaking through language barriers and using symbols rather than sounds to communicate with other people? You can make a playful contribution to help shed light on this research question!
https://colorgame.net/en/

Spot on!
The Max Planck Institute for Social Anthropology is launching a series of video clips called "Spot On – Three Minutes of Anthropology", where researchers of the Institute present a three-minute introduction of themselves and their work. The first video, featuring Brian Campbell, is already online. In it, he explains his work on "Convivencia: Iberian to Global Dynamics, 500-1750"; a multidisciplinary venture jointly conducted by the Max Planck Institute for Social Anthropology, the Max Planck Institute for European Legal History (MPIeR), the Kunsthistorisches Institut in Florenz and the Max Planck Institute for the History of Science.
www.youtube.com/watch?v=6S_om7SSf2Y

Russian roulette with mental health

In no other federal state are as many people admitted to psychiatric units against their will as in Bavaria: the numbers add up to around 60,000 a year, almost two and a half times as many as in Baden-Wuerttemberg. Now the free state is revising the corresponding legislation. As in other federal states, this law will in future be known as the *Psychisch-Kranken-Hilfe-Gesetz* (Act on Assistance for Persons with Mental Illness). However, our author is critical of the new regulations and does not believe that they provide appropriate support for persons with psychiatric disorders. On the contrary, these patients are classified as a danger to the public.

TEXT **GUNDA WOESSNER**

In April 2018, Jens R. drove a van into a crowd of people in Muenster. Four people died, several were seriously injured, and the perpetrator shot himself at the scene. A short time later, it turned out that the driver was mentally unstable and drove deliberately into the crowd. In March 2015, Germanwings pilot Andreas L. crashed an *Airbus A320* in the French Alps, killing almost 150 people. He had been receiving psychiatric treatment for some time. One summer evening in June 2013, Manuel F., who suffered from schizophrenia, stood naked in the Neptune Fountain in Berlin and attacked a police officer with a knife. The police officer subsequently shot him dead.

> The draft law treated people with psychiatric disorders like criminals

These prominent, widely publicized examples reinforce the impression that people with psychiatric disorders are a danger to the public. The police in particular often see them as a singularly dangerous group of people. Depending on the context and study, incidents involving people with mental illness account for between ten and 30 percent of all police contacts. The police are usually called on to help when mentally ill people are suffering crises with which other people or institutions are barely able to cope. This reinforces the subjective impression among the police that people with psychiatric disorders are a particular problem.

According to a non-representative survey of police commissioner candidates, only around ten percent believe that mentally ill people are no more dangerous than people whose mental health is sound. Moreover, half of those questioned stated a belief that mentally ill people are unpredictable. In

Vague unease: people with psychiatric disorders are often believed to be unpredictable or even dangerous – and unfairly so. In actual fact, only a few of them behave aggressively.

Photo: Pedro Gabriel Miziara/unsplash

the Eurobarometer survey on mental well-being conducted in 2006, 37 percent of respondents stated that people with psychiatric disorders were a danger to others, and nearly two thirds were convinced that psychiatric patients are unpredictable. This survey is representative of the general population.

Does this mean that it is legitimate and even appropriate to focus security policy measures on mentally ill people?

This is precisely the intention of the Bavarian Act on Assistance for Persons with Mental Illness (*Psychisch-Kranken-Hilfe-Gesetz*), which was passed by the Bavarian cabinet and and discussed in the regional parliament, the Landtag, after its first reading in April. According to the first draft of this law, people with mental health problems were to be held in psychiatric units and reported to the police. The police also had to be informed when they were discharged. The patient's data was to be stored in a central file which could also be accessed by the security authorities. This draft was based on the Bavarian laws on hospital treatment orders and preventive detention. In other words, people with psychiatric disorders were to be treated like criminals. The draft law has since been made less severe, but only in response to pressure from professional associations. The Bavarian state government has now distanced itself from the idea of a central file of psychiatric inpatient records. Moreover, averting danger is no longer the primary objective, as was the case in the original draft; instead, the focus has shifted to the treatment and cure of patients with psychiatric disorders.

> Mentally ill people were locked away with criminals until well into the 17th century

In actual fact, only a very small percentage of mentally ill people attract attention due to violent behavior, as various international studies conducted in recent years have shown. In the public arena, however, media interest – as we have seen – centers on spectacular killings, which makes it difficult for laypersons to take a differentiated view and form their own opinions. As a result, the belief that people with psychiatric disorders are dangerous has become ingrained.

Scientific findings, on the other hand, allow for a more nuanced view. Psychiatric illness can have many faces: depression, anxiety disorders, post-traumatic stress disorders, eating disorders, addiction, psychosis and dementia, to name just a few. Only a very few patients with mental illness belong to the risk group that is prone to violence. Moreover, violent outbursts are invariably associated with additional factors, as for example in the case of schizophrenia, which is more often linked with acts of violence than other psychiatric illnesses. In the case of delusional disorders such as those that can occur with schizophrenia, the risk of the patient becoming violent strongly depends on the nature of the delusion.

It also depends on whether or not the patient is under pressure, has a drug problem, is receiving psychiatric or psychotherapeutic treatment, and whether the disorder has become chronic. In fact, international studies show that less than ten percent of those suffering from schizophrenia commit violent crimes. Even though this percentage is higher among patients who also have some form of addiction, there are still only a very few patients in these risk groups who actually commit acts of violence.

The risk of violence is even lower in the case of all other psychiatric disorders, with the exception of drug addiction, alcoholism and certain personality disorders. It is of course important to take the actual potential risk seriously – for example when people suffering from delusion threaten to harm others. However, this does not permit the assumption that the risk is general. A study of 36,000 people conducted recently in the U.S. showed that anxiety disorders, for example, are in no way associated with violence. In the case of people with depression, the risk of self-harm is more prominent than the risk of aggression directed against others. Moreover, depending on the psychiatric disorder in question, the

age of the patient, the duration and progression of the disorder, and various socio-economic factors also influence the specific probability of a mentally ill person becoming violent. These findings have been confirmed by various studies from a number of European countries. There is consequently no simple causal connection between mental illness and violence, even in risk groups.

These empirical findings directly oppose the alleged first-hand experiences for example of the police, which emerge in stereotypes about the mentally ill. The result is the fueling of prejudices reminiscent of times believed to be long gone.

Criminals who commit serious crimes and people with psychiatric disorders have fascinated "normal" people since time immemorial. There is something uncanny about them, something alien, that fosters fear and uncertainty. At the same time, attitudes towards them are somewhat sensationalist. The associated ideas and myths are deeply rooted in history and still contribute significantly to the modern-day view that people with mental illness are one step away from criminals. For centuries, criminal behavior and psychiatric illness were attributed to the same cause. Mentally ill people were locked away with criminals until well into the 17th century, as both groups were believed to be dangerous.

The establishment of hospitals and nursing institutions for the mentally ill at the beginning of the 20th century marked a new chapter in the treatment of people with psychiatric disorders. Nevertheless, patients in so-called lunatic asylums were still more commonly associated linguistically and in the public perception with prisoners and criminals than with sick people. It is a well known fact that the Nazis cruelly pushed the exclusion of "asocial" persons such as criminals or the mentally ill to extremes. Both groups – criminals and the mentally disturbed – were designated "unworthy of life" and fulfilled the selection criteria for forced sterilization and euthanasia.

Although it seemed in recent years that the stigmatization of people with psychiatric disorders was subsiding, it now appears to be on the rise again despite all the public information campaigns. One representative study conducted in Germany shows how attitudes towards the mentally ill changed between 1990 and 2013. While the number of people in favor of treating psychiatric disorders with psychotherapy or psychotropic drugs increased, a significantly higher percentage of those questioned in 2013 stated that they were afraid of people with mental illness and felt uncomfortable in their presence than was the case 23 years earlier. In all, hostility towards people with psychiatric disorders rose. These developments are disturbing. In fact, they seem almost absurd considering that one third of the German population succumbs to at least one mental disorder every year. Around one in four people will become mentally ill at some point during their lives. Mental illness is the fourth most common reason for work incapacity, ahead of cardiovascular disease and infections. Consequently it can affect any one of us.

The first draft of the new Bavarian law on assistance for persons with mental illness reflects many of these prejudices, citing risk prevention as the "primary objective" of hospitalization, for example.

> There has not even been an attempt to establish a clear definition of when a person constitutes a threat

The treatment and cure of psychiatric patients was merely said to be "an additional objective". Other clauses in the draft law also put mentally ill people almost on a par with people who pose a threat to the public. The hospitalized patient would for example only have the right to notify a trusted person if this were consistent with the objective of the hospital treatment.

The courts and police were also to be informed when the patient was due to be discharged. This new clause was justified by the claim that the police had not always been able to ensure that measures required in individual cases would be implemented in

Photo: Pedro Gabriel Miziara/unsplash

a timely manner. According to the Documents of the Bavarian Landtag on draft legislation, this situation is not really acceptable from the viewpoint of risk prevention. This reflects an alarming development. The mentally ill are presented as dangerous people who have to be kept under police observation. This stigmatization marginalizes them even further, quite apart from the fact it is incomprehensible how and to what the police wish to react when they are informed that a hospitalized person is to be discharged.

Professional associations that criticize the new law rightly refer to the fatal consequences for the people concerned. One significant criticism related to the risk of mentally ill people becoming increasingly marginalized. It is by all means possible that the uncertainty provoked by the draft law has placed an additional obstacle in the way of patients in need of psychiatric and psychotherapeutic treatment. Considering the growing risk of aggressive behavior in risk groups that are not undergoing treatment, the law may have actually exacerbated the threat of acts of violence rather than reducing it. It is frustrating to see how little empirically proven links and the effect of the intended measures were taken into account during the legislative process.

Incidentally, the same applies to other laws that allegedly serve the purpose of keeping the population safe. A similar situation occurred when the new Federal Criminal Police Act (*Bundeskriminalamtsgesetz* – BKAG) raised the possibility of expanding surveillance activities to include the electronic tagging of people who constituted a threat. The federal government mentioned several ways in which this would prevent criminal activity. First and foremost, the person under surveillance would be deterred from performing acts of terrorism as they would be aware that the risk of discovery was greater. Secondly, the police would be able to intervene more quickly in cases where violations triggered an alarm, for example because the person under surveillance had entered potential targets for attack such as railway stations or airports. Moreover, electronic tagging would also prevent tag wearers from traveling to countries where they would be able to take part in terrorist training camps. Yet there is no empirical evidence of such effects. On the contrary, it is unlikely that anyone plotting a terrorist attack would be deterred by cost/benefit considerations. There are other measures by which people can be prevented from traveling abroad. Furthermore, alerting the police more quickly in the event of reported violations would not prevent attacks completely.

There are also parallels with regard to the unclear terminology. There has not even been an attempt to establish a clear definition of when a person constitutes a threat. Consequently there is something arbitrary about the classification of people who are or pose a threat, particularly when the reason cited for hospitalization is that the patient constitutes a risk to the common good, as formulated in the draft of the law on assistance for persons with mental illness. The preconditions should be evaluable and clearly defined, especially in the case of substantial interference in the freedoms guaranteed by Basic Law such as the sectioning of people with psychiatric disorders. The European Court of Human Rights, for example, expressly draws attention to the need to protect people with mental illness from arbitrary treatment, particularly with regard to hospitalization.

> Traditional notions go hand in hand with fantasies of government control

Merely the fact that the free state of Bavaria wished to enact a law on assistance for persons with mental illness with the aim of averting threats makes it very clear where its interests lie. As with the recently passed law on police duties or the law on more effective surveillance for dangerous persons that came into force in summer last year, the priority is to combat alleged "threats" with ever more far-reaching powers of intervention.

Traditional populist ideas consequently go hand in hand with promises of safety and control fanta-

Photo: Pedro Gabriel Miziara/unsplash

sies on the part of the state that endanger the liberal society based on principles of solidarity that we have created. This is of course not only the case in Bavaria. The thrust throughout Germany is probably at least comparable: a focus on persons who are vaguely assumed to be dangerous, the extreme extension of police powers for intervening at a very early stage of risk, and greater flexibility in the preconditions for intervention. At the beginning of May this year, these fears drove tens of thousands of Bavarian citizens onto the streets of Munich to demonstrate against the planned law on police duties; they were joined by thousands of other demonstrators from all over Germany who were concerned about our fundamental rights.

Laws that reinforce stigmatization and promote simplified concepts of good and evil do not help make society more stable. In fact, they are more likely to divide it. It is therefore important to remember that sensational acts of violence by mentally ill people are only isolated occurrences, and that a law on assistance for the mentally ill must generally aim to achieve a better quality of inpatient care and treatment for people with psychiatric disorders. At most, the police need improved education and training in dealing with mentally unstable persons when traditional forms of police intervention are no longer effective. This should include basic and differentiated knowledge of psychiatric disorders, which to some extent is already covered by police training curricula. The police could also learn from critical reflection on cases in which firearms were used on people with mental illnesses. A modern police force should not shy from this type of introspection.

A meaningful, enlightened criminal and social policy must be oriented on scientific knowledge and standards, not on populist trends. It is wrong to react to vague anxieties on the part of the population with equally vague, undifferentiated, populist measures. On the contrary, the right thing to do is to reflect on empirical insights, envision the effects of each measure, and venture on anti-stigmatization campaigns and better education. Here a contribution can be made by raising public awareness of scientific findings. ◀

Photo: Jessica Hath for the MPI for Foreign and International Criminal Law

THE AUTHOR

Gunda Woessner, born in 1970, is a Senior Researcher and Project Leader in the Department of Criminology at the Max Planck Institute for Foreign and International Criminal Law in Freiburg. After graduating with a degree in psychology, she completed a doctorate on sexual offender typology. Afterwards, she worked at institutions such as the Psychiatry and Psychotherapy Clinic at the University Clinic in Muenster. Gunda Woessner has been working at the Max Planck Institute in Freiburg since 2008, where she is in charge of research projects on electronic surveillance and treatment and recidivism among violent and sexual offenders. In 2015 and 2016, she was a Professor of Psychology at the University of Applied Police Sciences in Baden-Wuerttemberg.

The Nobel Prize as a turning point

Scientists from 100 countries of the world work at the Max Planck Institutes. Here they write about their personal experiences and impressions. Mohamed El-Brolosy from Cairo is a doctoral student at the Max Planck Institute for Heart and Lung Research in Bad Nauheim. He talks about the cultural and structural differences between Germany and Egypt, explains the bureaucratic obstacles that can hinder research in Egypt, and describes how karate is helping him improve his German.

I was one of those children who always wanted to know "What? How? Why?". As my parents are both academics – my father is a pharmacist, my mother a science teacher – I came into contact with science at an early age. However, as it turned out, the turning point was the award of the Nobel Prize for Chemistry to Ahmed Zewail in 1999. It was tremendously inspirational for me to see an Egyptian scientist being presented with the Nobel Prize, even though I was only seven years old at the time and didn't know exactly what a Nobel Prize was.

My research focuses on genetic compensation: how can living organisms adapt to mutations and prevent defects from occurring? I am trying to find out how cells identify and fight genetic changes by producing larger quantities of other genes that take over the function of the mutated gene. In April 2017, I received a two-year grant from Boehringer Ingelheim. Afterwards, I would like to continue my scientific career as a postdoc at a prestigious laboratory in Europe or the U.S.

Apart from the good structure and organization, what I like most about Germany is how open people are towards people from other countries. It was relatively easy for me to get into conversations with others – not only at the Institute, but also in everyday situations like on the train.

Graphics: iStockphoto

Mohamed El-Brolosy, 25, studied pharmacy and biochemistry at the German University in Cairo. After obtaining his Master's degree, he moved to the International Max Planck Research School for Molecular Biology in Goettingen, from which he graduated with another Master's degree. Since May 2016, he has been working for his doctorate under the supervision of Didier Stainier at the Max Planck Institute for Heart and Lung Research in Bad Nauheim. Mohamed was Vice President of the Student Union at the German University in Cairo and has been the Secretary General and deputy spokesperson of the Max Planck PhDNet since January 2018.

On the other hand, what I miss most here is the sun. The weather often got me down during my first few months in Germany. Even vitamin D pills only helped to some extent. All the same, it was interesting to experience other weather conditions – snow, for example. I'd only ever seen it on television. I once went skiing with my Goettingen group. I must have fallen over a hundred times, and next day I was black and blue, but it was still great fun.

After science, my greatest passion is karate. I had my first karate lessons when I was just five years old. When I was growing up, I won several international competitions. Just recently, I came first in the German University Championship competition. What's more, karate is the perfect opportunity for me to improve my German. I've been learning German since I was ten years old, but the lessons mainly focused on grammar – which is actually rather different from the grammar used by Germans every day.

In Germany, the conditions for scientists are definitely better than in my native country. There are not many research facilities in Egypt – and most of them are only modestly equipped. You also have to deal with all kinds of bureaucratic obstacles. That makes me all the more grateful to be able to do research in Germany in perfect conditions. At the same time, I am well aware that others aren't as fortunate as I. There are so many intelligent minds in Egypt, but most of them simply don't have the money to pursue their ideas and projects.

Fortunately, there are initiatives such as the German University in Cairo. As I myself benefited directly from these, I want to give something back to my country. I dream of an Egyptian research institution which is as well organized and equipped as the Max Planck Institutes. Everybody should have the opportunity to study and do research – regardless of their origins or social status. It might sound rather kitschy, but ultimately this is exactly what it's all about: making an impact and making the world a little bit better. That's why I'm a scientist.

Photo: private

Building blocks that **fall from the sky**

How did life on Earth begin? Scientists from the "Heidelberg Initiative for the Origin of Life" have set about answering this truly existential question. Indeed, they are going one step further and examining the conditions under which life can emerge. The initiative was founded by **Thomas Henning**, Director at the **Max Planck Institute for Astronomy** in Heidelberg, and brings together researchers from chemistry, physics and the geological and biological sciences.

TEXT **THOMAS BUEHRKE**

The great questions of our existence are the ones that fascinate us the most: how did the universe evolve, and how did Earth form and life begin? Does life exist anywhere else, or are we alone in the vastness of space? By approaching these puzzles from various angles, scientists can answer different aspects of this question. For a long time, there was a clear division of tasks: astrophysicists and geophysicists were responsible for studying the universe and Earth, biologists and chemists for studying life. However, recent developments are forcing researchers to break down this specialization and combine different disciplines. "That's what we're trying to do with the Heidelberg Initiative for the Origins of Life, which was founded three years ago," says Thomas Henning. HIFOL, as the initiative's name is abbreviated, not only incorporates researchers from different disciplines, but also cooperates closely with international institutions such as the McMaster University in Hamilton, Canada.

The initiative was triggered by the discovery of an ever greater number of rocky planets orbiting around stars other than the Sun. "We now know that terrestrial planets of this kind are more commonplace than the Jupiter-like gas giants we identified initially," says Henning. Accordingly, our Milky Way alone is home to billions of rocky planets, some of which presumably offer environmental conditions that favor the emergence of life as we know it. It is precisely this realization that broadens the scope of the Heidelberg Initiative: it

Precious cargo: meteorites may have brought key chemicals – such as the nucleobases adenine, guanine and uracil – to Earth, thereby providing the ingredients for the formation of RNA molecules.

Photo: DLR

Cosmic nurseries: stars and planets form in clouds of gas and dust. The image above shows three such areas: the Omega and Eagle Nebulae and the Sharpless 2-54 complex (from left). This process of formation not only gave rise to our solar system some 4.6 billion years ago, but also continues to take place at many locations in space. It is also responsible for producing the red dwarf star Trappist-1, which is located 40 light years from Earth, and the seven relatively Earth-like rocky planets that have been identified in its system so far (right).

must ask not only how life could have emerged on Earth but also, more generally, what conditions are needed for something like this to happen – including on extrasolar planets.

PRAISE AND CRITICISM FOR AN EXCELLENT STUDY

Late last year, Thomas Henning and his colleague Dmitry Semenov, as well as Ben Pearce and Ralph Pudritz from McMaster University, caused quite a stir with a publication in which they proposed a scenario for the emergence of life on Earth. "As well as recognition and praise, it also brought us some criticism," says Henning.

The criticism came from the more traditional origins-of-life scientists, who challenged the study of the astronomers following the thought: what do astronomers understand about biomolecules – even if they have a deep knowledge of astrochemistry? The National Academy of Science took a different view, however, and awarded the publication the 2017 Cozzarelli Prize for its "outstanding scientific excellence and originality". In fact, astronomers can indeed contribute to questions of what conditions potentially existed when the first molecules of life or their precursors were formed – and of how this came about.

As a starting point for the study, Henning and his colleagues applied the widely used "RNA world" hypothesis proposed some 30 years ago by Walter Gilbert, a Nobel Prize winner in Chemistry. This states that the first ever terrestrial life forms were based on ribonucleic acids (RNA). Structurally, RNA resembles DNA, the information carrier of life today: both are made up of four organic bases, including adenine, guanine and cytosine; however, RNA contains a base known as uracil instead of thymine. In addition, RNA is typically single-stranded – unlike the double-stranded structure of DNA.

Likewise, molecules of RNA can also communicate genetic information and perform catalytic functions. In most organisms, however, RNA serves as an information carrier in a subordinate role to DNA, only acting as a storage medium in viruses. Did the more complex DNA therefore evolve from simpler RNA molecules or related biopolymers?

Photo: ESO

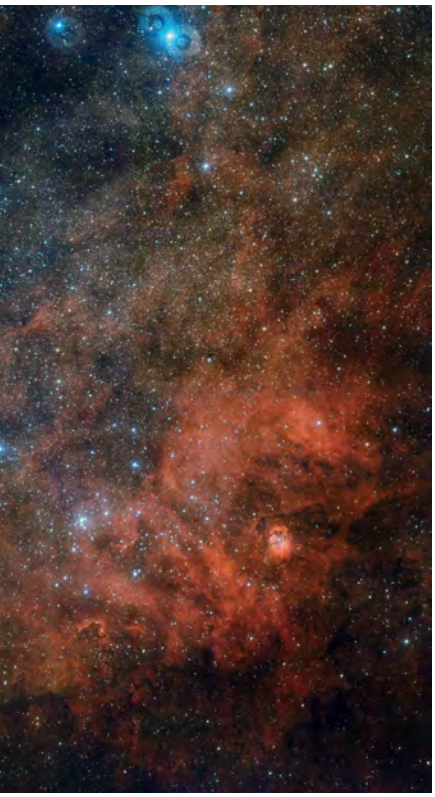


Photo: M. Kornmesser/ESO

In 2009, a chemical experiment by British researchers was considered a major breakthrough, for it showed that RNA building blocks can form if certain molecules are present and react with one another under very specific conditions. But where were the most favorable conditions present in nature?

For a long time, it has been suspected that life emerged at hydrothermal vents – so-called black and white smokers – on the deep seafloor. However, it is unclear whether the nitrogen needed for synthesis exists at a sufficient concentration in that environment. Moreover, the substances are diluted by a steady flow of water, which prevents complex chemical reactions from taking place.

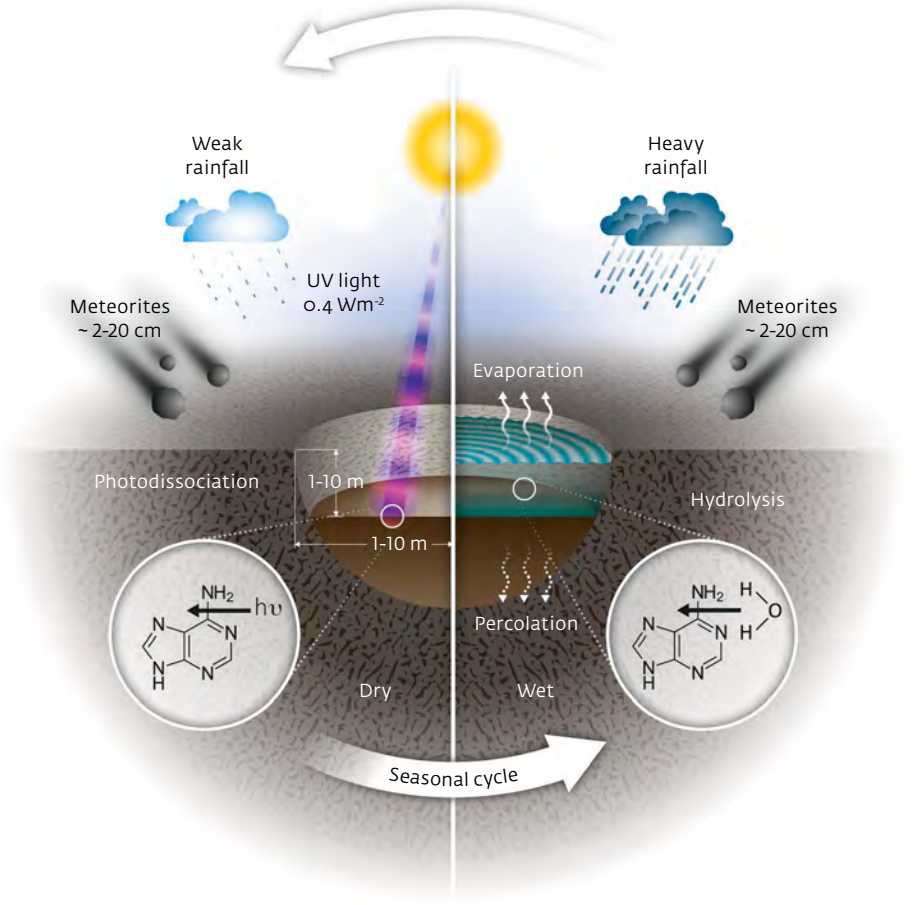
"This is where we come into play," says Thomas Henning. "We asked ourselves what other geochemical conditions might have been present to allow this RNA synthesis to take place." The idea is that the most important building blocks came to Earth from space. Indeed, the nucleobases adenine, guanine and uracil, as well as amino acids, have been detected inside meteorites. These bases are formed from simple molecules of hydrogen cyanide, carbon monoxide and ammonia in the presence of water.

ZIRCON CRYSTALS INDICATE A SOLID CRUST

Meteorites have also been found to contain the mineral Schreibersite, which releases phosphorus capable of forming phosphorylated molecules in water – these too are required for RNA synthesis. Astronomical observations have shown that all of the necessary precursor materials to form RNA are present in the dust discs in which planets form, so they must also have been present in the solar nebula that gave birth to our solar system 4.6 billion years ago. But how and when did the organic building blocks arrive on Earth? And what did Earth look like at the time?

There are almost no remnants of the very early phase in which Earth cooled from a glowing ball into a rocky planet. Only the presence of tiny zircon crystals, which could be as much as 4.4 billion years old, suggests that Earth formed a solid crust at quite an early stage. At that time, Earth was exposed to a much heavier bombardment of meteorites than it is today, as is demonstrated by crater statistics for the Moon, which received the same onslaught. The cosmic projectiles presumably brought both water and organic molecules to our planet.

Just as little is known about the distribution of land and water in primeval times as it is about the temperature, for example, which is a crucial factor in chemical reactions. For this reason, the astronomers calculated models in which they varied key parameters of the developing crust over a wide range of values. Earth at the time undoubtedly had water reservoirs with a wide range of sizes, just as it does now. >



The cradle of life: Dmitry Semenov (left) and Thomas Henning from the Max Planck Institute for Astronomy have outlined a scenario in which various reactions once occurred in small, warm pools. These reactions led to the formation of the first self-replicating RNA molecules. The diagram on the left shows the numerous influences that affected chemical compounds in these small bodies of water.

Large lakes and seas were presumably unsuitable breeding sites for RNA, because the precursors must be present in concentrated form in order to react with one another. However, the model showed that small pools with a diameter and depth of just a few meters were ideal: they were large enough not to dry out too quickly, yet small enough to allow high nucleobase concentrations to accumulate rapidly.

At the same time, the biomolecules were at the mercy of destructive influences: in the water, they were endangered by electrolysis and, in the open, by the intensive UV radiation of the sun. Some 95 per cent of UV radiation is absorbed by a layer of water just one meter thick. The optimum scenario seems to be one where the pools experienced seasonal variations in fill level due to rainfall and drying out through evaporation and percolation: "The cycles in which shallow pools first dry out and then fill up with water again may have favored the formation of longer RNA chains," says Henning.

THE IDEAL RADIUS IS BETWEEN 40 AND 80 METERS

In the model simulations, the researchers also varied the impact rate and size distribution of the meteorites. If these are too small, they burn up completely in the atmosphere; if they are too large, they hit the ground with too much kinetic energy. "A radius of between 40 and 80 meters is the optimum size to allow the meteorites to deliver their molecular payload to the ground," explains Dmitry Semenov, an expert in chemical networks within protoplanetary discs and co-author of the study.

This range is two to four times the size of the meteorite that exploded over the Russian city of Chelyabinsk in February 2013. As that incident demonstrated in impressive fashion, meteorites of this order of magnitude do not make it to the ground unscathed – rather, they break up into many small fragments and fall to Earth over a large area. This means it is possible for tiny pieces, measuring just a few centimeters across, to have landed in the pools. Depending on their size, they would then have released the nucleobases over a period of several days to months. After that, the nucleotides – and the RNA molecules formed from them – would have to be synthesized within a few years.

The simulations show that meteorites could have transported a sufficient quantity of nucleobases, to small pools on Earth and thereby triggered the formation of RNA molecules in at least one such pool. The RNA world could have emerged within 200 to 300 million years from the point at which Earth's surface became habitable – that is, over four billion years ago.

Graphic: McMaster University

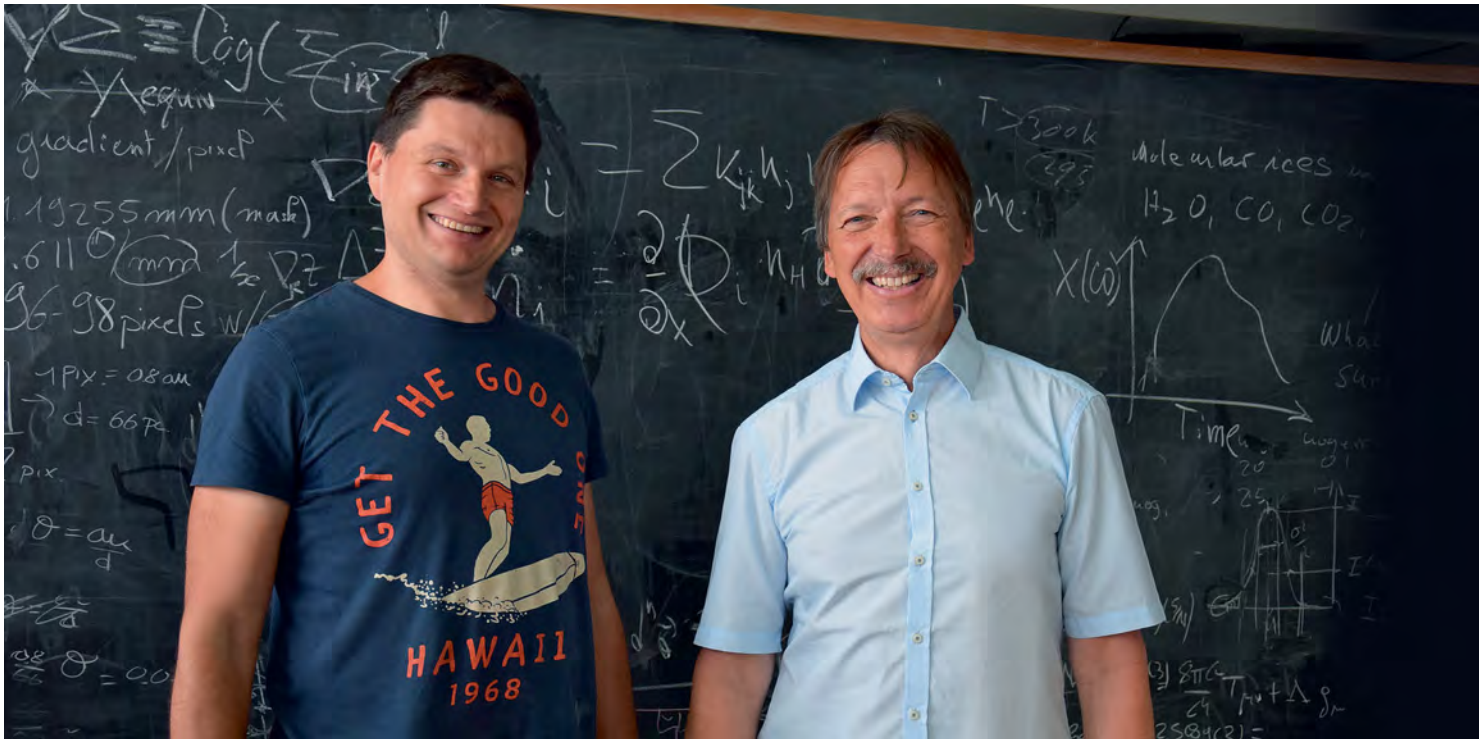


Photo: Axel M. Quetz/MPI for Astronomy

"Based on what we know about planet formation and the chemistry of the solar system, we've proposed a consistent scenario for the origins of life on Earth," says Semenov. "Now, the experimentalists need to work out how life could actually have emerged under these very specific early conditions." In fact, the nucleobases are just the first step. Other necessary processes include, for example, the formation of complex RNA-like molecules, cell membranes and ultimately the DNA-protein world of today's organisms.

It is impossible to talk about chemical experiments relating to the origins of life without mentioning the famous Miller-Urey experiment in the 1950s. Stanley Miller and Harold Clayton Urey placed simple chemical substances within a hypothetical early Earth atmosphere inside a reaction vessel. They then exposed them to electrical discharges in order to mimic the energy supplied by flashes of lightning. After some time, they were able to detect organic molecules, including amino acids, using a chromatograph.

Today, however, researchers assume that Earth's primordial atmosphere had a different composition to that assumed by Miller and Urey, containing less methane and instead higher levels of hydrogen, carbon dioxide, nitrogen and water. In these conditions, it was probably more difficult to synthesize the necessary building blocks for RNA.

GENUINE METEORITE MATERIAL REACTING IN A REACTOR

The job of investigating how this could have been possible falls to Oliver Trapp, who carried out research at the University of Heidelberg before accepting a professorship at LMU Munich. In order to maintain his productive collaboration with the team in Heidelberg, he has become a Max Planck Fellow: the Max Planck Society supports him with research funding and finances part of his 16-person group.

"In our chemical experiments, we reproduce the conditions stipulated to us by the astrophysicists," says Trapp. The researchers therefore take real meteorite material and place it in a reactor, where its reactions then produce numerous organic molecules that can be analyzed using fast chromatographic techniques. The results are surprising: the tiny meteorite particles on the nanometer scale act as catalysts for these reactions.

Interestingly, substances formed in the process then act as catalysts themselves, speeding up the production of the same or even other substances. The reaction enters a state of dynamic imbalance: only the substances that form catalytically the fastest are able to accumulate in large enough quantities. "A

Evolution in the lab: working with Harold Clayton Urey in the 1950s, Stanley Miller (pictured) succeeded in producing organic molecules in a reaction vessel – including amino acids. This famous experiment is today inspiring researchers to carry out further tests.

sort of chemical evolution takes place," says Oliver Trapp. "The aim is to see whether this chemical evolution leads to an RNA world." In these experiments, it has also become apparent that a kind of motor is needed to drive the reactions: the natural light/dark cycle of day and night. In other experiments, Trapp's group is studying fatty acids and the question of how cell membranes could have formed.

The analysis of chemical reactions in different conditions requires the use of high-throughput screening techniques, which allow Trapp's laboratory to run and analyze chemical processes in 64 minireactors, each with a capacity of just 1.5 milliliters. If certain conditions prove especially promising at this stage, they are then studied in greater detail in two-liter reactors. "We jokingly refer to this as our Urey-Miller 2.0," says Trapp.

SEARCHING FOR BIOMARKERS IN THE ATMOSPHERE

The reactions are very complex, and the researchers are only just beginning to address many of the questions. However, Oliver Trapp believes that the emergence of life is inevitable if the conditions are right. "I'm even convinced that the chemical structure of potential extraterrestrial life will closely resemble that of life on Earth."

This also raises the question of whether we will be able to detect the activity of life on another planet. The corresponding biomarkers are generally considered to be molecular oxygen, ozone and methane. However, it is important to bear in mind that the oxygen concentration on Earth did not reach its current value until approximately 300 million years ago. That is a relatively short time frame in terms of biological evolution.

In addition, detecting these substances on an exoplanet could be hampered by a problem that has been hitherto unknown – one that affects planets orbiting cool, low-luminosity stars known as "M dwarfs". The latest examples of such planets are Proxima Centauri b and Trappist-1d. In these systems, the habitable zone lies much closer to the star than is the case with our hotter Sun. A potentially inhabited planet will therefore presumably exhibit bound rotation, in which the same hemisphere always faces the star, resulting in perpetual day on one half of the planet and perpetual night on the other.

Computer simulations by a research group led by Ludmila Carone from the Max Planck Institute for Astronomy in Heidelberg show that a specific air current forms in the atmosphere of such planets. This current causes the ozone to accumulate in the equatorial region, while it is practically absent in all other regions. "If we can't detect ozone on a distant planet, that doesn't necessarily mean there's no oxygen there at all," Carone explains. "We might simply have looked in the wrong place – and the ozone is hiding elsewhere."

Nevertheless, astronomers are searching for a potential second Earth in M dwarf systems too, especially as these are much more common than stars that resemble our Sun. The Heidelberg Max Planck researchers have also been on a very special planetary hunt for a good two years now. Working with colleagues from other German and Spanish institutes, they have built an instrument that is studying around 300 M dwarfs using the largest telescope at Calar Alto Observatory in southern Spain and looking out for signs of rocky planets.

However, the James Webb Space Telescope is another source of great hope for astronomers. Launching in two years' time, at the earliest, this successor to Hubble will travel millions of kilometers from Earth on its mission to explore the universe. One of the prima-

A gigantic compound eye: the gold-sputtered main mirror of the James Webb Space Telescope has a diameter of six and a half meters and is made up of 18 segments. From May 2020, at the earliest, the instrument will scour the heavens and train its sights on distant exoplanets.

ry objectives is to study exoplanets. The Max Planck Institute for Astronomy developed and built key components for one of the four measurement instruments, which goes by the name of MIRI, and so the Heidelberg astronomers will have the chance to make some of the first observations using the super telescope.

Like his colleague Oliver Trapp, Thomas Henning is also confident of the existence of life on faraway planets: "Simply by virtue of the enormous number of rocky planets in our Milky Way – perhaps as many as a billion – and the knowledge that life emerged very quickly on Earth, I think it's very likely that life exists on other planets." Are we therefore heading for a second Copernican Revolution? "No," replies Henning, "we're already in the midst of it." ◀

www.mpg.de/podcasts/ursprung-des-lebens (in German)

Photo: NASA/Desiree Stover

SUMMARY

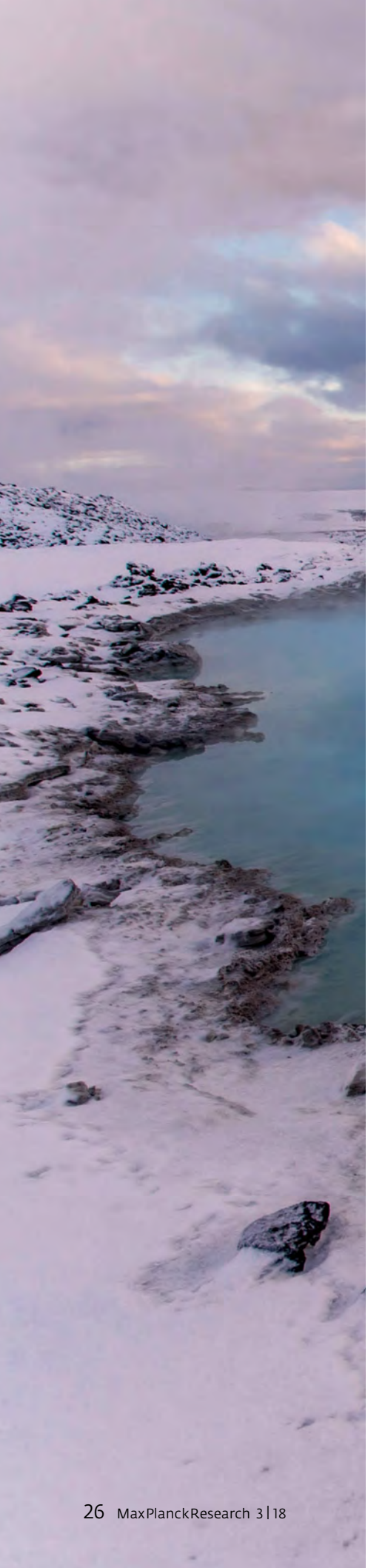
- **Today's life is based on the genetic information carrier DNA. As a forerunner to this, a world based on the simpler biomolecule RNA could have existed on the early Earth.**
- **The building blocks for RNA might have arrived on Earth inside meteorites. Computer simulations suggest that the subsequent synthesis of RNA began in pools measuring just a few meters in diameter.**
- **Using high-throughput screening, it is possible to test a very large number of chemical reactions in a short time and thus to narrow down the optimum conditions for the emergence of life.**

GLOSSARY

Electrolysis: Splitting of a chemical compound under the action of electrical current, resulting in the conversion of electrical energy into chemical energy. Electrolysis is the reverse reaction to that taking place in a battery or fuel cell.

Exoplanet: A planet outside the gravitational field of our Sun but within the gravitational field of another star. Around 3,800 exoplanets are currently known to astronomers.

Nucleobases: Constituents of nucleic acids such as DNA or RNA. DNA contains the nucleobases adenine, guanine, cytosine and thymine; in molecules of RNA, thymine is substituted for uracil. They are called bases because they dissolve in water to form weakly basic solutions. Adenine and thymine, as well as guanine and cytosine, each form base pairs, which then combine with the sugar molecule deoxyribose and a phosphate group to produce the basic backbone of the DNA double helix.



Elixirs from the **primordial soup**

In the Bible, the universe was created step by step: first light, then water and land, and finally the terrestrial animals and humankind. However, from a scientific viewpoint, it seems that the building blocks of life might not have come into being successively, but rather at the same time – at least, this is what **Hannes Mutschler** of the **Max Planck Institute of Biochemistry** believes. He and his colleagues in Martinsried, near Munich, are researching the role played by RNA molecules in the emergence of life.

TEXT **CLAUDIA DOYLE**

Let us go back on a journey through time to the beginnings of our planet. Around 4.5 billion years ago, the Earth was an extremely inhospitable place: its surface was an incandescent sea of molten stone, the sky was full of meteorites that rained down incessantly from space and ripped deep craters in the Earth, and the atmosphere was a mixture of carbon dioxide, ammonium and methane. Living organisms? Not a trace – not in this inferno.

Over the next billion years, the fiery turmoil subsided. The Earth cooled down; oceans and continents formed. And somewhere in the water, life began: the elements of carbon, hydrogen and nitrogen bonded to form complex molecules, and the first cells came into being. Yet how exactly did all this come about?

"It goes without saying that we can't turn back time. That's what makes it so hard to find out what really happened," says Hannes Mutschler, who leads the Biomimetic Systems research group at the Max Planck Institute of Biochemistry. "This is why we are trying to recreate the origins of life in the lab – in conditions like those that prevailed on Earth at the time."

CELLS CREATED BY HUMAN HAND

He and his colleagues aim to create artificial systems that behave like living cells. There are two different ways to go

Photo: Christian Frumolt/Look Foto

Fluctuations between heat and cold may have contributed to the emergence of life on Earth. Laboratory experiments have shown that repeated freezing and thawing can produce complex RNA molecules that can be passed on in cell-like vesicles. This shows that the first cells may have come into being in hot springs such as those that feed the Blue Lagoon in chilly Iceland.

The conditions on Earth in prehistoric times and those in Hannes Mutschler's working group's laboratory could not be more different, yet the scientists can still research the early stages of life thanks to modern research methods. Left to right: Viktoria Mayr, Kai Libicher, Hannes Mutschler and Laura Weise, Alexander Wagner and Kristian Le Vay.

about this. The first is to take an existing cell and successively remove all the parts that are not essential to life. This method was chosen by American scientist and entrepreneur Craig Venter, who at the beginning of the millennium contributed significantly to the decoding of the human genome. The second method, adopted by Hannes Mutschler, is to reverse the process and create a cell from the bottom up.

AS SIMPLE AS POSSIBLE

Mutschler and his team aim to reconstitute parts of simple "protocells" using the bare minimum required – enzymes, nucleic acid components, and a cell envelope. First, the scientists have to identify the molecular building blocks needed for a cell to be viable. Then they have to assemble them correctly in the test tube. "It's like working with a gigantic Lego set," says Mutschler.

The problem is that nobody is able to say exactly what a minimalistic cell needs in order to live. Over millions of years, evolution has gradually refined numerous processes and interwoven them.

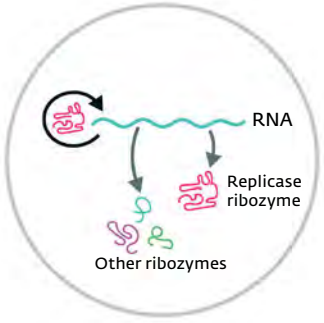
Nowadays, if we look inside a modern cell, it is difficult to distinguish which of the many processes are essential for survival and which are replaceable. "It's as if you would take apart a modern car and be left standing in front of a pile of sheet metal, cables and electronics," says Mutschler. Not all of these components are essential to the functioning of the car, but it is not so easy to see which of them are irreplaceable.

Even in the case of individual molecular structures, it is often unclear which elements are vital. One example of this is the ribosome. This molecular machine uses the cell's genetic information as a template and assembles amino acids in the correct order to form proteins. The structure of the ribosome is highly complex: more than 100 genes are involved in its formation. Is there an easier way? Quite possibly. But nobody yet knows what it is.

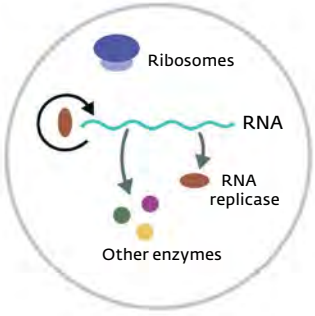
Even today, scientists disagree about the origins of life. Some researchers believe that a simple metabolic process was the beginning of everything. After all, living organisms are characterized by their ability to convert energy and use it for their own survival and reproduction. Energy may have been supplied by differences in the concentration of positively charged hydrogen atoms, for example. These so-called proton gradients were created wherever the acidic water in the early oceans came into contact with alkaline water from subterranean hot springs. Genetic analyses have shown that primal metabolic reactions do in fact draw energy from proton gradients.

But can metabolic molecules exist and function in free, unprotected form,

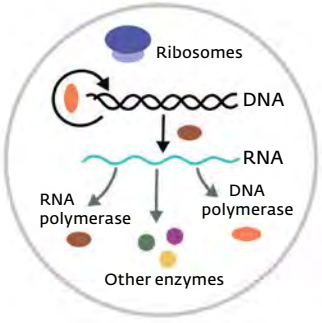
Photo: Axel Griesch



RNA-based minimal cell



RNA/protein-based minimal cell



DNA/RNA/protein-based minimal cell

or do they have to be protected and held together by envelopes? After all, what good is it if the first complex molecules form but drift apart in the open sea? For this reason, some researchers believe that tiny droplets consisting of fat molecules acted as the precursors of modern cell membranes, and it was they that made life on Earth possible.

MOLECULAR CLUSTERS INSTEAD OF CELL MEMBRANE

These membranes have to be stable, able to divide, and capable of controlling which substances are transported in and out of the cell. However, cell membranes of the type found in modern-day cells may not have been necessary at first. Small molecular clusters held together by electrostatic forces – known as coacervates – may initially have performed the tasks of cell membranes. One of the goals of Mutschler's research is to prove this hypothesis. In cooperation with two other working groups from the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, the researchers in Martinsried are investigating whether simple biopolymers can exist in coacervates without membrane and whether they are able to catalyze reactions.

In contrast, other researchers believe that life began with the transfer of information from one generation to the next. But how did this transfer take place?

Nowadays, this task is performed by the molecule deoxyribonucleic acid (DNA). DNA doubles whenever a cell divides. Each daughter cell receives a copy of the DNA and thus a full set of genetic information.

However, many scientists think it is unlikely that genetic material originally consisted of DNA. Instead, some suggest that genetic information was conveyed by ribonucleic acid (RNA) molecules, which cells now use as a mediator for the formation of proteins. In a sense, these RNA molecules are DNA copies that migrate from the cell nucleus to the ribosomes in the cell plasma, where they act as templates for the formation of proteins.

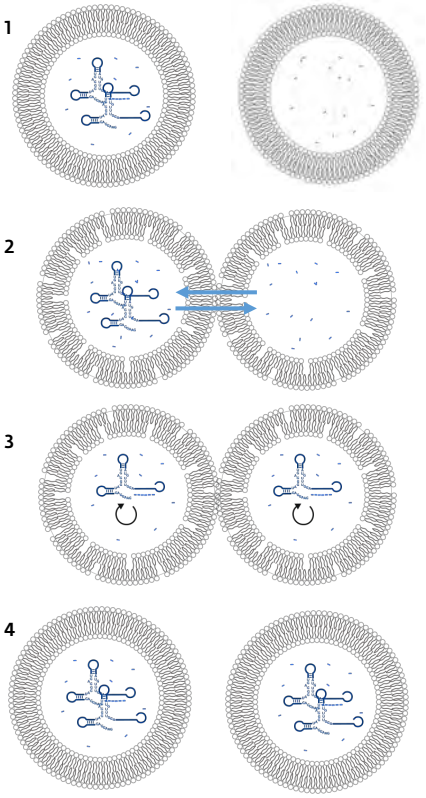
Originally, however, RNA could have been more than an intermediate

Top Different cell variants with minimal components, like those that may have existed when life emerged on Earth: along with RNA-based protocells (left), which use ribozymes to copy their genetic material, there may also have been cells that used proteins (RNA replicase) and ribosomes to replicate their genome (center). Modern DNA/RNA/protein-based cells (right) use DNA as the information carrier for the production of proteins with RNA as the mediator.

Below Part of a chromatography structure with which the researchers can separate mixtures of substances into their components. The individual substances can be divided into different test tubes with the help of the collector.

Photo: Axel Griesch; graphics: MPI of Biochemistry

» In the early days of life on Earth, RNA played a central role by storing information and acting as a biocatalyst. However, RNA molecules probably never acted alone, but were instead supported by other biomolecules.



1 A protocell with (left) catalytic RNA molecules (ribozymes) and without ribozymes (right). **2** The cells exchange their content while in a frozen state. **3** + **4** The ribozymes replicate themselves in the thawed cells. In prehistoric times, simple cell cycles may also have been driven by freezing and thawing, allowing RNA molecules with the ability to self-replicate to spread through the first cells.

product: it may also have served as the repository for genetic material. The advantage of RNA: unlike DNA, it can fold more easily in three-dimensional form. This means that like modern proteins, RNA molecules form structures that act as natural catalysts and accelerate chemical reactions. Known as ribozymes, these RNA structures are not usually as efficient as protein enzymes, yet cells contain thousands of active ribozymes and they are central to the survival of every cell. The catalytic center of the ribosome, for example, consists entirely of RNA, i.e. it is a ribozyme. The ribosome may therefore even be a relic of a long-gone biological era, the so-called RNA world – a world in which RNA performed a dual function as a repository of information and a catalyst for chemical reactions.

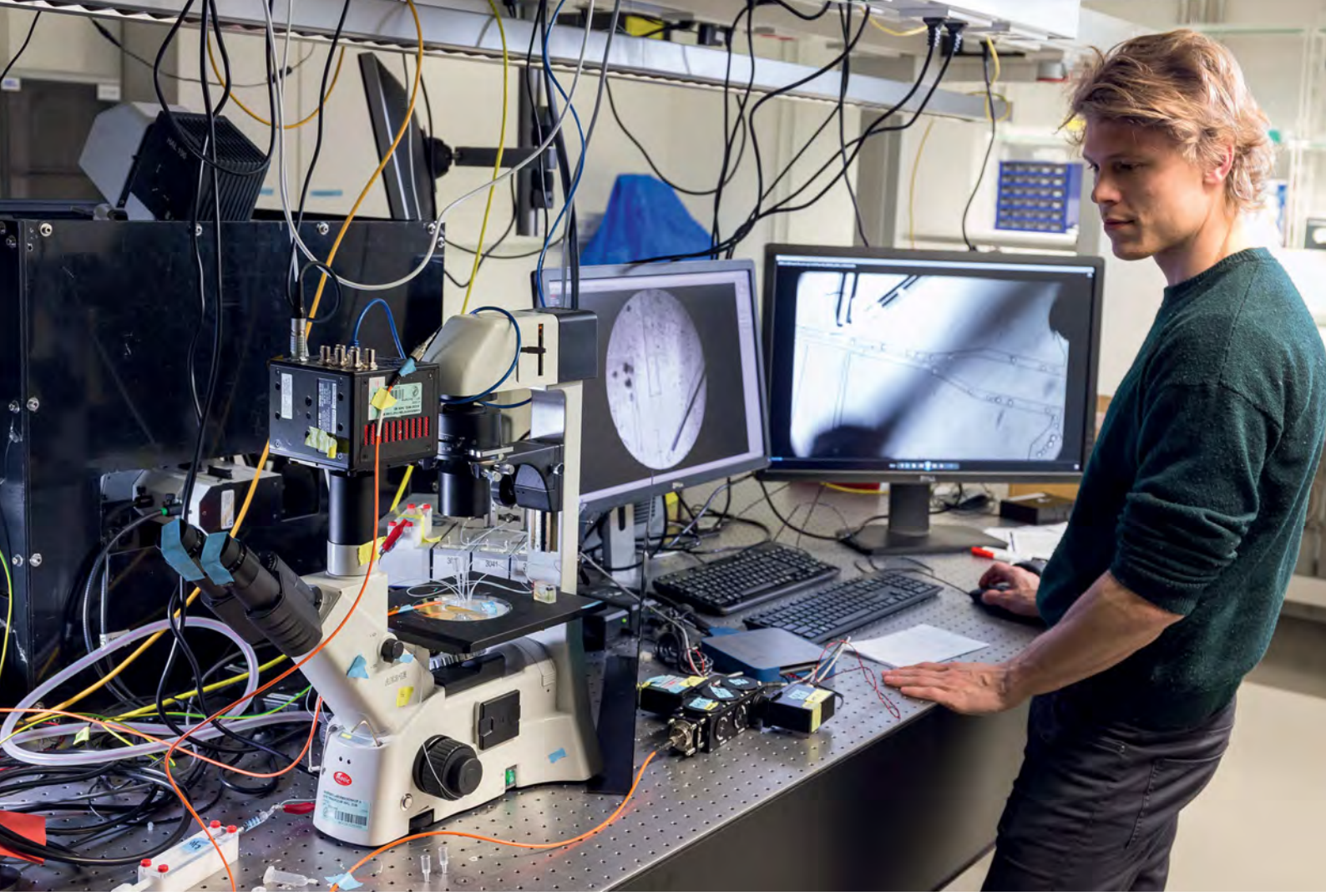
But what triggered the formation of the longer RNA molecules from which the first ribozymes developed? In the Earth's early days, the individual building blocks, known as nucleotides, presumably bonded spontaneously to form very short RNA molecules. "Not much can be done with such short snippets; most of the RNA molecules found in cells are longer," says Mutschler. However, for a long time it was unclear how the long chains needed for ribozymes could form. During the time he spent as a postdoc at the Laboratory of Molecular Biology in Cambridge, Mutschler discovered that in the right conditions, these snippets can themselves bond together to form RNA chains, even complex ones.

FREEZING AND THAWING

One particularly promising procedure, which is conducted several times in succession, involves freezing and thawing a saline solution containing RNA molecules. To do this, the researcher places short RNA chains designed at the computer into saline water. Then he cools the solution slowly. The liquid begins to freeze. At first, ice crystals consisting of almost pure water form, while the positively and negatively charged salt ions remain in the liquid. The fragile RNA likes this environment: the ions give it stability, help it to fold properly, and promote the bonding and linking of individual RNA fragments.

Mutschler then thaws the solution. The RNA strands, which were previously precisely arranged and held together by so-called hydrogen bonds, separate from each other and float about freely again. During the next freezing process, they rearrange themselves and form another bond. Mutschler has to repeat this procedure about twelve times until a strand consisting of around 200 building blocks is formed.

Graphics: MPI of Biochemistry



A microscope with image analysis software is able to recognize various cell types. This enables Kai Libicher to scan and sort 20,000 artificial model cells per second.

Photo: Axel Griesch

"This process would presumably happen by itself, but much too slowly. The repeated freezing and thawing accelerates the bonding considerably," explains Mutschler.

However, one long RNA strand is not yet enough to transfer information to the next generation. The RNA also has to be able to replicate itself independently. In modern biology, an enzyme called RNA polymerase helps it do this. However, this might not always have been the case. Mutschler is therefore currently investigating whether repeated freezing and thawing can also produce a ribozyme with a copy function.

Moreover, the temperature fluctuations have an additional effect: they appear to be able to trigger a basic mechanism that transfers genetic material between protocells. Tiny droplets of fat filled with genetic material adhere to each other during freezing and exchange their contents.

Mutschler's experiments in the laboratory have shown what repeated cycles of freezing and thawing can achieve. Now he has to prove that these processes could also have taken place in the environmental conditions that existed on Earth more than 3.5 billion years ago – the age of the oldest bacteria fossils yet known. Because conditions on Earth were quite chaotic during its early stages, the ecosystems that existed were highly diverse. "This is both a blessing and a curse," says Mutschler. Although this means that scientists can test a wide variety of environmental influences, the list of these is extremely long, ranging from deep-sea hydrothermal springs to craters left by meteorites.

Since many chemical reactions also require UV light, Mutschler assumes that life is more likely to have started at the surface of a body of water rather than deep in the ocean. He believes this most probably happened in hot springs located in cold environments, like those found in Iceland: "Simple molecules could easily have formed in the hot saline water of these springs and merged into more complex molecules in the cold surrounding areas."

PRIMORDIAL EARTH IN THE LAB

Mutschler and his colleagues now wish to investigate this hypothesis further by conducting experiments. To this end, they are cooperating with Paola Caselli's research group at the Max Planck Institute for Extraterrestrial Physics. This institution houses reaction chambers in which scientists can research the origin of organic compounds in space. However, they are equally capable of simulating the conditions that prevailed on the as yet unpopulated Earth. Environmental conditions such as temperature, light wavelength, and the

Hannes Mutschler is unable to turn back time, which is why he will probably never know with absolute certainty exactly what the first cells on Earth looked like. Yet for him, one thing is certain: RNA molecules played a central role in the emergence of life.

composition of the atmosphere can be set with great precision and varied as required. In this way, Mutschler aims to find out how stable RNA is under prebiotic conditions, and whether such conditions can support catalysis and evolution.

Scientists are increasingly coming to believe that genetic information, metabolism, and cell envelopes cannot give rise separately to living cells. Instead, it seems probable that all three of these elements evolved at the same time. The obvious assumption is that the components of life must have developed successively. However, the carefully configured reactions often do not work. They are only initiated when the reaction mixture contains exactly the right amounts of excipients and by-products. Consequently, it seems probable that a wide range of molecules came into being at more or less the same time.

Life may have therefore have emerged in a rather more disorderly fashion than in the researchers' test tubes. Mutschler also favors this idea. "I support the hypothesis that RNA performed a central role as a biocatalyst and an information repository when life first began. However, I also believe that RNA never acted alone and received help from other biomolecules right from the start."

If research into the origin of life is to be successful, it will therefore be crucial in the future to allow chaos in the test tubes – but only just as much as is necessary for life. ◀

www.mpg.de/podcasts/ursprung-des-lebens (in German)

Photo: Axel Griesch

SUMMARY

- **Scientists want to know which components are essential for a cell to be viable. They are therefore attempting to reconstitute a cell with the minimum components – proteins, membrane molecules, and DNA or RNA.**
- **By repeatedly freezing and thawing solutions in the lab, researchers are able to link 200 building blocks for RNA molecules and form longer strands. The first longer RNA molecules on the primordial Earth could therefore have formed in hot springs located in a cold environment.**
- **The most important building blocks of life – genetic material, metabolism and cell envelope – may have come into being not successively, but more or less at the same time.**

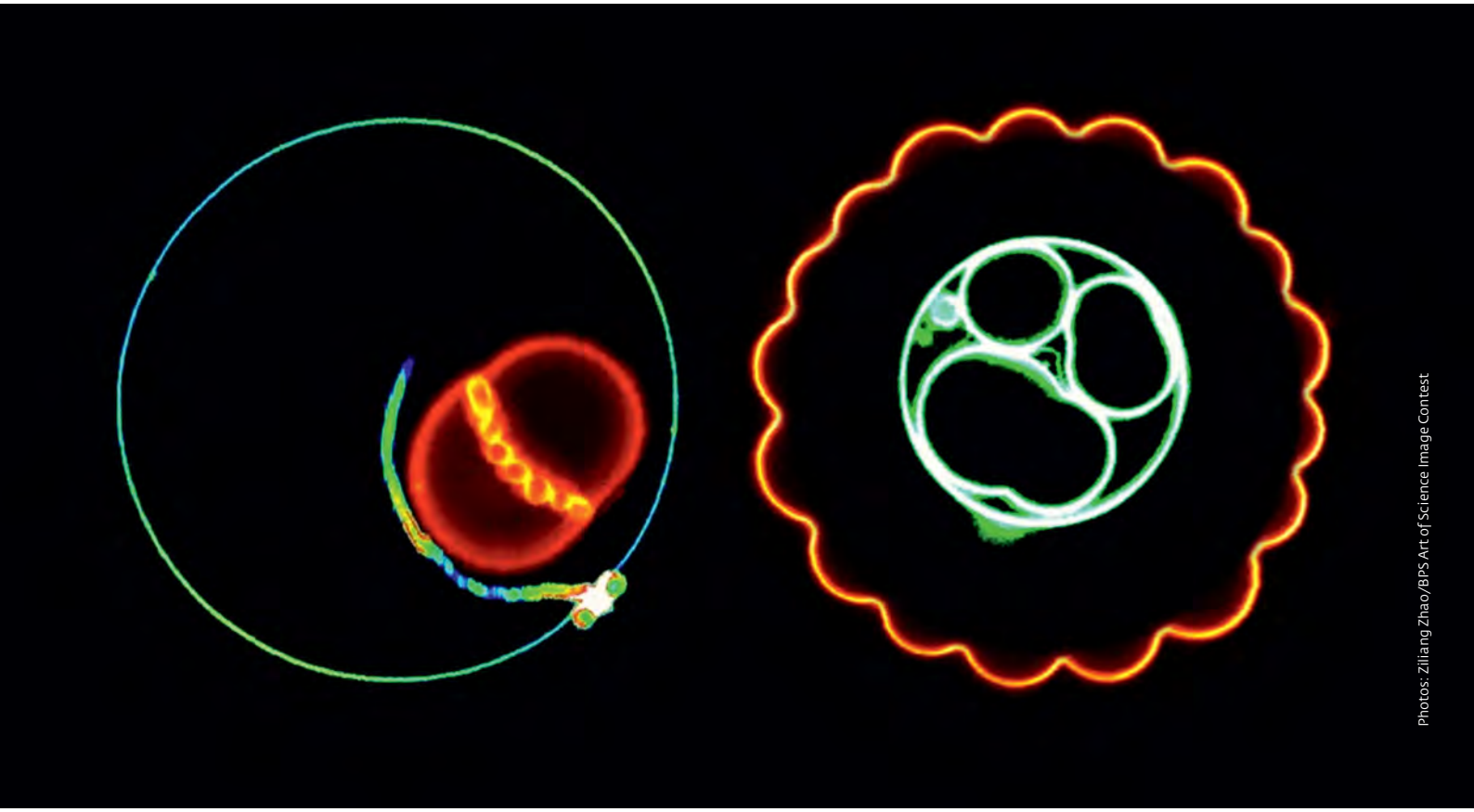
GLOSSARY

Coacervates: Aggregates of macromolecules held together by electrostatic forces between oppositely charged molecules. Chemical reactions can take place inside these structures, where they are protected from external influences; the structures range in size from a thousandth to a tenth of a millimeter.

Ribozymes: Like proteins (enzymes), certain RNA molecules are able to accelerate biochemical reactions. In addition to catalytically active RNA molecules, ribozymes of this type also comprise proteins to which catalytic RNA is bound. As catalysts, ribozymes reduce the activation energy of chemical reactions and thus accelerate them many times over. Ribozymes may have been the first self-replicating biological macromolecules on Earth, as they can function as information repositories and transmitters besides catalyzing chemical reactions.

How cells **get their shape**

Some time around four billion years ago, life started to become encapsulated. The first cells emerged – protected spaces that facilitated the bonding of complex molecules. **Petra Schwille** from the **Max Planck Institute of Biochemistry** in Martinsried and **Rumiana Dimova** from the **Max Planck Institute of Colloids and Interfaces** in Potsdam are exploring the boundaries of cellular life. The two researchers are investigating the dynamics of biomembranes.



Photos: Ziliang Zhao/BPS Art of Science Image Contest

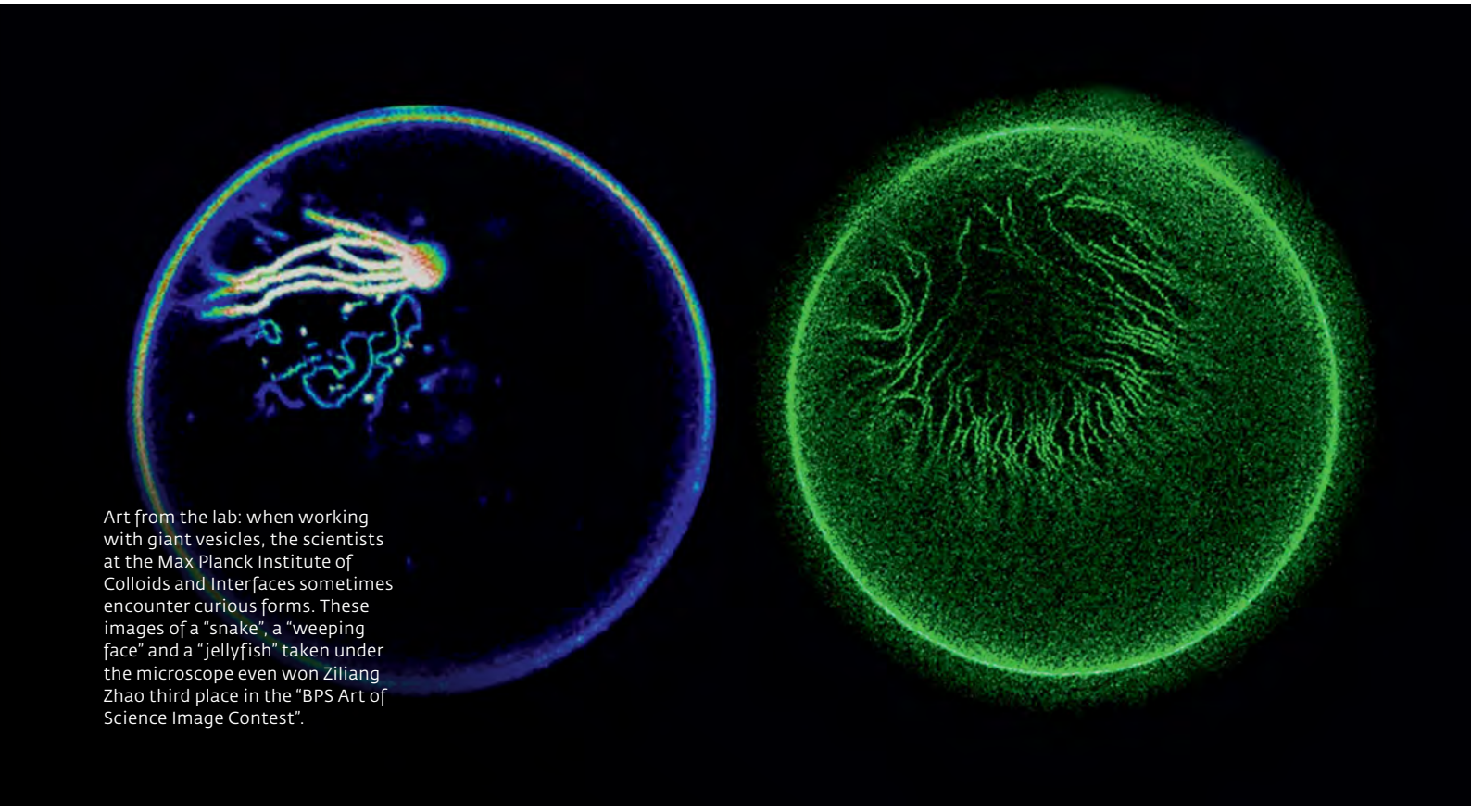
TEXT **ELKE MAIER**

Sometimes life becomes a matter for dispute – at least when we are talking about fossils that are three and a half billion years old. After an American palaeontologist discovered microscopic fossils in Western Australia in 1993, experts spent decades discussing whether these were the remains of living organisms or mineral structures that merely looked like cells.

These ancient relics reveal even less about how the first cells emerged from inanimate matter or about the principles according to which the earliest forms of life functioned. Neither does a look at the present-day living world offer much help: after billions of years of evolution, there are no organisms left on Earth that bear any resemblance to the very first lifeforms.

Researchers in the field of synthetic biology are therefore attempting to obtain new information about the functional principles of life in the laboratory. Nine Max Planck Institutes have joined forces to set up the MaxSynBio research network, which aims to create an artificial cell with minimal components as the lowest common denominator of life. The scientists involved are studying various aspects of living systems – energy supply, metabolism and movement, and growth and division.

"We are trying to break down the processes of life into individual modules and put them together to form a functioning system," says biophysicist Petra Schwille, Director at the Max Planck Institute of Biochemistry in Martinsried and coordinator of MaxSynBio. Like her colleague Rumiana Dimova at the Max Planck Institute of Colloids and Interfaces in Potsdam, she is investigating the mechanisms that



Art from the lab: when working with giant vesicles, the scientists at the Max Planck Institute of Colloids and Interfaces sometimes encounter curious forms. These images of a "snake", a "weeping face" and a "jellyfish" taken under the microscope even won Ziliang Zhao third place in the "BPS Art of Science Image Contest".

enable cells to divide and multiply. The researchers are focusing on the cell membrane – the thin membrane of liquid fat molecules that separates the cell from the outside and which made life possible in the first place.

Life, in fact, is the result of chemical alliances. Complex molecules such as proteins or nucleic acids can only form if countless individual building blocks are assembled in the right order. This is only possible if the molecular partners are available in sufficiently high concentrations to be able to join and bond. At the same time, these first delicate bonds are easily torn apart, especially in an aqueous environment.

A PROTECTED SPACE MAKES LIFE POSSIBLE

Therefore a closed space is needed – a space of the type provided by the first cells. "Cells are essential to life," says Petra Schwille. "It's inconceivable how life could exist without them." The crucial component is the cell envelope, which must be stable and afford sufficient protection while being flexible enough to facilitate growth and division – after all, life has to be able to reproduce.

The first protocells were probably simple, water-filled vesicles that consisted of fatty acids and contained self-replicating RNA molecules. In contrast, modern cells are surrounded by a plasma membrane consisting of phospholipids and embedded proteins. This membrane creates a protected space in which the countless chemical reactions that make up life take place; in addition, it facilitates the targeted transport of substances from the outside to the inside and vice versa. It is mechanically stable yet highly flexible so that the cell can grow and divide. "*Omnis cellula e cellula*" – all cells come from cells, wrote pathologist Rudolf Virchow in 1855.

But how do you make a cell divide in the lab? In such a way that it creates two viable daughter cells of equal size? This is the question being explored by Petra Schwille and her working group. The scientists aim to simulate this fundamental process with the aid of the so-called Min proteins that control cell division in the intestinal bacterium *Escherichia coli*.

The Department's clean room is opposite Schwille's office at the Max Planck Institute in Martinsried. Anyone who wants to go inside first has to step over a shoe rack containing a pair of plastic clogs. Located right behind the door, it blocks the way into the next lab, where no dust is allowed to enter. "This is where you take off your outdoor shoes," says Petra Schwille. "We put the shoe rack across the doorway so that nobody just walks in." This could easily happen to anyone lost in thought – and could possibly ruin the next experiment.

In the clean room, a scanning electron microscope and several micromanipulators are used to mill tiny chambers and ultra-fine channels in plastic

Photo: Axel Griesch

Left-hand page Petra Schwille and her team at the Max Planck Institute of Biochemistry study the behavior of cell division proteins in chambers and channels just a few thousandths of a millimeter in size. As even the tiniest dust particles could immediately clog the minute indentations, the researchers wear protective clothing and work in the clean room.

Right A thriving colony: Petra Schwille (right) and her doctoral student Beatrice Ramm are delighted that their *E. coli* cultures are flourishing. These bacteria serve as miniature factories from which the researchers obtain the cell division proteins they need for their experiments.

Photo: Axel Griesch

and silicone plates. In these indentations, which are just a few thousandths of a millimeter in size, the researchers study the behavior of the Min proteins under controlled conditions. Even the smallest dust particles would clog the fine structures immediately. "The Min proteins orchestrate cell division in *E. coli*," says Petra Schwille. "They show the cell where its center is located and consequently the right place to divide."

Inside the rod-shaped *E. coli* cell, the two proteins MinD and MinE flow back and forth between the cell poles. The driving force behind the incessant oscillation is the interplay between the two proteins: they form complexes, bind to the cell wall and are released shortly afterwards in response to certain biochemical signals. On their way through the cell, the Min proteins spend only a very short time in the middle. This results in a concentration gradient that directs another protein known as FtsZ to the center. "After the Min proteins have located the middle of the cell, FtsZ forms a central ring that initiates the actual process of division," the scientist explains. Without FtsZ, the cells would not be able to divide and would keep on growing longer.

PLENTY OF ACTION IN SPECIALLY DESIGNED CHAMBERS

The researchers in Martinsried obtain the cell division proteins for their experiments directly from *E. coli*. The microbes are cultivated in glass flasks and Petri dishes for this purpose. After isolating the proteins from the cells and purifying them, the scientists attach tiny fluorescent appendages that glow under UV light. This enables them to follow the movements of the proteins under the microscope as they happen.

To do this, they place the Min proteins in the specially made chambers and channels, which are first lined with thin layers of lipids in order to simulate conditions inside the cell. In 2013, Petra Schwille and her doctoral student at the time, Katja Zieske, were the first to succeed in making Min proteins oscillate outside a living cell using an artificial system of this kind. The molecules arrange themselves into artistic patterns, which the researchers can influence by changing the shape of the chambers. After adding the FtsZ protein, it is even possible to reproduce the first stage of the formation of a division ring in this artificial environment.

All this can now be facilitated in artificial cell envelopes. In order to make these, the researchers use the same phospholipids as those found in the plasma membrane of modern cells. Each of these molecules has a hydrophilic head containing a phosphate group and two hydrophobic tails consisting of long hydrocarbon chains. In order to accommodate these opposing preferences, the phospholipids arrange themselves in double layers, with the heads facing outwards and the tails inwards. This is the form they take in the

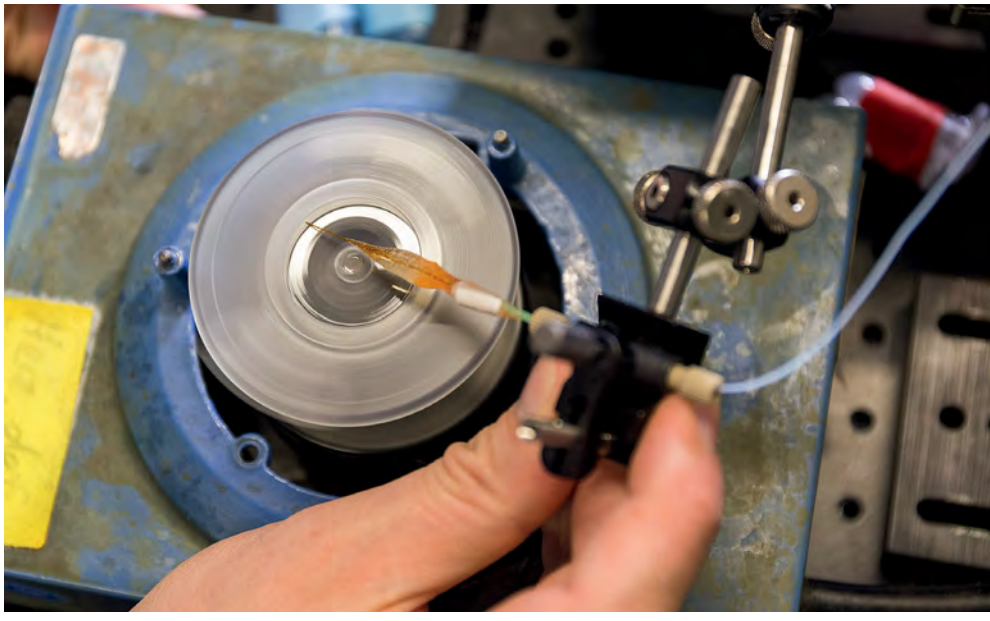
cell wall – a double layer only a few millionths of a millimeter thick.

Phospholipids readily form small bubbles in water/lipid mixtures. This process can be controlled by means of mechanical movement, e.g. centrifuging. This is how industrial companies produce liposomes as transport vehicles for cosmetics or drugs, and it is also the method used by the researchers in Martinsried to produce lipid bubbles as models for protocells. The starting point is a water/lipid mixture containing the cell division proteins encapsulated in the bubbles.

The Min proteins oscillate in these artificial cell envelopes as if they were in living cells, and the FtsZ division ring also forms. These oscillations, which occur solely as the result of self-organization, still fascinate Petra Schwille many years later. "Our goal for the next stage is to actually make the artificial cell divide," she says. Here the researchers are still looking for other factors that play a role in the division process.

Precision work: a special experimental set-up enables the researchers to encapsulate the Min proteins directly in the synthetic vesicles (bottom). Postdoc Michael Heymann performs this tricky task at the microscope with great patience and dexterity (top).

Photos: Axel Griesch (2)



Rumiana Dimova's work at the Max Planck Institute of Colloids and Interfaces in Potsdam has shown that in principle, the ability of cells to divide can be influenced by simple physical mechanisms. The Bulgarian biophysicist leads a working group in Reinhard Lipowsky's "Theory and Biosystems" Department.

She currently has even more work than usual, as she is also the editor and co-author of the mammoth book entitled "The Giant Vesicle Book", which will be published later this year. The "giants" (giant vesicles) are particularly large lipid bubbles up to 100 micrometers (a thousandth of a millimeter) in size. For Rumiana Dimova, they are the perfect model system: they are not only simple to produce and handle but can also be manipulated and observed easily on account of their size. This enables researchers to see directly under the microscope how the cell membrane reacts to certain chemical substances or electrical impulses, for example.

In order to obtain the giant vesicles, Dimova and her team usually use ready-made phospholipids and solutions available from laboratory supplies. "This is very convenient, although the resulting model system is drastically simplified," says the scientist. If specific experiments require vesicles that approximate as closely as possible to natural ones, the researchers use living cells and expose them to a mixture of chemicals.

This chemical cocktail stimulates the cells to form so-called "blebs", tiny protrusions in the cell wall that grow in size and ultimately separate from the cell in the form of giant vesicles. As these contain the same substances as the cells from which they originated, they are particularly useful as realistic models. The researchers in Potsdam use them to find out how physical factors affect the form, mechanical attributes, and growth of the cell envelope along with its ability to divide. For this, they turn their attention to the interior of the giant vesicle.

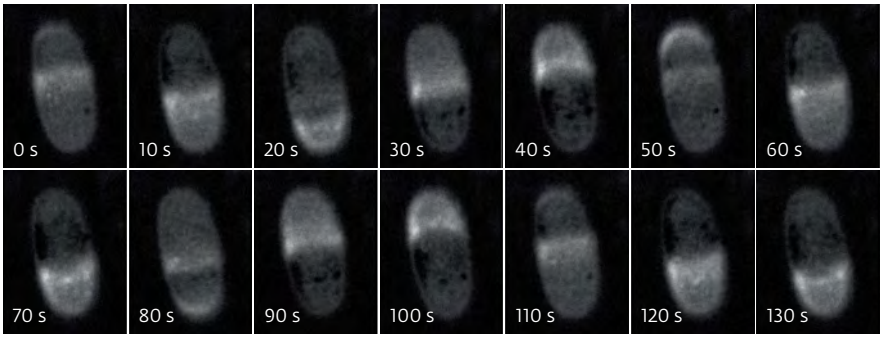
DROPS OF OIL IN VINAIGRETTE DRESSING

A living cell houses various organelles, each of which performs different functions. The Golgi body, for example, secretes proteins, while the mitochondria provide a supply of energy. These classic organelles are enveloped in one or even two membranes. However, the cell also contains organelles with no membranes, compartments with no fixed boundaries that most resemble drops of oil in vinaigrette dressing. Proteins or ribonucleic acids (RNA), for example, are concentrated in these reaction chambers with no fixed confines so that specific reactions can occur.

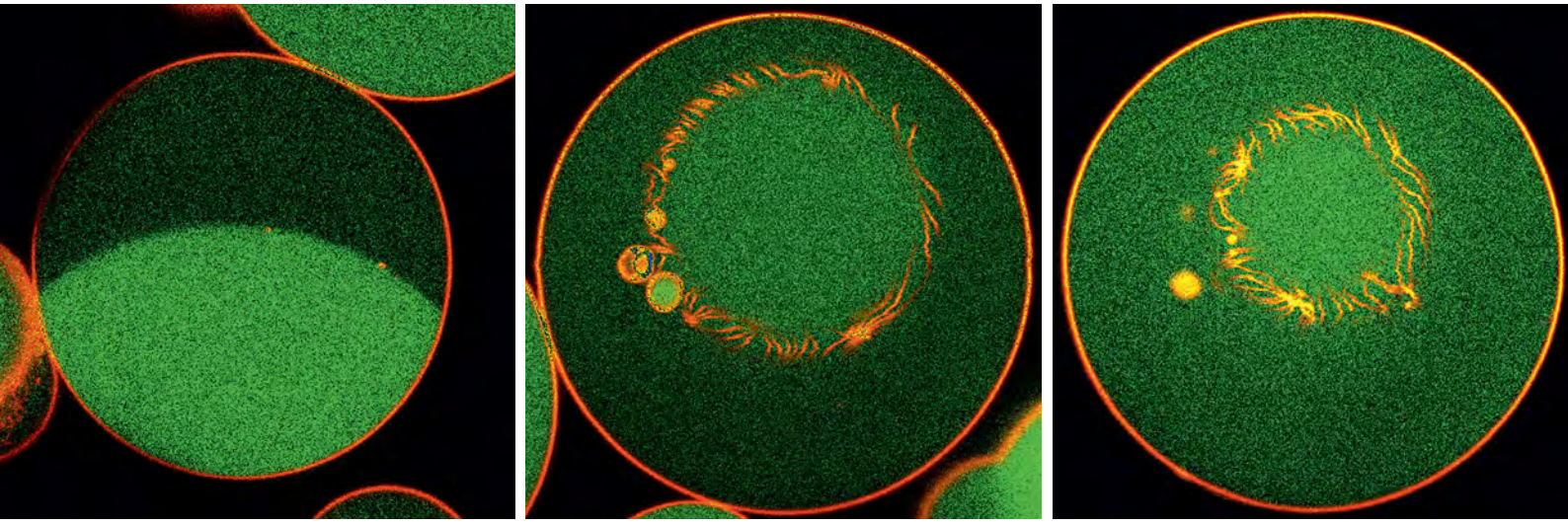
The most well-known of these membraneless organelles is probably the nucleolus inside the cell nucleus, in which components for ribosomes are produced. These nucleoli were first described back in the 1830s. Since then, researchers have identified many such liquid compartments. Some of them exist for just a short time and then disintegrate. They are found in the cell nucleus, cell plasma, or right on the inside of the cell envelope. "Membraneless organelles are currently one of the hot topics in biophysics," says Rumiana Dimova.

How do such liquid structures develop in the liquid interior of the cell, and how do they manage to keep their shape? What happens when these inclusions come into contact with the cell membrane? And how does this influence the cell's shape? Little time has been spent on investigating these and similar questions to date, but research in this area is rapidly gathering momentum. >

Constant oscillation: cell division proteins MinD and MinE display the same behavior in synthetic chambers as in living cells. They oscillate from pole to pole and generate concentration gradients that show where the center of the cell is located.



Photos: Angew Chemie Int Ed. 52 (1), 459–462 (2013)



The scientists in Potsdam are using giant vesicles as chambers in which to simulate the formation of these membraneless compartments. "The mechanism behind this is phase separation," says Rumiana Dimova – the same mechanism that causes oil droplets to form in a well-mixed vinaigrette dressing as soon as it is left to stand. In order to create a two-phase system, the researchers let the vesicles grow in a solution to which two water-soluble polymers, polyethylene glycol (PEG) and dextran, have been added.

"The polymers become encapsulated in the giant vesicles," explains the scientist. "We then increase the osmotic concentration of the surrounding medium. This causes the water in the vesicles to penetrate the membrane to the outside, as a result of which the concentration inside the vesicle increases. The increased polymer concentration inside the vesicles causes two phases to separate: two droplets form and can be easily viewed under the microscope."

Rumiana Dimova and her team are investigating how these droplets interact with the cell membrane. What happens when one of these droplets touches the membrane? Does it merely touch the membrane, or does it also wet it? "This has a decisive influence on the dynamics of the membrane, for example its curvature," says the scientist.

A BALLOON LEAKING AIR

This type of two-phase system even allows researchers to reconstruct the composition of membraneless organelles. For this, they let their vesicles grow in a solution that contains biopolymers such as proteins and RNA instead of PEG and dextran. "Proteins and RNA are the main components of membraneless organelles," says Dimova. "And there are plenty of possible points of contact with membranes inside the cell – not only on the inside of the cell envelope, but also on the endoplasmic reticulum, for example." This is a densely branched channel system enclosed by membrane that accounts for more than half of all the membranes inside the cell.

Moreover, the giant vesicles can be made to divide – just by continuing to increase the osmotic concentration outside the vesicle. This causes the pressure inside the vesicle to drop so far that the droplets drift apart until they are touching the vesicle's inside wall. By this stage, there is no tension left in the vesicle wall – like a balloon from which all the air has leaked. Droplets wetting the membrane can cause the membrane to bulge and constrict the vesicles.

"Our experiments have shown that simple physical processes such as phase separation and wetting have an enormous influence on the shape of cells and their organelles," says Rumiana Dimova. Depending on whether the nearby membrane is curved or under tension, the envelope can protrude inwards as well as outwards. "This type of invagination facilitates the flexible storage of cell wall material that is not currently needed," says the scientist. Structures of this kind may even have played a role in evolution as the precursors of organelles enclosed in membrane such as the endoplasmic reticulum.

Yet why is cell division in nature so complicated when it could be so much easier? Why did evolution come up with something as complicated as the Min system in *E. coli*? "'Why' questions are even harder to answer in the field of biology than in the other natural sciences," says Petra Schwille. "There isn't actually any objective reason why this type of cell division should be better

Photos: Rumiana Dimova/MPI of Colloids and Interfaces

Left-hand page The researchers in Potsdam use water-soluble polymers to generate a two-phase system inside the giant vesicle similar to a drop of oil in a vinaigrette dressing. If one of these droplets touches the vesicle wall, the wall can deform, protrude inwards and even form tubular structures (second and third images from left).

Right Rumiana Dimova and her colleague Ziliang Zhao at the Max Planck Institute of Colloids and Interfaces view the results of their two-phase experiments at the computer.

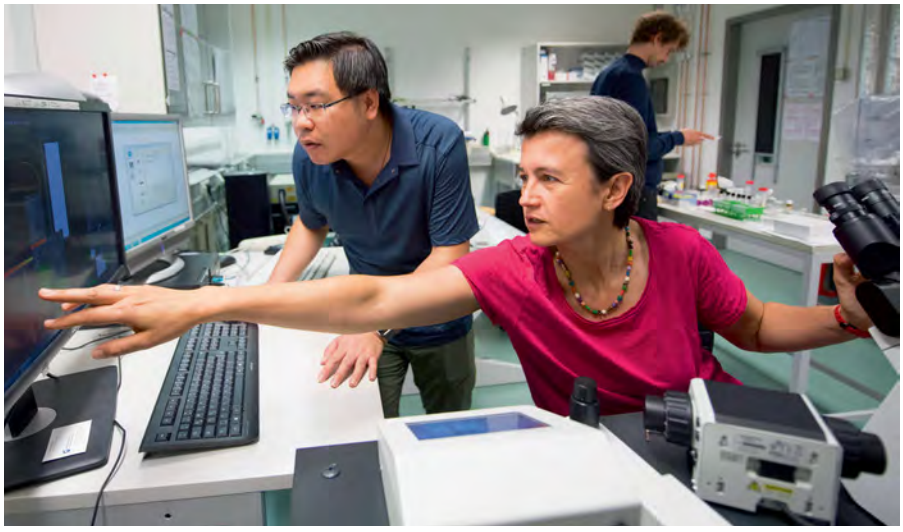


Photo: Jens Jeske

than all the others. However, it's ideal for the rod-shaped bacteria, and the oscillations presumably have ancillary effects – they might help distribute the DNA evenly in the daughter cells, for example. This isn't certain though."

What is certain, however, is that the separation of the genetic material and the actual division of the cell are a key stage on the way to new life. Both processes have to be perfectly coordinated if two viable daughter cells are to result. This precise spatial and temporal coordination requires a sophisticated system.

Yet will it ever be possible to find out how the first cells isolated themselves from their environment and what caused these cells to start dividing? How can we know what actually happened when matter made the transition from inanimate to animate? Petra Schwille takes a pragmatic view of these concerns: "We don't necessarily have to become fixated on how the first cells worked in order to understand the fundamental principles of life," she wrote in an essay. "Instead, we should concentrate on the basic modules of living systems. After all, the first functional flying machines built by humans were not made of feathers." ◂

www.mpg.de/podcasts/ursprung-des-lebens (in German)

SUMMARY

- **The MaxSynBio research network was established jointly by nine Max Planck Institutes with the aim of creating a synthetic cell with the minimum components necessary. In this context, the scientists are focusing on the basic mechanisms of living systems such as growth and division.**
- **Cell division in the intestinal bacterium *Escherichia coli* is controlled by so-called Min proteins. These form concentration gradients inside the cell that show where the new cell wall is to be drawn in.**
- **Even simple physical mechanisms such as phase separation and wetting have an enormous influence on the cell's shape, mechanical properties, growth and ability to divide.**

GLOSSARY

Organelle: Definable area inside a cell to which a specific function can be assigned.

Plasma membrane: Biomembrane that encloses modern-day cells. It separates the cell from the outside world while facilitating exchange; it also performs many other functions.

Protocells: Precursors of the first cells. The first lifeforms are believed to have originated from these around four billion years ago.

Ribonucleic acid (RNA): Single-strand macromolecule consisting of four different nitrogenous bases, a ribose sugar and a phosphate group. RNA performs a variety of tasks inside the cell. Among other things, it is responsible for transmitting the protein building instructions from the DNA in the cell nucleus to the ribosomes.

Wetting: Describes the behavior of liquids when they come into contact with solid or fluid bodies – in this case the lipid membrane. Wetting influences the physical properties of the membrane and thus affects its shape and ability to divide.

Storks on the wing

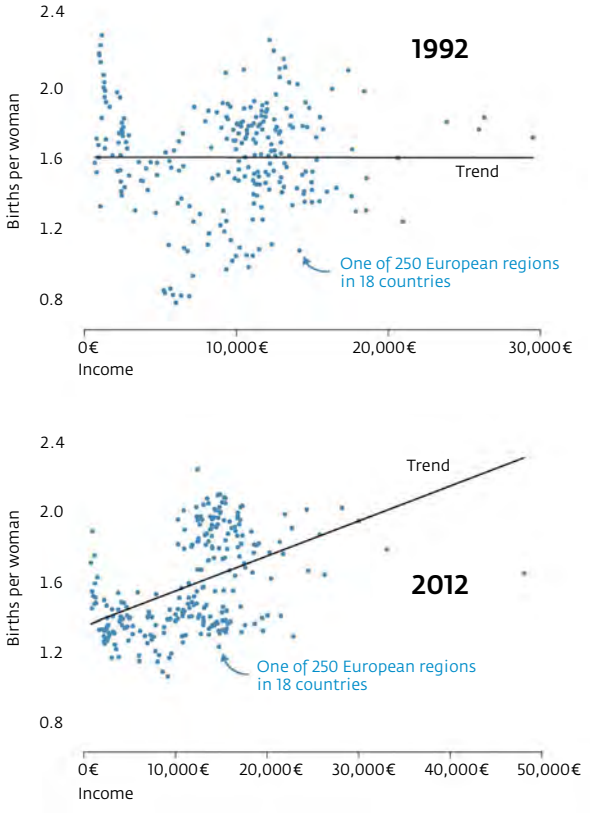
Scientists know which animals will be overwintering in Africa and which will be staying in Europe shortly after they begin migrating

Young storks just a few weeks old in their nest; they have been fitted with transmitters. The devices weigh less than 60 grams and record the GPS coordinates and acceleration of each bird. The latter information tells the researchers whether the bird is flapping its wings or gliding.

Every year in the late summer and fall, a fascinating drama plays out around Lake Constance: the storks leave to spend the winter in South-West Europe, North Africa or West Africa. In the spring of 2014, scientists at the Max Planck Institute for Ornithology in Radolfzell strapped GPS transmitters to a number of young storks that were just a few weeks old and have been meticulously tracking their flight ever since. By performing sophisticated analyses of the GPS data, the researchers, working in cooperation with colleagues from the University of Constance, have discovered that there are leader birds within the groups of migrating storks. These leader birds guide the groups to regions with favorable thermals, where they are literally sucked up by the warm rising air. This means they can switch from active flight to gliding in order to save energy. The follower birds are poorer gliders and have to flap their wings more frequently on their journey. They benefit from the experience of the leader birds but fly more slowly and lose height more quickly. The length of time for which a stork can glide determines where it will spend the winter: the best gliders fly the farthest. Just a few minutes after each bird departs, the scientists can predict on the basis of its wingbeats whether it will be overwintering in Europe or flying on to West Africa. (www.mpg.de/12041435)

Higher income means more children

There is a good chance that rising incomes in Europe will no longer lead to lower birth rates in the future. As prosperity increased through the decades of the 20th century, the number of children born to each woman declined. However, data collected from 20 European countries over the last 30 years shows that this correlation no longer exists. Nowadays, the regions of Europe where incomes are higher tend to have higher birth rates. This conclusion is drawn in a study published by Sebastian Kluesener and Mikko Myrskylae from the Max Planck Institute for Demographic Research in Rostock in cooperation with Jonathan Fox from the Free University of Berlin. The researchers believe that this turnaround is mainly due to the expansion of childcare facilities and the increased flexibility of working conditions, which are making it easier to combine family and working life. "Even in areas with very low birth rates, people always wanted to have more children," says Myrskylae. "They now have the opportunity to have the bigger families they want." (www.mpg.de/12041447, in German)



Families trending: thanks to more flexible working conditions and support from the government, more children are being born, particularly in highly developed metropolitan areas.

Photo: MaxCine/Christian Ziegler (top); graphic: Max Planck Institute for Demographic Research

Drummed speech

A tribe in the Amazon sends an astonishing variety of messages by drum beat

How can an entire language be translated into drum beats? An international team of researchers, including Frank Seifart and Sven Grawunder from the former Department of Linguistics at the Max Planck Institute for Evolutionary Anthropology in Leipzig, has found an answer to this question by analyzing drummed speech in the North-West Amazon. The Bora, an indigenous group, uses special drums to relay informal messages and public announcements over long distances. Drum messages are customarily sent to ask someone to bring something or announce the outcome of alcohol-free drinking competitions. What surprised the scientists was that rhythm is crucial when transmitting information. Although the Bora drums have four pitches, only two of them are used to send verbal messages, and even these pitches play a subordinate role. More important are the intervals between vowels, which are reproduced by drum beats. This suggests that the rhythm of language may play a more important part in processing language than previously assumed. (www.mpg.de/12017337)

Message center in the Amazon: the Bora indigenous group uses special drums to imitate the rhythm of their speech.

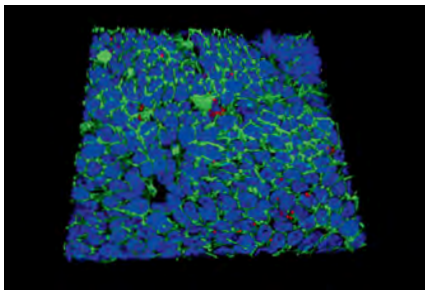
Light gets ions going

Light makes some materials conductive in a way that no one had previously imagined. In ordinary silicon solar cells, electrons flow when the sun shines. However, scientists at the Max Planck Institute for Solid State Research in Stuttgart have now made a surprise discovery: in one particular form of perovskite, another material used for solar cells, light releases not only electrons, but also ions, i.e. electrically charged particles. Moreover, this novel photo effect takes place on an extremely large scale: the conductivity of the ions is increased by a factor of one hundred. This high light-induced ion conductivity tends to damage solar cells made from the material under investigation as it can change their structure; however, systematic measures can now be taken to counteract this impact. The researchers in Stuttgart assume that this effect will facilitate the development of innovative, light-controlled electrochemical applications such as batteries that can be directly charged with light. (www.mpg.de/12009261)

Invisible pathogens

Stomach bacterium extracts cholesterol from the gastric mucosa to defend itself against attacks by the immune system

For a long time, stress and an unhealthy diet were believed to be the main causes of stomach inflammation (gastritis) and ulcers. The bacterium *Helicobacter pylori* was not identified as the actual culprit until the 1980s. Moreover, this pathogen, with which half of the world's population is infected, is seen as the biggest risk factor for stomach cancer. With the help of mini-organs grown in the laboratory, scientists at the Max Planck Institute for Infection Biology in Berlin have now discovered how the bacterium is able to survive the immune system's attempts at defense: it extracts the fat molecule cholesterol from the membranes of gastric epithelial cells. This means that areas consisting of cholesterol can no longer be formed in the cell membrane. These lipid rafts are essential for the correct assembly of receptor molecules for cytokines in the immune system. In this way, the bacterium creates a niche in which it remains undetected by the immune system. This probably also explains why no one has yet succeeded in developing a vaccine against *H. pylori*. (www.mpg.de/11974260)



A mini-organ consisting of human gastric epithelial cells infected with *Helicobacter pylori* (red: *H. pylori*, blue: cell nuclei, green: cell membranes). Thanks to these so-called mucosoids, researchers can investigate inflammatory processes over a long period and obtain important information about how cancer starts.

Photos: Gaiamedia/Aexcram (top), Rike Zietlow/MPI for Infection Biology (bottom)

Chimpanzees suffer from heat stress

Primates living in the savannah are at risk of overheating and dehydration, particularly during periods of drought

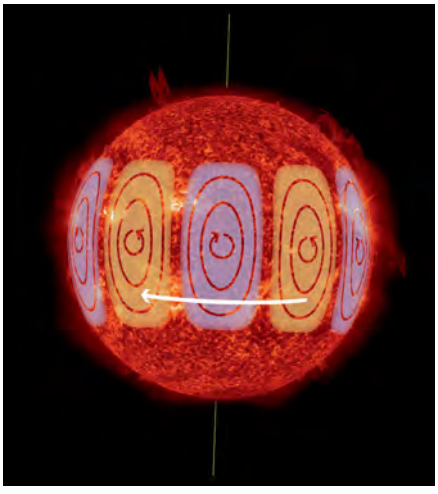
Heat and drought are the biggest problems facing savannah chimpanzees; in contrast, they appear to have enough food. They have adapted their behavior to prevent overheating: they bathe in water sources, spend time in caves and are also active at night.

The climate in the grass savannah of Senegal is brutal. The dry season lasts no less than seven months, and the average temperature is 37 degrees. These conditions are apparently a major source of stress for the chimpanzees living there, as researchers from the Max Planck Institute for Evolutionary Anthropology in Leipzig have discovered. The scientists collected the chimpanzees' urine and analyzed the concentration of hormones produced to cope with heat stress, dehydration and lack of food. The results clearly show that the animals are particularly prone to heat stress and dehydration towards the end of the dry season, when temperatures reach around 45 degrees, and it has not rained for months. The biggest challenges faced by savannah chimpanzees are therefore finding enough water and not overheating. Lack of food appears to be less of a problem, although the savannah has relatively few food sources for the animals. The chimpanzees have apparently expanded the range of foods they eat in order to adapt to their hostile environment. These results support the hypothesis that heat stress and dehydration were also serious problems for our hominin ancestors when they settled the open grasslands. These early humans probably adapted to the heat and drought by sweating more profusely and losing some of their body hair. (www.mpg.de/12039762)

Giant swirls on the sun

The waves that have now been found on the Sun are similar to those that control the weather in the Earth's atmosphere

A team of scientists led by the Max Planck Institute for Solar System Research and the University of Goettingen has discovered gigantic swirls on the Sun. These Rossby waves propagate in the direction opposite to rotation, have lifetimes of several months and maximum amplitudes (deflections of the vibration) at the equator. For forty years, scientists had speculated about the existence of such waves on the Sun, which should be present in every rotating fluid system. They have now been clearly identified for the first time. For this, the scientists analyzed data that had been gathered by NASA's *Solar Dynamics Observatory* over a period of six years. The solar Rossby waves are closely related to the Rossby waves that occur in the Earth's atmosphere and oceans. On weather maps, they appear as meanders in the jet stream separating cold polar air in the north from warmer subtropical air further south. In principle, waves of this type arise on every rotating sphere due to the Coriolis force. (www.mpg.de/12032196)



Turbulent Sun: the Rossby waves move counter to the Sun's direction of rotation. Their amplitude (the maximum deflection of the vibration) is largest close to the equator.

Photo: Erin Wessling/MPI for Evolutionary Anthropology (top); MPS/NASA/HormesDesign (bottom)

Avatars for the virtual zoo

Using just a few photos, a new technique can create lifelike models of animals that are able to move just like their real-life counterparts

Filmmakers and computer game developers will in future have access to a new method of animating animals. A team of researchers from the Max Planck Institute for Intelligent Systems in Tuebingen has developed a technique that can create lifelike 3D avatars of almost all quadrupeds using nothing but photographs. These can be animated to realistically imitate the movements of real animals. The researchers can bring the avatars to virtual life with relatively little effort because, unlike previous methods, they start with models that they already presented in an earlier work. These models include dogs, cats, horses, bovine animals, goats and hippos. The new method also adapts the models for other quadrupeds: bears, rhinos and even the extinct Tasmanian tiger. (www.mpg.de/12106987)

The technique developed by the researchers in Tuebingen uses photos of animals (bottom row) to create 3D models (top row) that can reproduce different postures and whose surface is designed according to the original body cover (middle two rows).

Graphics: MPI for Intelligent Systems

Fewer genes, better adaptation

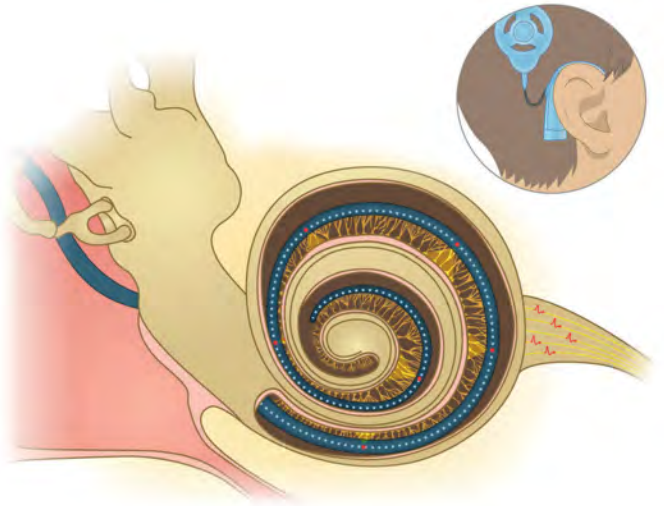
In evolution, new traits are often based on mutations and copies of existing genes or the development of new ones. However, the loss of genes can also trigger the development of attributes that are essential for survival. Scientists at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden have developed a method of determining gene loss. For this, they investigated the genomes of more than 60 mammals to find out which genes have been lost in each species. These analyses show that dolphins and whales have lost several of the genes that are needed for hair growth. Since these species live exclusively in water, hair can no longer serve to warm the organism and would make swimming slower. Fruit-eating bats, on the other hand, lack genes that suppress the secretion and effect of insulin. This enables the animals to extract energy from sugar more effectively – certainly an advantage for a species that consumes large quantities of sugar. Some species that have developed the same traits in order to adapt to their environment but are not closely related have lost exactly the same genes, such as the pangolins and armadillos, for example. Both have lost a gene that is involved in repairing DNA damage caused by UV light. The animals' scales apparently afford sufficient protection from UV light so that they no longer need the DNA repair gene. The loss of genes has therefore contributed towards the development of new traits in mammals during the course of evolution. (www.mpg.de/11994695)

Hostility is contagious

Aggressive behavior towards other ethnic groups can easily escalate and end in conflict. Jana Cahlíková from the Max Planck Institute for Tax Law and Public Finance and colleagues in the Czech Republic and Slovakia are collaborating in a new kind of experiment to test the influence of social environment on the dynamics of hostility. The researchers studied adolescents from schools in eastern Slovakia and their behavior towards the Roma people. For the experiment, two players each received two euros and had to decide simultaneously whether to pay 20 cents to reduce the other person's income by one euro. The players remained anonymous but were told whether their counterpart belonged to the Slovak majority or the Roma minority. Moreover, the scientists had three young people from the same class make the decision in quick succession, and the subsequent players knew of the decisions made by their classmates. It turned out that aggressive behavior on the part of the first players clearly incited the others to act equally aggressively. It was noted that this influence more than doubled when the hostility was directed at Roma rather than the players' own social group. (www.mpg.de/12033500)

Fast light channels fire hearing

Optogenetic cochlear implants may one day enable deaf people to listen to music

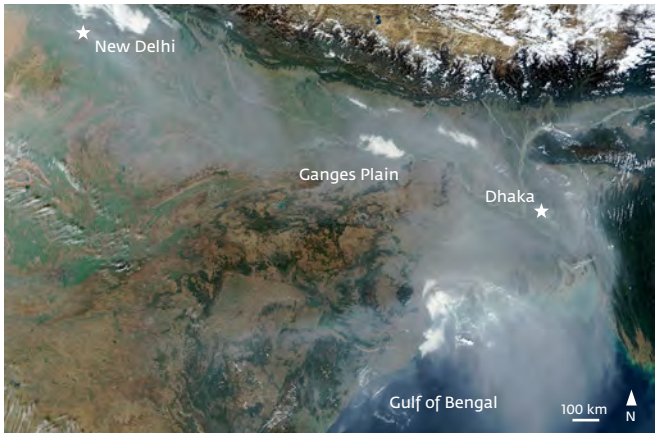


Unlike conventional cochlear implants, optogenetic implants stimulate the nerve cells in the cochlea with light pulses from tiny light sources (light blue dots). For this to succeed, the cells must have light-sensitive ion channels in their membranes.

A conversation on the street, a concert visit – everyday things are often impossible for people with impaired hearing. Conventional electric cochlear implants stimulate the auditory nerve cells in the cochlea with twelve to 24 electrodes, thus circumventing defective or missing sensory cells in the cochlea. Since they do not convey enough information about pitch, the hard of hearing can understand speech in quiet surroundings but cannot hear the melodies in language and music. One alternative may be implants that initially convert sounds into light signals and thus trigger light-sensitive molecules in nerve cells. This would make it possible to stimulate the neurons temporally and spatially with greater precision. Until now, the ion channels, known as channelrhodopsins, have been too slow for the cells in the auditory nerve. Scientists at the Max Planck Institute of Biophysics in Frankfurt have now converted several channelrhodopsins into molecular light switches that are ultra-fast by means of mutation. Experiments with nerve cells from the brains and auditory nerves of mice have shown that the nerve cell channels can be fired at nearly their maximum natural excitation rate. Since nerve cells do not produce channelrhodopsins naturally, the scientists are using harmless viruses as gene "shuttles" to transport the gene for the molecules into the cells. Researchers at the Goettingen campus have been able to demonstrate that auditory nerve cells in mice produce large quantities of the channel proteins after the virus is injected into their cochleae. Laser pulses conducted into the cochlea along a 50-micrometer thick optical fiber trigger electrical impulses in the mice's auditory nerves and brain stems. Optogenetic cochlear implants could one day enable profoundly deaf patients to understand speech in loud surroundings and enjoy music. However, further studies are necessary before such implants can be put to practical use. (www.mpg.de/12025243, in German)

The Janus head of the South Asian monsoon

The same thing happens every year. During the dry season in winter, the combustion of fossil fuels and biomass causes a gigantic haze of pollution to form over South Asia: the *Atmospheric Brown Cloud*. An international team of scientists led by the Max Planck Institute for Chemistry has now discovered why it disappears as soon as the monsoon ushers in the rainy season in the spring. It appears that updrafts, storms and chemical reactions strengthen the atmosphere's ability to clean itself. One crucial factor is that more hydroxyl radicals form in a circulation of winds above the monsoon. These molecules act as a kind of cleaning agent: they oxidize airborne particles and pollution, as a result of which some of the pollutants dissolve more easily in water and are washed out of the atmosphere by precipitation. However, the pollutants that are not washed away are driven into the upper troposphere by the monsoon and then distributed around the globe. (www.mpg.de/12104908)



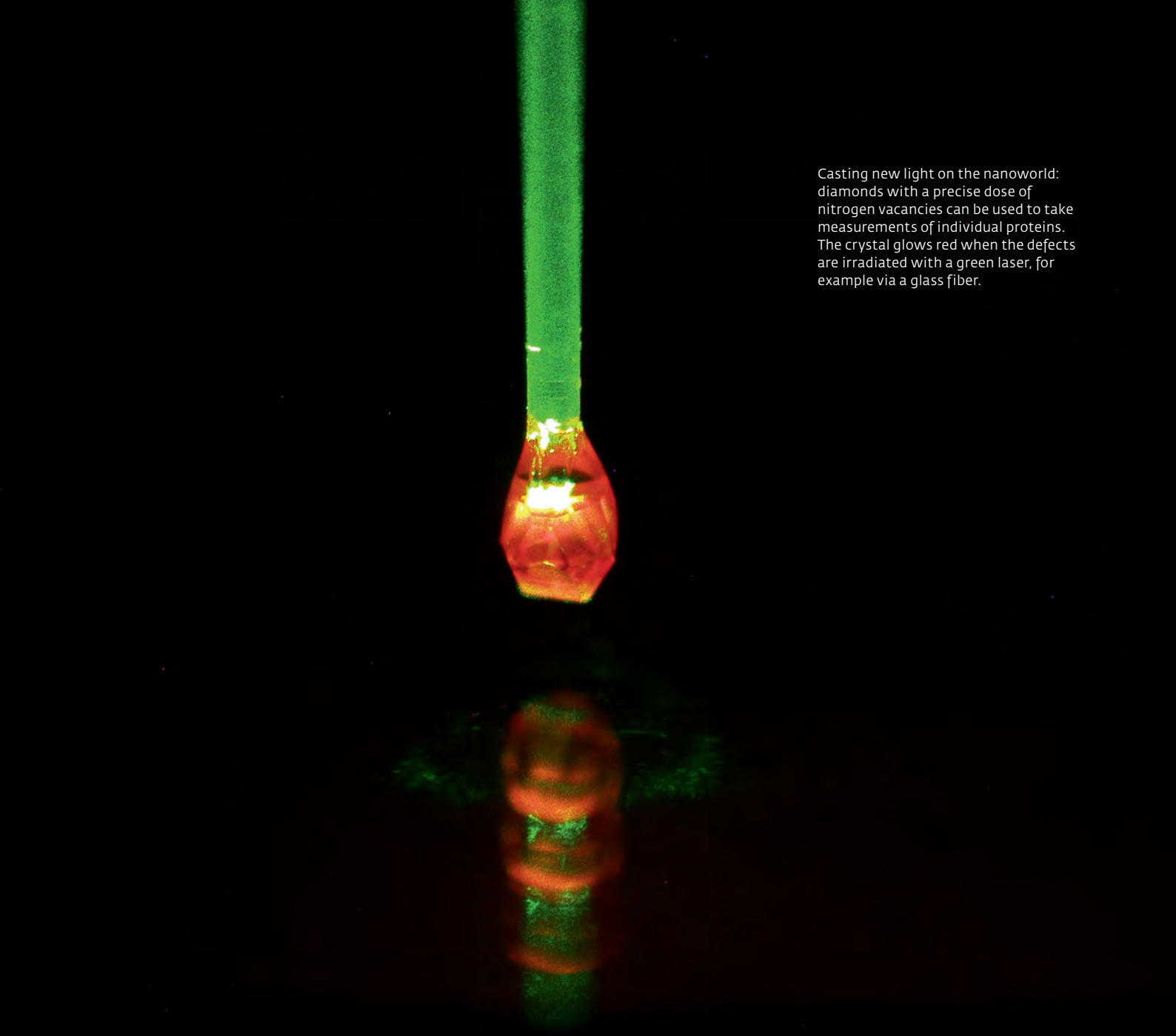
Every year during the winter months, a huge haze of pollution forms over South Asia – and disappears again in March.

Graphics: Institute for Auditory Neuroscience, University Medical Center Goettingen; photo: NASA, Jeff Schmaltz, LANCE/EOSDIS Rapid Response

Diamond – a flawless sensor

Brilliant-cut diamonds can emit a dazzling array of light, but that is not what attracts **Joerg Wrachtrup** to these precious stones. The Professor of Physics at the University of Stuttgart and Fellow at Stuttgart's **Max Planck Institute for Solid State Research** works with less conspicuous diamonds. His team uses these to develop sensors that are intended to allow live observation of the molecular machinery in a living cell. These insights into the nanoworld could also be of benefit in medicine.

Photo: University of Stuttgart



Casting new light on the nanoworld: diamonds with a precise dose of nitrogen vacancies can be used to take measurements of individual proteins. The crystal glows red when the defects are irradiated with a green laser, for example via a glass fiber.

Photo: University of Stuttgart

TEXT **ROLAND WENGENMAYR**

Diamonds can also look like this – a tiny, rectangular block of jet-black material in a small box that Matthias Pfender has taken out of a drawer. Pfender is a doctoral student working under Joerg Wrachtrup, and we are in a laboratory at the University of Stuttgart, where Wrachtrup is Professor of Physics. Wrachtrup also carries out research as a Fellow at the neighboring Max Planck Institute for Solid State Research, of which he has a good view from his office window at the university.

Matthias Pfender then shows us a tiny yellow plate of diamond, whose laser-cut shape is reminiscent of a small plastic building block in a child's bedroom. "We don't exactly give our diamonds a brilliant-cut finish," Wrachtrup smiles when he sees the astonished look on his guest's face. On the contrary, his research involves deliberately incorporating defects into diamond crystals, and these defects manifest themselves as discoloration. "Bling" is definitely not the word – and burglars would be disappointed with these tiny stones, which are barely recognizable as diamonds.

Here in Stuttgart, the physicists are more interested in the crystals' inner qualities, so to speak, because the defects that give the diamonds their color also have special quantum properties. They can be used as extremely small, ultrasensitive quantum sensors for magnetic fields – or as components for the quantum information technology of the future. Both areas are the subject of research by teams working under Joerg Wrachtrup, who has spearheaded a veritable diamond fever among the scientific community. The number of research teams working in the field is growing steadily, and many of them are being set up and led by Wrachtrup's former students.

The purpose of the visit to Stuttgart is to see the smallest magnetic sensors

» A technique that allows the direct observation of biomolecules, atom for atom and in the living environment, could mark a breakthrough in biomedical research.

in the world. One day, these are expected to be capable of deciphering chemical structures, such as those of biomolecules. "The dream is to be able to study small or large molecules in living cells or their membranes using a quantum sensor of this kind," says Wrachtrup, outlining the long-term aim of his research.

There are a variety of tricks that allow existing optical microscopy techniques to track the movements of proteins, for example, but optical microscopes are unable to resolve how atoms arrange themselves in biomolecules while they perform their functions. However, this is often a crucial part of understanding the biochemical processes of life. In many cases, such processes are driven by tiny movements in specific sections of large, coiled molecules. A precise view of proteins at work could also help researchers develop starting points for new medical agents.

Until now, the techniques for resolving a molecular structure on the atomic scale required the molecules to be placed in hostile environments for life – that is, in a vacuum and in the cold. However, a molecular structure recorded using X-rays can deviate significantly from the structure operating in the living cell. Therefore, a technique that allows the direct observation of biomolecules, atom for atom and in the living environment, could mark a breakthrough in biomedical research.

DEFECTS WITH SPECIAL QUANTUM PROPERTIES

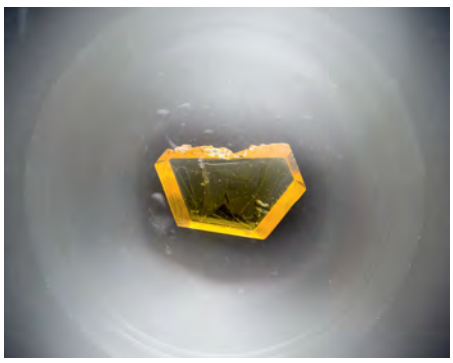
Over a coffee, Joerg Wrachtrup offers a lively explanation of why he and his colleagues need diamonds for measurements of this kind: they are the only materials into which the scientists can incorporate defects with special quantum properties.

The artificial crystals are manufactured using two processes. One of these is the established industrial process, in which carbon is compacted under enormous pressure and at high temperatures to form diamond, the hardest and most precious form of carbon that exists. "This produces particularly perfect, stress-free diamonds," says Wrachtrup. The other method is known as chemical vapor deposition. Here, the diamond grows on a substrate, depositing one layer of atoms at a time. This method can be used to produce extensive, flat samples of diamond that can be readily cut into various shapes using lasers. Such diamonds have a characteristic platelet shape, like that of the yellow sample we saw in the lab.

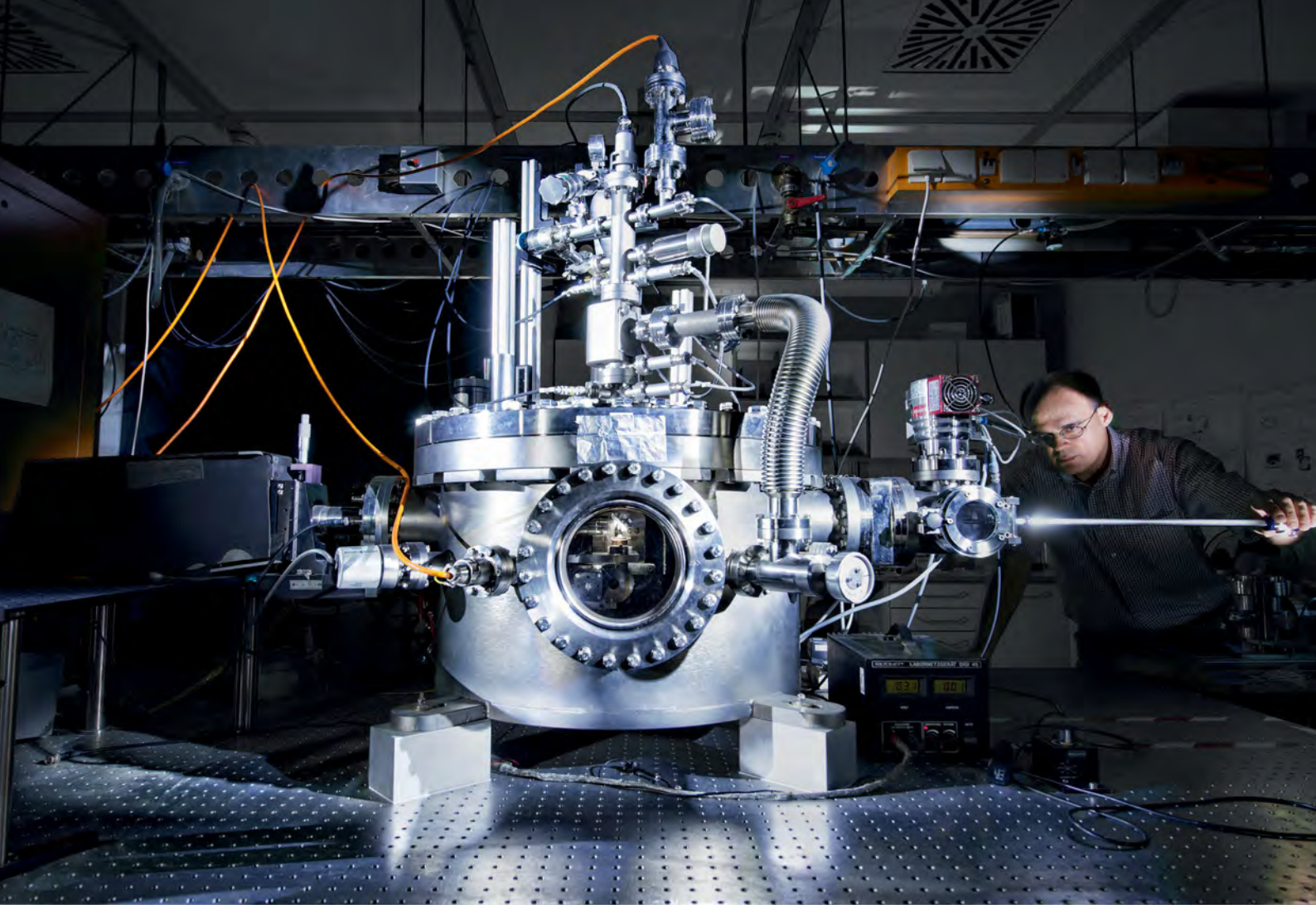
Producing ideal diamonds for use as quantum sensors is one objective of the collaboration between the Max Planck Institute for Solid State Research and the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg. This also involves incorporating a precise dose of nitrogen atoms into one of the artificial gemstones. Nitrogen atoms are a similar size to carbon atoms and therefore fit well into the crystal lattice. In large numbers, nitrogen atoms also produce a yellow discoloration because, unlike the pure carbon lattice, they can absorb or emit visible light. Defects of this kind are therefore also known as color centers.

That is just the beginning, however. The key ingredient for the perfect defect is a hole, a missing atom in the

Variants of diamonds: an industrial process at high pressure and high temperature produces particularly perfect gemstones, which take on a yellow color due to the large number of nitrogen atoms that are incorporated (left). Chemical vapor deposition, on the other hand, leads to the growth of flat crystals that can be cut into various shapes (right).



Photos: Wolfram Scheible (2)



Physically refined: in order to convert an artificially manufactured diamond into a quantum sensor, Andrej Denisenko pulls it into the chamber of an implanter using a telescopic rod. There, nitrogen atoms are added to the crystal, giving it special quantum properties.

three-dimensional network of the crystal lattice. The holes produced during the diamond's preparation migrate through the diamond lattice until they become attached to nitrogen atoms, because defects often tend to stick together. In a stroke of luck for researchers, this effect produces what are known as nitrogen-vacancy centers, or NV centers for short.

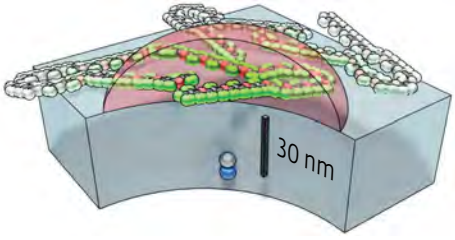
The special thing about these double defects is that they connect several individual electrons together into a tiny bar magnet. Electrons themselves are not elementary magnets; the origin of the magnetism is their spin, a sort of quantum mechanical pirouette. The very special environment in the NV center causes them to combine to form a tiny bar magnet, which is able to rotate. On entering a magnetic field, however, this bar magnet acts like an old-fashioned electrical rotary switch and can only click into place in two positions: parallel or antiparallel to the field. This behavior is determined by the laws of quantum physics. Since these two states can store the information zero and one, they turn the magnet into a perfect quantum bit – the smallest processing unit of a quantum computer, which may one day be many times faster than conventional computers at solving certain tasks. In addition, an NV center in a diamond can also be used as an ultrasensitive quantum sensor for magnetic fields.

Such quantum sensors for magnetic fields are suitable not only for examining the structures of individual proteins or other biomolecules, but also for analyzing irregularities in the structure of solids in nanoscopic detail. For this, Joerg Wrachtrup is working with Klaus Kern, Director at the Max Planck Institute for Solid State Research. As a result, quantum sensors in diamonds could help to accurately analyze the structure of superconductors, which can already conduct electricity losslessly at relatively high, but not yet practicable, temperatures. Such analyses could help scientists to understand this effect better and to develop practical everyday materials for the resistance-free transmission of electricity.

DIAMOND'S STRUCTURE PROTECTS THE QUANTUM STATE

The reason why the double defect – consisting of a nitrogen atom and a vacancy in the diamond's crystal lattice – is so well suited to gaining insights into the nanoworld is that this structure provides exceptionally good protection for the sensitive quantum state in which these spins exist. This means that even at room temperature, the NV

Photo: Wolfram Scheible



Magnetic resonance imaging in the nanoworld: a nitrogen-vacancy center (the blue and white spheres) in a diamond can detect tiny magnetic signals, and can be used to determine the structure of an individual protein.

centers retain a quantum state stored in the electron spin for several thousandths of a second – an eternity in the quantum world.

INFORMATION FROM THE NV CENTERS READ USING LIGHT

In conventional materials, the spin state would be destroyed approximately a billion times faster, unless colossal efforts were made to insulate it and cool it down to temperatures well below freezing point. This is because artificially prepared quantum states are usually extremely sensitive, especially to the thermal vibration of neighboring atoms. Room temperature is therefore essentially forbidden territory for many quantum technologies. The fact that NV centers retain their special quantum state even at room temperature makes them ideal for researching biological systems, which cease to operate at very low temperatures.

However, NV centers also have another important property: they can translate the quantum states of the tiny magnets directly into information that can be read using light. This is where the properties of the color center come into play. In simple terms, if you shine the right color of laser light at the diamond, the NV centers will glow, and the intensity of this glow depends on the quantum state of the respective tiny magnets. With the help of a microscope lens, the light can then be captured and analyzed with a camera sensor.

Accordingly, anyone who can manipulate the NV centers in the diamond skilfully has an extremely useful system at their disposal. Because it is microscopically small and therefore part of the molecular world itself, it can approach the molecules in question directly in order to act as a magnetic superlens. The spatial resolution can be enhanced to the size of a single NV center. "If we trace the samples with this, we can detect magnetic fields at a resolution of one ångstroem," says Joerg Wrachtrup. An ångstroem is a tenth of a nanometer, which is in turn equal to a billionth of a meter. For example, a carbon atom – the building block of the diamond lattice – has a covalent radius of slightly less than one ångstroem.

In practical terms, measurements with the quantum sensor follow the pattern of a long-established technique known as nuclear magnetic resonance (NMR) spectroscopy. The medical variant of this is magnetic resonance tomography, which is better known as magnetic resonance imaging (MRI). Both techniques exploit the fact that the atomic nuclei of certain chemical elements act as tiny magnets. The most important of these is the omnipresent atom hydrogen, which is built into all biologically relevant molecules on a massive scale. Another example is 13C. This naturally occurring stable isotope of the carbon atom plays an important role for the team in Stuttgart: it contains one more neutron than 12C, which is almost a hundred times more common in nature.

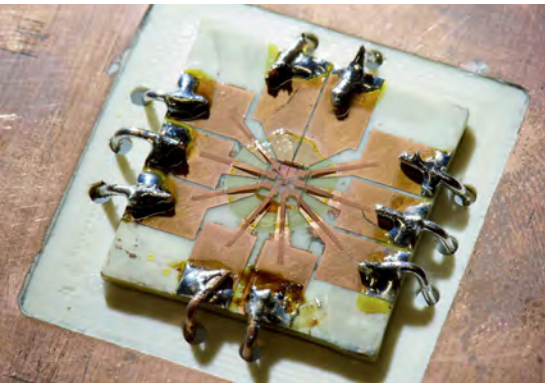
THE ENVIRONMENT HAS AN IMPACT ON SPINNING NUCLEI

NMR and MRI measurements, including those with an NV center as a sensor, work by causing magnetic atomic nuclei to spin in a strong magnetic field. In the Stuttgart researchers' laboratory, this field is generated by a superconducting magnet in a tank containing a coolant; this looks a lot like the hot water storage tank found in some homes. The researchers place the diamond quantum sensor in a tube that sits beneath the tank and encloses a cavity measuring about a hand's width across. A whole host of optical instruments complete the experimental setup on the lab bench, which is approximately the size of a double bed.

Graphic: Aslam et al., Science 357, 67–61 (2017)

Diamond in the pipeline: Nabeel Aslam (left) and Matthias Pfender adjust the optical instruments that they use to read the results of magnetic field measurements taken with a quantum sensor (top). They place the sensor in a cavity (left, partly obscured by a tank containing coolant) inside the field of a superconducting magnet, which operates at a temperature well below freezing point. To obtain the measurements, the researchers must fire microwave pulses at the diamond. They therefore clamp the crystal into a structure that generates pulses of this kind (below).

Photos: Wolfram Scheible (2)



Once the researchers have applied the sample to the diamond for analysis, they fire a radio signal at it to tilt the atomic gyroscope of the sample molecules. The rotating nuclear spins then gradually return to their original position. In the process, they emit a radio signal of their own, and this response is recorded by receiving coils. Medical MRI scanners use the response to generate images of the inside of the body.

NMR spectrometers, as well as the Stuttgart team's quantum sensors, deliver different information. The most important part of this, and the easiest to decipher, is the chemical element represented by the emitting nucleus. However, the signal also contains considerably more information because, like small compasses, the spinning nuclei are influenced by the atoms in their environment. As a result, NMR signals can be used to draw very accurate conclusions about the chemical structure of molecules. Like a fingerprint, certain parts of the signal indicate where the emitting atom is within the molecule and what chemical bonds it has to neighboring atoms. NMR spectroscopy has therefore become one of the most powerful tools for elucidating chemical structures, although the technique would be even more powerful if it could also determine the structure of a single molecule. However, their relatively large coils mean that today's NMR instruments are not sensitive enough for the radio signals emitted by molecules.

MAGNETIC SENSOR TECHNOLOGY IN THE NANOWORLD

The quantum sensors from Joerg Wrachtrup's lab can transcend the boundaries of magnetic sensor technology in the nanoworld. This involves applying the sample to the surface of the tiny diamond. In the extreme case, a single NV center directly below it acts as a sensor. "It's then far smaller than the molecule it's being used to examine," Wrachtrup points out. This allows it to detect exactly how far away a specific atom is in the molecule. You can imagine it

The Stuttgart-based researchers use a diamond to measure the field of a cube-shaped magnet (left). The intensity of the glow from the quantum sensor when irradiated with green laser light depends on the strength of the magnetic field.

as like standing directly under an apple tree so that you can see exactly where the individual fruits are hanging above you. Of course, there are limits to the visibility: the signal strength of the spinning nuclei falls away quickly with distance, so the NV center can only cover a volume with a radius of a few nanometers. If the methods for analysing the chemical fingerprints in NMR spectroscopy are one day adapted to evaluating the light signals from NV centers, they will allow the precise chemical structure of a molecule to be deciphered.

A PROTEIN'S MOTION CAN BE OBSERVED

Initial experiments have shown that this works in principle. As part of an international scientific collaboration back in 2015, the Stuttgart-based researchers demonstrated that the technique can be used to observe the movements of a protein. For this test, the team took a key protein for cell division and placed it in an environment that simulated the conditions in a living cell.

However, before they could resolve the signals from individual atoms in such a protein accurately, they had to crack another fundamental problem: the difference between the nuclei's magnetic transmission frequencies is so small that they are difficult to separate. They are like radio stations that are very close to each other on the tuning dial – only a good radio can receive them clearly.

This is precisely the problem with using NV centers as quantum sensors: although they are sensitive, they are unable to resolve the atomic transmission frequencies in a molecule because a single measurement only delivers a weak signal that is hard to distinguish from neighboring signals. You can imagine the problem as two loosely coupled pendulums, the first of which is supposed to measure the frequency of the second. The measuring pendulum must swing for long enough so that it can accurately tune in to the frequency of the other pendulum. The quantum sensor is like a pendulum that cannot swing for long enough.

STORING MULTIPLE MEASUREMENT RESULTS

The researchers in Stuttgart therefore had the idea of storing the results of multiple individual measurements. They came up with this approach not least because they are also researching how quantum information can be processed using NV centers. This depends on being able to store a quantum bit for a prolonged period of time. It therefore seemed obvious to save the information from the magnetic quantum

Photos: Wolfram Scheible (2)

» This would allow researchers to watch life itself at work in a cell, so to speak.

sensors in the same way as they store, for example, intermediate results of quantum information processing from an NV center.

The scientists' trick is to transfer the frequency information from a short magnetic measurement with an NV center into a directly adjacent long-term memory. For this, they use the nuclear spin of a 13C atom. This variant of carbon also occurs time and time again in the diamond lattice, and sometimes in the direct vicinity of an NV center. The researchers then repeat the measurement with their quantum sensor several times, using a complex sequence of radio waves and microwaves to store result after result. In this way, the frequency information stored in the 13C nucleus becomes more and more precise. Thanks to this trick, the quantum sensor can now separate the closely neighboring frequencies transmitted by the sample molecule.

This step was the key to being able to use the quantum sensor for NMR examinations in the nanoworld. However, there is still a great deal of research to do. Together with their colleagues at the Fraunhofer Institute for Applied Solid State Physics (IAF), the Stuttgart researchers are developing a nano-NMR scanner, which is based on a diamond quantum sensor and may in future provide insights into the nanoworld in many laboratories or even in medical radiology.

"The grand vision is to take the technology and apply it to actual microscopic imaging," says Wrachtrup. His team is therefore working on combining the quantum sensor with extremely high-resolution optical microscopes. The optical microscope image could show where a specific protein molecule is currently located in a cell, and the nano-NMR sensor would then record the chemical structure of the protein. This would allow researchers to watch life itself at work in a cell, so to speak. Moreover, such a technique could open up completely new avenues for the early detection of diseases: clinical MRI scanners equipped with the diamond would be so sensitive that they could detect much smaller tumours than today's apparatus. Diamonds for nano-NMR could therefore usher in the next quantum leap in biology and medicine. ◂

SUMMARY

- **To gain a better understanding of biological processes and to identify new approaches to medical treatments, researchers led by Joerg Wrachtrup are developing a quantum sensor that can analyze the structure of individual proteins and other biomolecules while these are actively operating in cells.**
- **An NV center in a diamond can be used as a quantum sensor in order to examine the atomic structure of individual biomolecules. This is possible because the vacancies in the crystal lattice detect NMR signals from atoms in their environment. The information can then be read optically.**
- **In order to resolve the NMR signals from different atoms using their quantum sensor, the Stuttgart-based researchers gather the results of individual measurements in a quantum memory so that the various signals are amplified and can be clearly distinguished from one another.**

GLOSSARY

NMR spectroscopy: NMR stands for nuclear magnetic resonance. It provides information about the magnetic properties of individual atoms. As the magnetic signals are influenced by the atoms' position in a molecule or crystal, NMR spectroscopy can be used to analyze the chemical structure of a sample material. In its medical derivative, known as magnetic resonance imaging (MRI), it provides detailed insights into the human body.

NV center: A nitrogen atom that occurs in diamond, paired with a gap in the crystal lattice (NV stands for "nitrogen-vacancy"). Thanks to its special electronic configuration, a defect of this kind acts as a tiny bar magnet that detects very weak magnetic fields and converts them into optical information.

Superconductor: A material that conducts electricity without electrical resistance. At atmospheric pressure, the effect only occurs at temperatures significantly below -100°C. Coils made of such materials generate strong magnetic fields and are therefore used in NMR spectroscopy and magnetic resonance imaging.

On a journey of discovery in the digital world

He was one of the first computer science students in Germany. Today, **Kurt Mehlhorn**, Director at the **Max Planck Institute for Informatics** in Saarbruecken, can look back on the many problems he has solved – with solutions that are also applicable to navigation systems and search engines. At least as important to him, however, are the numerous academic careers that began in his group. And he still has ideas for new research projects.

TEXT **TIM SCHROEDER**

If you talk to people who work with Kurt Mehlhorn, there is one word they are bound to use: relaxed. They will also tell you that he never greets new colleagues or employees with the formal German "Sie", instead simply saying "Hi, I'm Kurt." Every day at twelve o'clock sharp, Kurt Mehlhorn heads to the cafeteria for lunch with his working group. He greets people to his left and right as he climbs the stairs, exchanging a few words with closer acquaintances. "I just really enjoy living in an environment that works well," he says.

Kurt Mehlhorn cares about the people he works with – and has quite clearly kept his feet on the ground despite the numerous accolades he has accumulated over his lifetime. He belongs to the first generation of German computer scientists, who learned the subject from scratch. In 1968, computer science was introduced as a field of study at six of the country's universities, and Kurt Mehlhorn was among the first students to register for the subject at the Technical University of Munich (TUM). At that time, computer science was a new world that was aching to be explored. The first students at TUM studied under Friedrich Ludwig Bauer, one of the pioneers of German computer science. "He made us realize that computer science was an exciting new world and that we were all a bit like Columbus," says Mehlhorn.

AIMING FOR BETTER INTELLIGENCE AMPLIFIERS

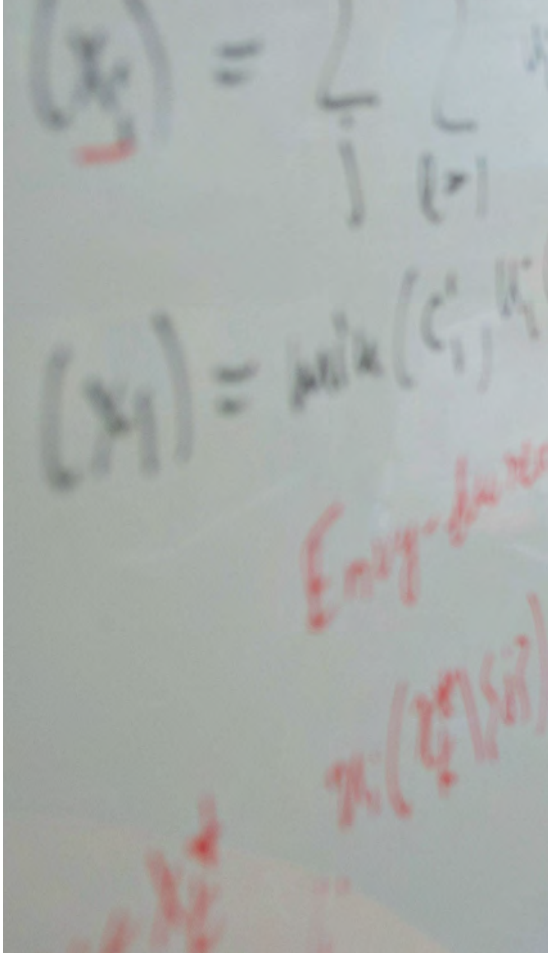
Today, 50 years on, computer science encompasses countless fields and niche areas and has millions of applications – it is thanks to computer science that we can shop for shoes online, find our way using a satnav, and send WhatsApp messages. Over the years, however, Kurt Mehlhorn has remained faithful to the aspect of computer science that always fascinated him the most: the mathematical side. "In the first ten years, all I needed for my work was a pencil and paper," he laughs, "and even now, many a working day results in nothing more than a full wastepaper basket."

Math and computer science deal in truths, he says. You can derive proofs and thereby clarify, once and for all, that something is the way it is. Though he has enjoyed math since his school days, computer science eventually became his subject of choice: "Because math is about taking a purely structural approach and explaining principles. In computer science, I can develop solutions that allow people to do something new. Here, mathematical proofs can be put to direct use – to create new methods and better or more reliable computing processes." For him, computers are amplifiers of intelligence, just as other machines are amplifiers of forces – and his aim has always been to improve these intelligence amplifiers.

Kurt Mehlhorn has been Director at the Max Planck Institute for Informatics in Saarbruecken since 1990 and served as Vice President of the Max Planck Society between 2002 and 2008. >

Photo: Tom Pingel

A passionate computer scientist and cyclist: Kurt Mehlhorn always cycles to his Institute – and he's recently started using an e-bike.



A troubleshooter: Kurt Mehlhorn believes it is important to support his members of staff, one of whom is doctoral student Bhaskar Ray Chaudhury. He therefore takes the time to discuss their research projects whenever possible.

He is considered one of the world's leading theorists. However, when it comes to the question of his lifelong contribution to computer science, the first thing that enters his mind are not his specialist articles or books, but rather the people he has accompanied on their academic careers. "I've supervised some 80 doctoral students and about as many postdocs – and many of them now have really good jobs all over the world." Apparently, many of his former students are now professors themselves, including at every computer science department of the Indian Institutes of Technology, for example.

CHARACTER-BUILDING: TEAM SPIRIT THANKS TO ROWING

On the way back from the cafeteria, Kurt Mehlhorn greets a young Asian student who is standing in the corridor outside his office. Taken aback, he asks: "Are you waiting for me? We didn't have an appointment, did we?" – "No, it's okay, I'm waiting for something else." The young woman is one of the new postdocs in his working group. In her home country, South Korea, she studied under computer scientists who had in turn been supervised by computer scientists who had studied under Kurt Mehlhorn's former doctoral students. "That's great," says the scientist. "Let me check my sums. Yes, you could actually say I'm her doctoral great-great-grandfather, so to speak."

It is no coincidence that the young people who began their research careers with him are so successful: "You have to give people challenging tasks and present them with interesting problems in order to hone their skills of perception." And perhaps a working group of this kind also requires a certain degree of team spirit, which Mehlhorn is good at nurturing – perhaps partly because it shaped him as a teenager back in his rowing days. "I was part of a rowing team until the age of 18. That's a really character-building sport, an extreme team sport if you will. You can only train together. If someone in the boat is missing, it doesn't work. And you need shared powers of endurance – you have to train a lot, for just a very small number of competitions." Perhaps it is the same sporting camaraderie that drives the people working in his team. While studying in Munich, Kurt Mehlhorn was one of the best students in his year group. After three years, a scholarship from the German Academic Exchange Service (DAAD) took him to Cornell University in Ithaca, U.S., where he went on to complete his PhD in 1974. He received an offer of an assistant professorship at Carnegie Mellon University, but his wife wanted to return to Germany instead. Mehlhorn therefore applied for assistant professorships at TUM and Saarland University in Saarbruecken.

He received a letter of acceptance from Saarland just a week later, but there was no word from Munich. "Today, you would make a quick call or send an email to enquire. In those days, however, phone calls were so expensive that it didn't even enter my mind to contact Munich and follow up." After five weeks of radio silence from Munich, Kurt Mehlhorn accepted the offer from Saarland University. It was not until a few months later that he found out what the problem was at TUM: the secretary had forgotten to put an airmail stamp on the acceptance letter for the position of research assistant in Munich, and so the good news from Bavaria was condemned to several weeks on a ship. "Sometimes these

Photo: Tom Pingel

things happen, and that's how I ended up in Saarbruecken," says Mehlhorn.

At Saarland University, he started working with the pioneering computer scientist Guenter Hotz, who held the university's first professorship in computer science. In September 1974, Hotz took Mehlhorn to a meeting of international computer scientists at the prestigious conference center in Oberwolfach, which was a customary meeting place for mathematicians in those days. "Back then, the meeting played host to the great minds of the computer science world. I presented two of my papers, in which I had tackled current problems in computer science. The results went down very well," says Mehlhorn.

One of the topics was matrix multiplication, a classical method of linear algebra in which values from two tables are multiplied together. "The mathematician Volker Strassen had discovered that matrix multiplication could be sped up by performing intermediate subtractions, to put it in simple terms," says Kurt Mehlhorn. "Following on from this, I provided the mathematical proof that multiplication actually couldn't be sped up without subtraction." The astonishment in Oberwolfach was palpable.

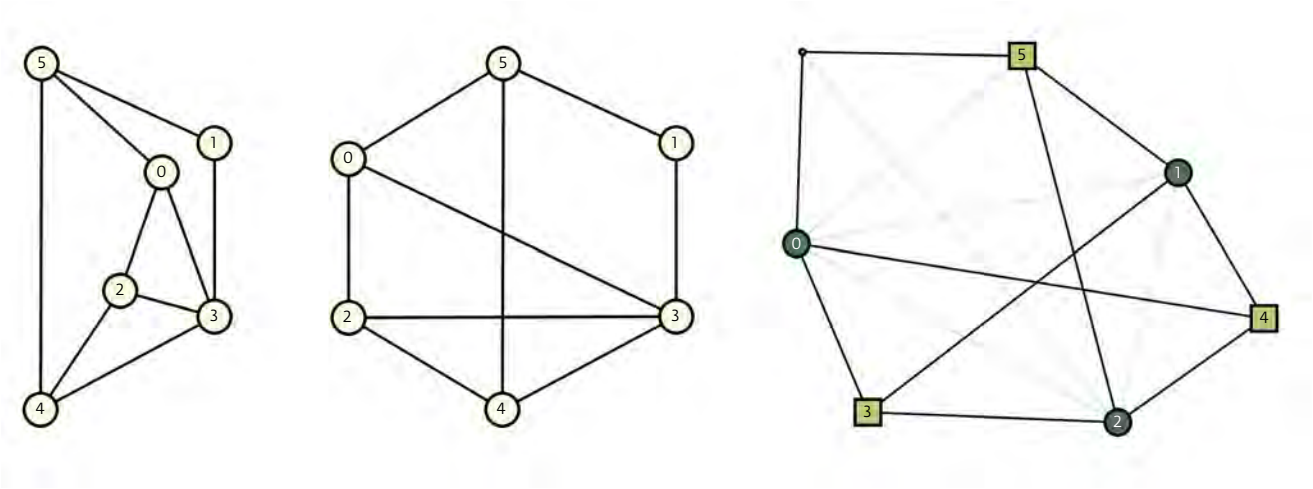
Mehlhorn suspects that his appearance in Oberwolfach might have contributed to his appointment as a professor a few months later, shortly before his 26th birthday. After the conference in Oberwolfach, he was offered a professorship at the University of Frankfurt and traveled there to attend the interview. It was then that Guenter Hotz made his move: he wanted to keep Kurt Mehlhorn and offered him a professorship in Saarbruecken. "As you officially needed to be 27 years old to become a professor in Saarland at the time, I then had to deputize myself in my own post for just over a year."

ALL ASPECTS OF THEORETICAL COMPUTER SCIENCE

At that time, the initial focuses of his theoretical work included search trees. Tools of this kind are used by computers to work their way through a data set, step by step and branch by branch. "It's a bit like a phone book, where you begin by searching for the first letter of a surname and then jump to the second letter, and the third, before finally narrowing the search down based on the first name," Mehlhorn explains.

At the time, the problem facing computer scientists was that the search appeared to become more and more complex the more changes and additions you made to the tree. It was as if the computer had to search a phone book in which entries were constantly being added or modified. "In Saarbruecken, we succeeded in developing a method that allowed the computer to perform the search with a consistent level of effort despite this problem." As search trees are needed in many applications, such as determining the shortest route between locations, Mehlhorn's method for the amortized analysis of search trees continues to be of fundamental importance today.

In the years he spent in Saarbruecken, Mehlhorn worked on all aspects of theoretical computer science and authored not only numerous specialist articles but also a three-volume textbook. The topics included searching in data sets, computational geometry, the analysis of graphs and the machine sorting of data – central processes that now play a key role in every computer and



every application of computer science. For example, the sorting and searching of data are part of the core functionality of search engines.

According to other present-day experts, one of Mehlhorn's greatest achievements is that he made the theoretical knowledge available in a practically useful form: together with his staff in Saarbruecken, he created a library of programming tools that allow computer scientists and engineers at today's companies and research facilities to write their own computer programs quickly and easily without always having to develop complex new software from the ground up. "Our idea was simply to pool our technical knowledge into this software platform and then offer it as a product," Mehlhorn explains. "And we thought we could easily finish the job in one year. We were wrong. In the end, it took us more than a decade, and back then the development process almost cost me my reputation."

PROGRAMMING WAS CONSIDERED MUNDANE WORK

To be precise, in the 1980s, programming was seen as somewhat mundane in the world of theoretical computer science. Writing software was dismissed as being intellectually nonchallenging. "People were surprised that I wanted to waste my time on the banalities of programming. Accordingly, I made a grandiose announcement in 1989 that we would have the tool finished within a few months," Kurt Mehlhorn recalls.

At first, everything seemed to be going well. The software worked – for example for calculating graphs. Graphs are made up of dots connected by lines, and these dots and lines are referred to as nodes and edges. You can imagine the graphs like cities on a map that you join up to plan the route for your next holiday, which is precisely how they are used by navigation systems. They are also used for surveying the surface of the Earth using drones.

Computer scientists differentiate between non-planar graphs, in which edges intersect no matter how the graph is drawn, and planar graphs, in which there are no points of intersection. Contrary to what the terms planar and non-planar might suggest, the question is not whether the body is flat or three-dimensional, but whether there are mathematical intersections in a plane. For numerous computer science applications, the question of whether graphs are planar or non-planar is of vital importance. Mehlhorn's team therefore developed an algorithm that can test graphs for planarity so that this could be included in the software library.

"However, a mathematician then sent us a graph with over 20,000 nodes, for which our software spat out an incorrect result. It was a disaster. My colleague Stefan Naeher came to me and said: 'Your master's student programmed it, so now you'll have to fix it.'" Mehlhorn spent a whole day looking for the error in the software – and he found it.

CERTIFYING ALGORITHMS WERE A KEY MILESTONE

However, he did not reprimand the student, because he now realized that the system had a fundamental weakness. It delivered results such as "is planar" but no information about the reliability of this result. "To make our software platform truly perfect, we needed a function that identified incorrect statements, an algorithm that checked the result itself." And so, the work continued.

It was worth it, because Mehlhorn and his team ultimately developed certifying algorithms that could check every result – a milestone not only for Mehlhorn but also for computer science in general. Now, for every non-planar graph, the program delivered an accompanying diagram showing the points of intersection. The software was now perfect. It performed complex calculations relating to planarity and other mathematical questions and, thanks to the certifying algorithms, also delivered instant quality control.

This meant that, in 1995, Mehlhorn and his colleagues Stefan Naeher and

Graphic: MPI for Informatics

Left-hand page With or without a point of intersection? Graphs made up of nodes (colored squares and circles) and lines, referred to as edges, feature in many computer science problems. However, the key question is often whether they are planar, meaning the edges do not cross (left), or non-planar, meaning there are intersections between the lines (center). The algorithm used in LEDA highlights a substructure (light-grey lines), proving that the graph is non-planar (right).

Right Analog computer science: Kurt Mehlhorn deliberates over many questions using a pen and paper, quite a lot of which ends up in the wastepaper basket.

Photo: Tom Pingel

Christian Uhrig were able to establish their own company, Algorithmic Solutions Software GmbH, which distributes the software under the name "LEDA" (Library of Efficient Data types and Algorithms). LEDA and the subsequent CGAL software library for geometric calculations are now used by numerous companies around the world – for example to analyze deformations in crash tests or to control sawbench conveyor belts. Here, a piece of software calculates in a matter of seconds how the machine needs to cut up the panels in order to remove knotholes while simultaneously minimizing waste.

In recognition of his development work, Kurt Mehlhorn had the exceptional honor of being elected to the National Academy of Sciences (NAS) in the U.S. as a Foreign Associate in 2015. The NAS is a community of scholars that only admits some two dozen researchers from abroad each year. Kurt Mehlhorn is one of only five computer scientists from outside the U.S. to be granted this honor. The NAS paid tribute not least to the development of LEDA as one of Mehlhorn's particularly important achievements. His research has also been honored with the Leibniz Prize, the Zuse Medal and numerous other awards. When he received the Beckurts Prize, he invested the prize money into his company.

In his office, however, there is nothing to be seen of these accolades. The

An explanation or a reference to a past hairstyle? At any rate, Kurt Mehlhorn delivers carefully prepared talks and lectures that are highly relatable to everyday life. One thing is for certain, however: his hair and beard were much more extravagant in the early 1980s than they are now.

only exception is a mortarboard on the windowsill, which he was given when he was awarded an honorary doctorate at the University of Gothenburg. "That's something truly special. The cap is adjusted, heated and formed directly on the head – quite a lot of effort goes into it." Next to the cap on the windowsill stand photos of his grandchildren and his three grown-up children, and there are also photos hanging on the walls and door. His daughter is artistically talented and creates figures that are somewhat reminiscent of *Nanas* by Niki de Saint Phalle. Two such figures stand on pillars beside the door, and one can even be seen on Mehlhorn's website, adorning a book about LEDA.

A MODEL FOR THE MOLD'S ROUTE TO THE OAT FLAKE

Even though Kurt Mehlhorn has already achieved a great deal, the research work is ongoing. In his group, some 30 people are currently working on a variety of theoretical questions. While Mehlhorn doesn't want to highlight a specific project, he does mention a worry he once had in relation to his research topics: "It must sound strange, but for years my only fear was that I would run out of ideas at some point." He's now been in the business for 50 years – and it hasn't happened yet. "Probably because I keep my eyes open and am interested in lots of different things. Twice a week, we meet here in the Institute to discuss current topics."

Sometimes, he also stumbles across something interesting purely by chance. In a TV program some time ago, he saw a report about an experiment by Japanese researchers. On a chip containing a network of channels, they had grown *Physarum polycephalum*, a mold that spreads by forming tentacle-like appendages. The idea was that, in the maze of pathways, the slime mold would find its way to a food source, in this case an oat flake. In the experiment, it only took a few hours for the fungus to find the shortest route to the food source. The appendage on this express route became thicker, while the fungus withdrew itself from the other routes. "The search for the shortest route is an age-old topic in computer science," says Mehlhorn. "For a mathematical model relating to the development of the fungus, we demonstrated that it always finds the shortest path."

Kurt Mehlhorn is undoubtedly a key figure in the history of German computer science and, as he says, he is the most senior professor of "real" computer science in Germany. Nevertheless, he has clearly never adopted any airs or graces. For years, he has traveled to work by bicycle or – weather and fitness permitting – by racing bike, touring bike, mountain bike or, most recently, e-bike. People say the special thing about Kurt Mehlhorn is that he can relate to people and hasn't lost touch with the real world. Mehlhorn also endeavors to connect with his students when he is giving lectures – using examples from everyday life or stories about search engines or satnavs. He says he puts a great deal of work into his lectures, because they need to be prepared perfectly in order to get the message across to the students. "I also speak freely, without a script – that's important for building a good rapport. I often hear it said that I express myself in a way that's easy to understand. And, ultimately, that's also how I bring in talented young people" – people who are inclined to join the working group and carry on its research long into the future. ◀

GLOSSARY

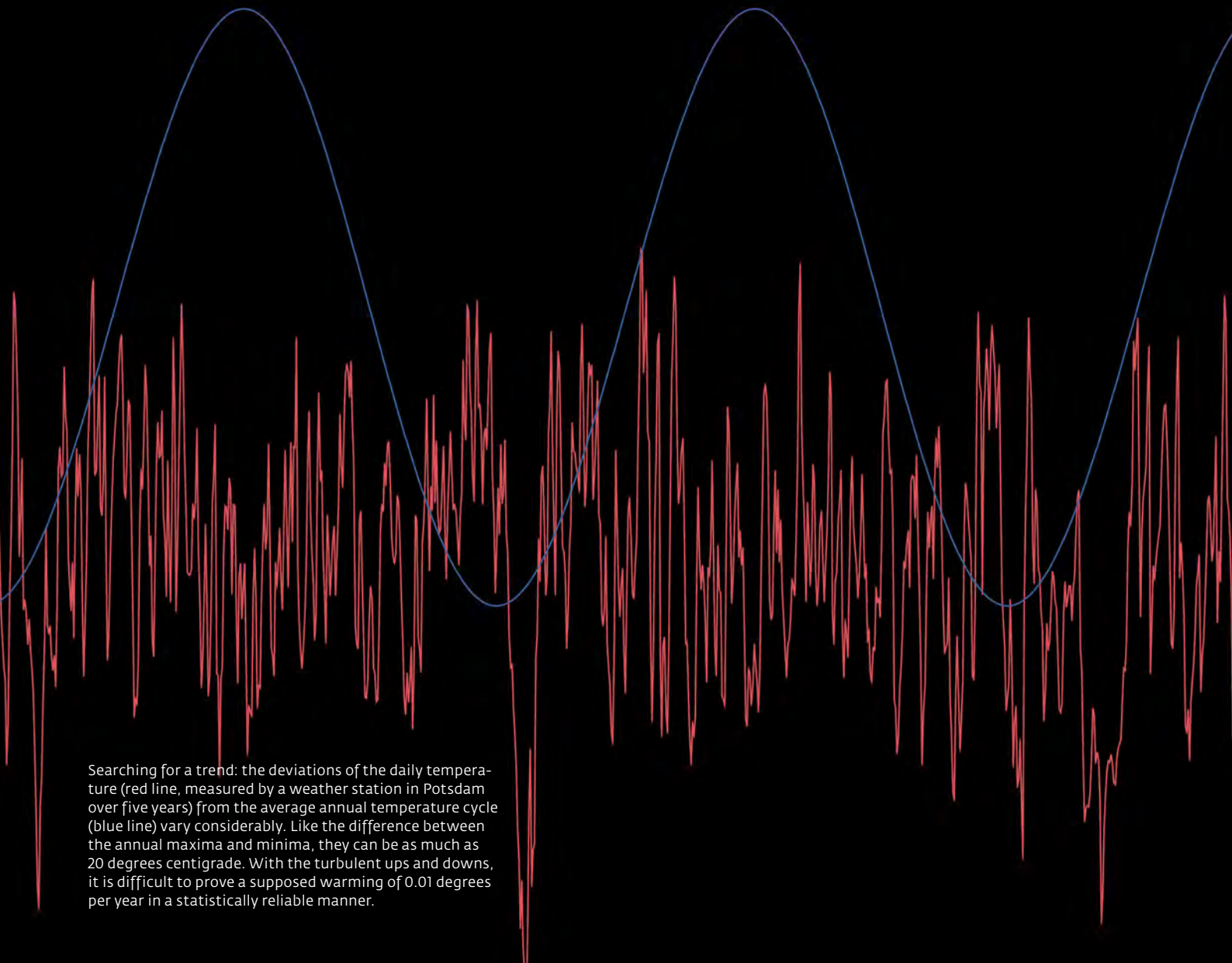
Algorithm: A detailed calculation rule used – by computers, for example – to solve a problem step by step.

Graph: In graph theory, an abstract structure of nodes and edges. Examples include family trees and network maps of underground railways. These are not to be confused with graphs of mathematical functions, which plot output values against their corresponding input values.

Photos: Tom Pingel (left), own collection (right)

Quirks in the computer

Storms, droughts and extreme rainfall could become more frequent due to global warming. At any rate, climate researchers are discussing this eventuality and are analyzing measured data to determine whether such a trend can already be observed. **Holger Kantz** and his colleagues at Dresden's **Max Planck Institute for the Physics of Complex Systems** are developing the necessary statistical tools.



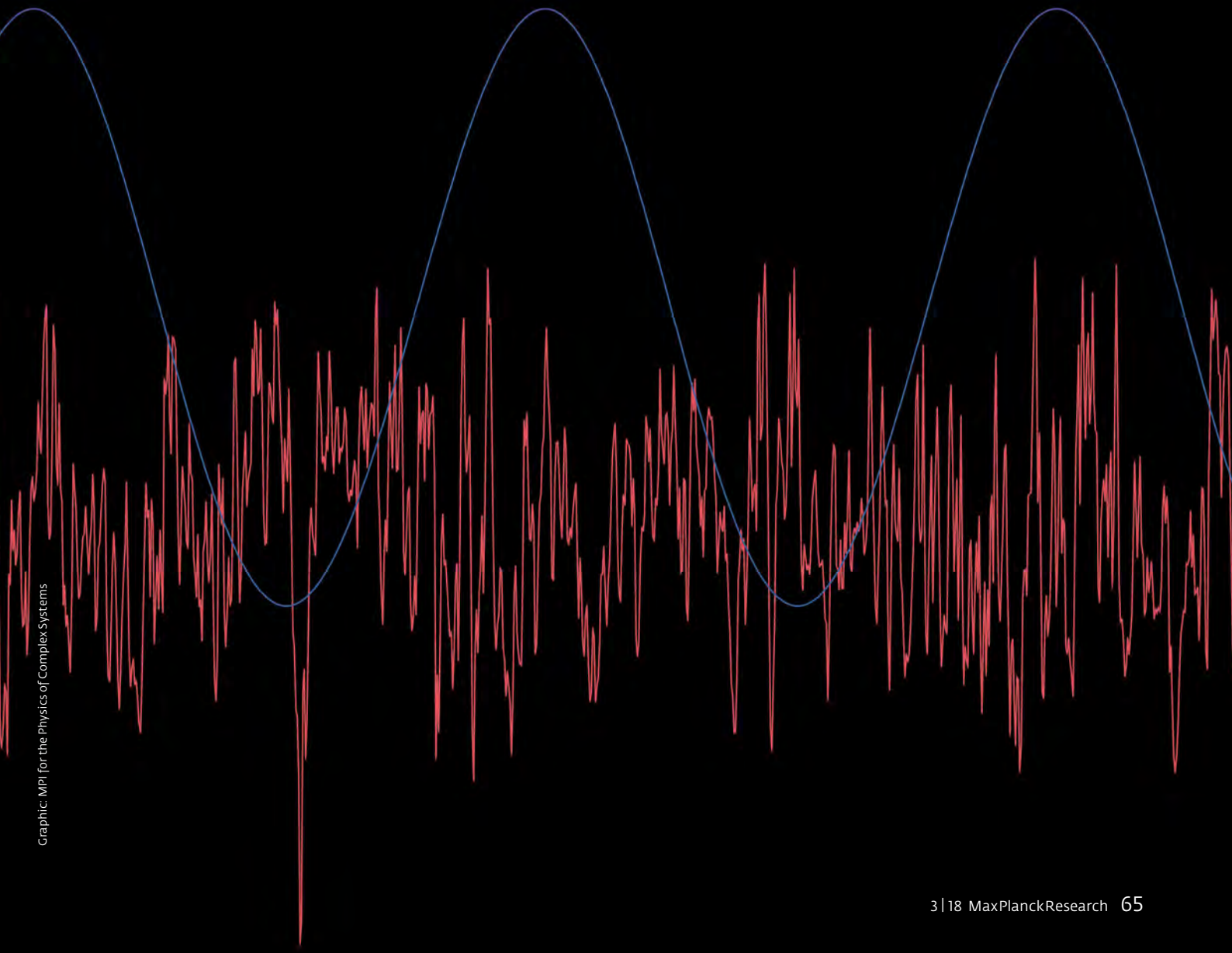
Searching for a trend: the deviations of the daily temperature (red line, measured by a weather station in Potsdam over five years) from the average annual temperature cycle (blue line) vary considerably. Like the difference between the annual maxima and minima, they can be as much as 20 degrees centigrade. With the turbulent ups and downs, it is difficult to prove a supposed warming of 0.01 degrees per year in a statistically reliable manner.

TEXT **KLAUS JACOB**

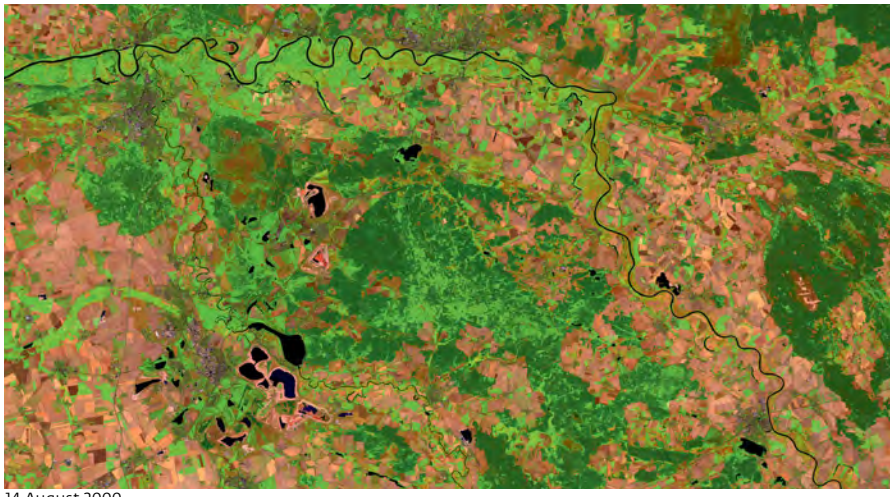
As if on cue, the weather sets the scene perfectly for our appointment in Dresden: frost and snow in late March is unusual, or you could even say: extreme. Holger Kantz, whose office is on the second floor of Dresden's Max Planck Institute for the Physics of Complex Systems, has spent the last decade studying extreme events with readings that deviate from the norm – a heartbeat that suddenly becomes erratic, a share price that plummets from one day to the next, or ocean waves that build up to form dreaded freak waves. In the last three years, the physicist and his team of six doctoral students and two postdocs have also turned their attention to studying weather and climate. The key question here is whether the number and intensity of extreme weather events are increasing. Are the rising temperatures brought on by climate change also leading to a greater risk of storms, floods, heatwaves and other quirks of the weather?

It's been a long time since climate researchers, who use models to look far into the future, first raised the alarm – and the regular reports of the Intergovernmental Panel on Climate Change (IPCC) have taken on an increasingly ominous tone. The arguments are clear: a warmer atmosphere can hold considerably more moisture, which leads to increased rainfall and therefore to flooding. Storms also risk becoming more severe, according to the reports, not to mention the heatwaves.

However, "the relationship between climate change and extreme weather is not quite that clear," says Kantz. Indeed, there are also arguments that point in a different direction: if it gets



Graphic: MPI for the Physics of Complex Systems



14 August 2000

20 August 2002

Two exceptional floods in four years: the Elbe flooded at several points in April 2006, including in the small town of Hitzacker in the district of Luechow-Dannenberg. Just four years earlier, the river had overflowed its banks by some margin, as seen in satellite images of the region south of Wittenberg.

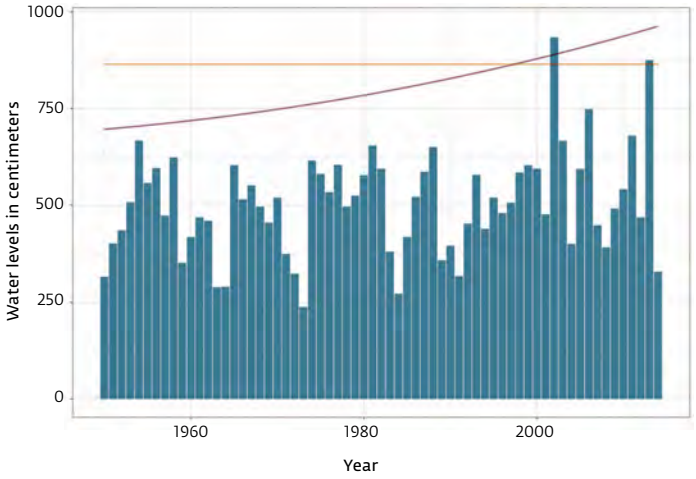
warmer at the poles, the temperature difference between high and low latitudes will decrease, which ought to lead to a calmer atmosphere. Moreover, if climatic zones shift, as will indisputably happen, it need not automatically lead to a rise in extreme weather events. Germany, for example, is predicted to develop a Mediterranean climate, which is no more dangerous than the temperate climate we enjoy today. Last but not least, the trend in local weather conditions can be completely different from that seen on a global scale.

BETTER ANALYSIS METHODS FOR MEASUREMENT SERIES

A look back at the recent past can help to determine how climate change and extreme weather are connected, and what types of storms threaten to strike individual regions. After all, the global average temperature has already risen by about 0.8 degrees since the industrial revolution, and this ought to have made its mark on the weather. The question is therefore whether storms and flooding have already become more frequent and intense.

Non-scientists who are worried about climate change believe they have known the answer for a long time. They have a tendency to blame climate change for every hail shower and every storm. Scientists, on the other hand, are more cautious because they must be able to pick out a clear trend in the

Photos: dpa/Holger Hollemann (top), NASA (bottom)



A trend or just pure chance? The maximum annual water levels of the Elbe have fluctuated considerably in recent decades. Although several exceptional floods have struck since the turn of the millennium, the statistics do not demonstrate a clear, systematic trend. Extreme event statistics were used to calculate the 100-year flood level, resulting in the purple line if the researchers allowed a trend or the yellow line if they assumed that the statistical properties do not change over time. For reasons of consistency, both lines should be exceeded, on average, only once every 100 years.

data. These experts include Kantz and his working group, who have spent a great deal of time analyzing data series and searching for patterns. However, it is not his job to make concrete statements about climate and weather. Kantz openly admits that "the researchers at the Max Planck Institute for Meteorology in Hamburg are the better people for that."

Ultimately, Holger Kantz has a different set of objectives: he is more concerned with finding better analysis methods than with gaining a deeper understanding of the climate or issuing weather warnings. He is working to develop principles that help other researchers solve specific problems. His field of work revolves around the world of formulas with a view to bringing order to chaotic graphs, since understanding the ups and downs in measurement series allows researchers to look into the future and make useful predictions. Kantz scopes out the limits of different methods (see box on page 69), seeking to identify their respective pitfalls, and tends to publish more of his papers in physics journals than in publications relating to weather or climate.

Nevertheless, meteorology is a field that suits the researcher well because it provides extensive data series relating to floods, temperature or rainfall over long periods of time – precisely what he needs for his work. Unlike many other data sets, most of this data is publicly available.

Of course, from time to time, he inevitably comes across a result that can be put to practical use. Rather than being his actual objective, however, this is something of a collateral benefit. For example, he has found a way to use measured wind data to predict strong gusts. Although the prediction only stretches one or two seconds into the future, that is sufficient to protect gigantic wind turbines. In this time, it is possible to adjust the rotor blades' angle of attack relative to the direction of wind flow so that there is no risk of damage. The Max Planck Society has even applied for a patent to protect this forecasting technique.

Of course, some paths also lead to a dead end in basic research. For example, Holger Kantz has examined whether there is a universal mechanism that causes extreme events – a mechanism that is applicable to any variable that fluctuates erratically, such as wave height, wind strength or heart rate.

"As a physicist, you tend to think about feedback loops," says Kantz, explaining his approach, which is guided by dynamical systems theory. His idea was that, in any given system, an initial deviation will build up into an extreme value, before the system returns to normal because a resource that triggered the process has been used up.

Kantz searched a wide range of data series for a typical cycle of this kind. A universal formula would be invaluable because it would allow researchers to make reliable predictions. However, Kantz has now reined in his expectations: "After ten years of research, we can safely say: there is no universality to extreme events." Apparently, the causes are too multifaceted to be described by a single dynamic mechanism.

TWO 100-YEAR FLOODS IN QUICK SUCCESSION

A simpler but by no means trivial task is to study the records of one type of extreme event, such as the flooding of the River Elbe. In August 2002, the river burst its banks following a period of heavy rainfall. The water level in Dresden reached 9.40 meters, more than seven meters higher than the normal value. This was the first time since records began that the river had risen to such levels, and the media rightly reported that it was a 100-year flood. Large parts of the city were submerged, and the floods caused well over eight billion euros of damage in Saxony. >

Graphic: MPI for the Physics of Complex Systems

» Although climate change already seems to be having a considerable impact at first glance, the statistics of local time series data do not provide a clear conclusion.

A statistical toolmaker: Holger Kantz leads a research group that develops mathematical methods so that, among other things, climate researchers can analyze weather data to identify possible trends.

Just eleven years later, in June 2013, the waters rose again, this time reaching a level of 8.76 meters. Many people assumed that two 100-year floods in such quick succession must be evidence of a trend. Did climate change already have a grip on the Elbe? Or had human interventions along the river's course led to a higher risk of flooding?

Statistics expert Holger Kantz set about answering these questions. However, he had to contend with a problem that is also a continual headache for climate researchers: the data series available to him was relatively short. After the Second World War, the water level gauge in Dresden had been moved, meaning that reliable data was only available for the last 65 years. Nevertheless, Kantz got to work. Plotting the maximum levels for each year on a graph, he obtained a varied picture of movement back and forth, with two particularly high peaks in 2002 and 2013. An extreme value analysis over time pointed to a surge in levels approaching those of 100-year floods. This seemed to be a clear indication that the risk had increased.

STATISTICS MAKE RELATIONSHIPS PLAUSIBLE

A word of warning, however: it is important to bear in mind that relatively short time series such as these don't come close to covering all of the possible scenarios. Next summer, perhaps, the river could rise to even higher levels than in all previous years, even without the effects of climate change. Indeed, after just 65 years, no one can say what the maximum water level really is. Perhaps the 100-year flood of 2002 is therefore not an indication of the impact of the greenhouse effect and instead simply serves to improve future statistical calculations. In that case, the hydrologists would only need to adjust the 100-year flood that is used as a basis for assessing protective measures.

As is befitting for a basic researcher, Kantz describes the difference in general terms: "Am I looking at an additional reality or a different reality?" In this context, an additional reality simply means a new maximum, whereas the different reality is actually driven by climate change, which establishes completely new boundary conditions.

At first glance, it seems almost impossible to achieve clarity regarding the relationships. Even statistics, with its tried-and-tested formulas, fails to provide any certainty. "We can never prove anything," says Kantz. "Rather, we can only make relationships plausible." To do this, he and his colleagues often take the following approach: first, the researchers assume that climate change has no influence on the flooding characteristics of the Elbe, for example, and use a computer to generate numerous possible data series that are consistent with this assumption. The scientists obtain these graphs in various ways, including by recompiling the actual measured values to obtain time series in which the data is combined randomly. They then compare these with the real measurements series of water level.

If climate change is actually at play, the measured data series should deviate considerably from the norm. In the case of the Elbe, however, it does not. So, although climate change already seems to be having a considerable impact at first glance, the statistics do not provide a clear conclusion. The result, as the experts would say, is not statistically significant. "However, that is no cause for celebration," Kantz points out. "It merely shows that our measure-

Photo: Juergen Loesel for TU Dresden

The power of mathematics: Holger Kantz's team has found a way to use measurements of wind strength to predict particularly strong gusts at short notice. Wind turbines can then be protected by altering their rotor blades' angle of attack.

ment series is not complete enough to produce a clear statement."

An example involving a dice demonstrates that appearance and gut feeling are poor guides when it comes to statistical tasks. After numerous throws fail to produce a six, people tend to expect this number when they next roll the dice. It has to come sometime, they think. However, this is actually a misconception: the probability is a sixth again every time, because the dice does not have a memory. Many a roulette player has lost money by listening to their gut feelings and trying to outsmart the statisticians.

UNEXPECTED RESULTS IN TEMPERATURE DATA

It is not only with the Elbe floods that Kantz has come across unexpected results, but also when he was analyzing data relating to temperatures in Germany. Before he could start, however, he first had to consider the locations of the individual meteorological stations. Quite a few weather stations stood in green fields when they were installed but are now surrounded by buildings. The problem is that cities develop a climate of their own; they get hotter as the multitude of brick buildings store up the sun's heat. This *urban warming* effect distorts the calculations and hints at the presence of climate change that may not exist at all. Kantz therefore excluded these stations from his considerations altogether.

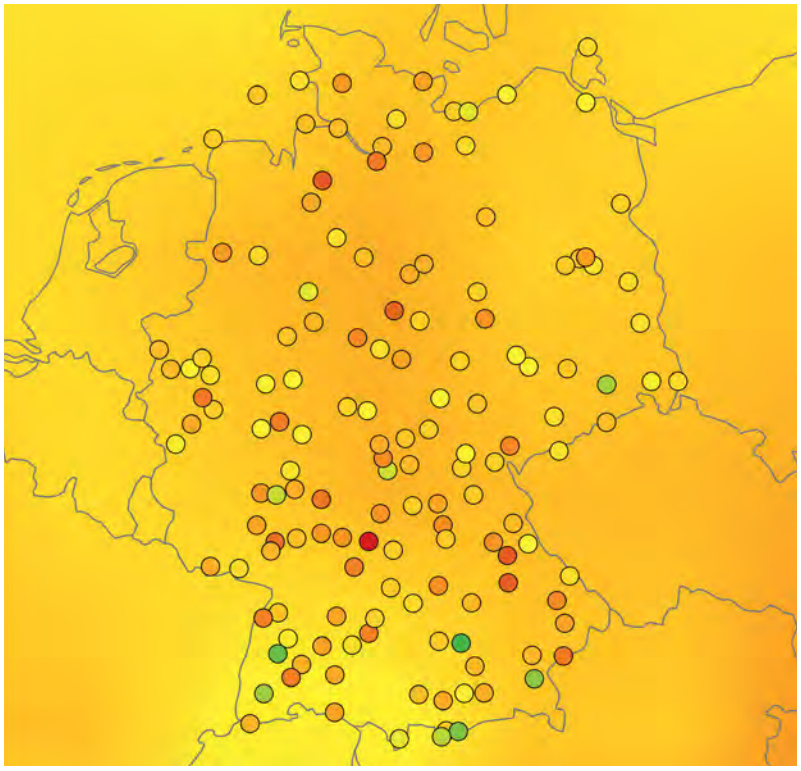
After processing the remaining data series with his statistical instruments, he reached a conclusion similar to that for the Elbe floods: it is not possible to prove that climate change is already influencing the temperatures – the relationship is not statistically significant. This applies to over half of the more than 100 stations.

The result is all the more surprising because meteorologists are constantly talking about new temperature records. It is no secret that the world is getting warmer – everyone can feel it. Here, the limits of the statistical methods become apparent, because when Kantz considers only the last 30 years, he obtains completely different results. In this

A COMPLEX REALITY IN CONCISE FORM

The world is full of complex systems, such as the atmosphere, the circulatory system or a river. Measurement instruments allow us to observe how such systems react, producing long series of data relating to the precipitation, heart rate or river level, for example. Holger Kantz analyzes the dynamic ups and downs and draws conclusions from them, ultimately with a view to making predictions. One important tool in this work is time-series analysis. From the flood of data, Kantz and his team extract important parameters such as the mean, the variance or a trend, the challenge being to find variables that concisely reflect the complex reality. Ultimately, the approach could be described as "data compression", because the researchers in Dresden are essentially slimming down a large number of measurements in order to extract the essential information. However, they must be careful not to lose any important details in the process.

Photo: shutterstock



Model and reality: data from weather stations over the past 30 years was used to determine local temperature trends for a period of 100 years. In some cases, these deviate considerably from the background field, which was obtained by interpolating temperature data using a weather model to create a comprehensive temperature map.

case, climate change is clearly visible and even takes on a sinister quality. However, if he uses the last 100 years as a starting point, the picture becomes blurred. The trend has been watered down because the temperatures were fluctuating strongly at the beginning. In other words, the climate change is obscured by the strong fluctuations.

STATISTICAL PROOF OF CLIMATE CHANGE

Even when the results of all stations are considered, the picture is still confusing: all stations show a positive trend. Although the values are not large enough to talk about statistical significance, the degree of concordance is puzzling. All of the values are on the positive side – surely that cannot be by chance. Here, Kantz speaks of an intrinsic contradiction, although this too can be explained without climate change: the weather stations in Germany are not independent of one another, as the locations all experience largely the same weather conditions. Rather than simply stopping when it reaches Hamburg, an area of low pressure also tends to leave its mark in Munich.

It was only when Kantz plugged foreign stations, which are characterized by different weather conditions, into his calculations that he obtained a different picture. The strong fluctuations in the individual regions canceled each other out – and a significant trend towards higher temperatures appeared. There was statistical proof of climate change after all. These different results can be confusing. However, Kantz stresses that he is in no way seeking to spread doubt about climate change. Rather, his analyses demonstrate how statistics can protect us against false conclusions, especially when it comes to regional events.

Holger Kantz is puzzled by one particularly strange realization: "Our climatic system has a kind of memory," he says. This sounds more like esotericism than serious science, and yet it speaks to a problem that preoccupies the physicist and his colleagues. Kantz returns to the example with the dice, where there is always a one-sixth probability of rolling a six. In other words, the dice does not have a memory. That is not the case with weather. Here, the past seems to have an influence on the future. If it rains today, it will rain again tomorrow – or, at least, there is a greater likelihood of rain than sunshine. Meteorologists refer to this phenomenon as persistence. Anyone who has absolutely no idea about the weather, they say, should adhere to this rule of thumb.

EXTREME EVENTS ALWAYS OCCUR IN CLUSTERS

But what is the origin of this consistency? It goes without saying that wind and weather react with a certain inertia. A low-pressure area therefore determines the weather conditions for several days, and El Niño dominates half the world's weather for an entire year. However, Kantz says that the phenomenon persists even if this inertia is excluded from the calculations. He is referring to the concept of long-range correlations.

The capacity for memory becomes apparent not only in short-term trends over the period of a few days, but also in long-term trends over months and years. Moreover, it influences extreme weather events such as storms and floods: these always occur in clusters, separated by long pauses. Kantz suspects that this is due to the enormous complexity of the atmosphere. Here, there is an interplay between phenomena that

Graphic: Philipp Mueller, Kantz working group (MPIPKS), data from the German National Meteorological Service (DWD), Climate Data Center

are – temporally and spatially – several orders of magnitude apart. There are momentary phenomena such as a flash of lightning and long-term events such as the monsoon. The interacting phenomena also differ hugely in size, ranging from a tiny air molecule to a huge thundercloud and the mighty jet stream – and everything is interrelated.

To gain a better understanding of such systems, Kantz works with simplified computer models that have all the relevant properties of this complex reality but that are easier to manipulate. He hopes to clarify why, for example, large structures react sluggishly but small ones react extremely quickly. He also hopes to answer the question of how long a measurement series must be to include all possible states, which would enable him to gain a better understanding of the Elbe's flooding statistics. Perhaps he will also find a cause for the strange concept of "weather memory". He already has his suspicions: the climate may be affected by very long-term phenomena that we aren't even aware of yet. These would give the impression of a memory that does not actually exist. Kantz: "It may be that our measurement series are simply too short." ◂

SUMMARY

- **Extreme weather events – such as storms, droughts and rainfall that leads to flooding – could become not only more frequent but also more intense as a result of climate change.**
- **Holger Kantz and his team develop statistical methods that can be used to analyze time series with a view to determining whether the frequency and intensity of extreme events are changing.**
- **This cannot be proven for the flooding of the River Elbe – despite two 100-year floods occurring in the space of eleven years.**
- **The statistical methods developed by the Max Planck researchers can be used to predict very strong gusts of wind at short notice, so that the rotor blades of wind turbines can be moved to a safe position in good time.**

GLOSSARY

Extreme weather: Weather phenomena that deviate significantly from a region's typical weather situations. These include storms, heavy rain or droughts and can cause considerable damage.

Significance: A term used in statistics to indicate whether extreme values in a measurement series are due to random variation or a specific cause. This can be determined more effectively the larger the quantity of data and the less the measured data is scattered around the mean.

Time series: A series of measured data over a defined period of time, in which the chronological order of the values carries important information.

Encounter and exchange: during the 13th and 14th century, the Piazza della Signoria was the political center of Florence. The idea that public places are necessary to shape society was formulated in ancient times, but is still valid today.

Photo: shutterstock

Creating space for **existential awareness**

Researching the old to develop the new – what better place to do this than in Florence? At the **Kunsthistorisches Institut in Florenz – Max Planck Institute**, the "Ethics and Architecture" research group led by **Brigitte Soelch** and **Hana Gruendler** invites discussion of the history and theory of architecture and the applicability of its teachings to the present and future of building.

TEXT **MARTIN TSCHECHNE**

It might have been a day just like today. Clear blue skies. A fresh, gentle, yet billowing breeze blowing through the streets of Florence from Monte Ceceri in the north east, where Leonardo da Vinci was to test his flying machines a couple of decades later. Leon Battista Alberti had walked up to the monastery church of San Miniato al Monte with his companions Agnolo Pandolfini and Nicola de' Medici – one a Stoic, the other a critic of the Stoic philosophy of calm forbearance. Yet since their seemingly acciden-

Photo: mauritius images

Free seating: as with the Loggia dei Lanzi, some of the Renaissance palaces in Florence have protruding plinths. Once designed as waiting areas for petitioners, they are now used by grateful visitors as seats that do not oblige them to buy food or drink.

tal meeting under the mighty dome of the cathedral, their dialogue had developed in an atmosphere of friendly mutual respect.

They had talked about virtue and destiny, aesthetics and morals, ethics, the relationship of humankind with creation, and the cornerstones of a good life. In the course of their conversation, they came out of the cathedral and strolled along the river out of the city and up the green hill. Their subject was the peace of mind. Agnolo advised and taught, Nicola listened and replied; it was he who had broached the topic.

THE ART HISTORIAN ASKS ABOUT THE RAILWAY STATION

In later centuries, their dialogue, *Della tranquillità dell'animo* (1441), was repeatedly extolled as the literary manifesto of an epoch that drew on the ideas of classical philosophy and invoked Aristotle and the Roman master builder Vitruvius to pave the way to a freer future that respected the dignity of humankind: the Italian Renaissance.

The cathedral architecture, the layout of the city – all this helped give meaning and form to the discussion. Alberti, an architect, master builder, mathematician, author and humanist, gave his dialogue an elaborate structure. The characters, their arguments and counterarguments, the whole conversation – all these were fiction. Yet the place was real.

Brigitte Soelch and Hana Gruendler, who together with Alessandro Nova are in charge of the "Ethics and Architecture" project at the Kunsthistorisches Institut in Florenz, sometimes follow the path taken by the literati up to San Miniato when they need a breath of fresh air. Florence is hard to endure. The queue at the entrance to the cathedral goes back as far as the side streets, the Baptistery is surrounded, and the flags of the tour guides wave atop a pushing, shoving mass of humanity like poppies in many different colors.

In almost every building there is a coffee bar, a guest house, a pizzeria or a souvenir shop awaiting an influx of tourists. On the Ponte Vecchio, it's impossible to make your way through the crowds. T-shirts and cheap leather jackets for the rest of the world. And a visit to see the paintings in the Uffizi Gallery? Not in this life. Men with submachine guns stand in front of the entrance. The city is choking on its beauty, its popular myth, its history.

"Have you actually seen the railway station?" asks Brigitte Soelch, and at first the question is startling. The Kunsthistorisches Institut in Florenz is located in Via Giuseppe Giusti, house number 44, a stately palace behind gray walls, just a few steps from the cathedral and right behind the Ospedale degli Innocenti, the city orphanage. In 1419, Filippo Brunelleschi, who shortly afterwards became the master builder responsible for the world-famous cathedral dome, laid the foundations of a building that was to become a moral, social and aesthetic sign of his times. His asylum for foundlings made the newly awakened early Renaissance concept of humanity very tangible, of humankind made in the image of God. This is reflected by the reliefs of babies created by Andrea della Robbia on the frieze above the arcades. Yet the art historian asks about the railway station.

THE CONCEPT OF GOOD FORM HAS IMPACTS ON LIFE

The building is a testimony to *longue durée*, adds her colleague Hana Gruendler – to the sustainability of a philosophy that shaped the face of Florence and still influences it today. This information is certainly helpful, as the Stazione Santa Maria Novella, built in 1932/34 by Giovanni Michelucci and his Gruppo Toscano, is a monument to Italian modernity with its clear, elongated, strictly functional front. It is also a stark contrast to the magnificent domes and cathedrals of the old town, the colonnades, bands of marble and highly effective perspectives.

"Not quite," corrects Gruendler. "Just look at the material from which the railway station has been made, especially the front. It's just like the main body of the Santa Maria Novella monastery directly opposite. It's the same as what we see on the incomplete façade of San Lorenzo, for example." >

Urban planning then and now: the "Ethics & Architecture" research group cites the Florentine suburb of Scandicci (right) as a current example of citizen-centered building. The visionaries who paved the way for this development left their traces in the old town (top) 600 years earlier.

Indeed, half of Florence seems to have been built using stone in this warm shade of yellow.

In such details, the researchers recognize the expression of an ethic, the concept of good form that also applies to a good life. Even the choice of building material is an affirmation of the city and its history, and a political manifesto. Special consideration may not have been given to ecological questions at the time, qualifies Gruendler, but some thought was certainly given to what characterizes a place. Where does a material come from? How does it get here? And how does it represent the character of this place, the popular myth of the Florentine? A warm, calming ochre in the light of the setting sun – even today, the color alone is enough to inspire thoughts of Tuscany.

The interaction between architecture and ethics is the focus of the researchers working on the project. How are forms of thinking expressed in a cityscape and its buildings? What dimensions and proportions are derived from ethical principles? And what understanding of reason and responsibility, of community, citizenship and democracy emerges from the arrangement of a city, its openness and structure, its green spaces and public squares, its agreements on the height of eaves, street layout and pavement width?

FLORENCE IS ALSO THE CRADLE OF FUTURISM

Gruendler and Soelch dig through historical layers to find the answers to these questions. They engage in an invariably exciting dialogue between their subjects of art history and philosophy, with occasional excursions into psychology, sociology and politics. They also invite guests and organize whole congresses to discuss the metaphors of architecture, the aesthetic education of humankind through the environments they construct, the idea of heaven in late Gothic architecture, and the virtual cloud in a present that is opening up new spaces. They talk about Bauhaus and the Werkbund, about the Wittgenstein house in Vienna, the Weissenhof estate in Stuttgart, Villa Tugendhat in Brno, or Alexander Rodchenko's aestheticized photos of the construction of the White Sea Canal. In Florence, they say, you bump into all this at practically every turn.

Brigitte Soelch solves the puzzle of her startling question about the railway station by explaining that the Renaissance and modernity were both more radical than anything that went before, and that both laid claim to being completely new. We are going forward into a new future, said the pioneers of both movements. We are leaving everything old behind us. And they said this in Florence. The city, as the art historian reminds us, was not only the cradle and zenith of the Italian Renaissance, not merely a repository of a closed chapter in history.

500 years later, the founders of futurism, the poet Filippo Tommaso Marinetti and painters such as Umberto Boccioni and Carlo Carrà, also sat together in the Caffè Le Giubbe Rosse (the Red Jackets) on the Piazza della Repubblica, where they extolled their

Photo: shutterstock

Photo: Brigitte Soelch/Kunsthistorisches Institut in Florenz – MPI

passion for everything new, for courage and rebellion, for struggle and speed, salti mortali, punches and slaps in the face in lampoons that were sometimes rather forced.

Nevertheless, the past always remains alive, is accepted or fiercely opposed, redefined and integrated into the present. And continues to be the fundamental basis of modern times. The ancient idea of the agora and the forum as a place of intellectual and political exchange runs all the way through history – sometimes only as an empty popular myth – to the shopping malls of the present day. The Federal Constitutional Court, says Brigitte Soelch, invokes the law of the ancient forum to justify why demonstrations may be held at Frankfurt Airport.

According to the art historian, the Renaissance succeeded in stepping out of the chronology of history precisely because it drew on ancient ideas. She calls to mind the plinths of the old palaces, which were often preferred to benches. Those who wished to be allowed inside first had to wait outside. This was what court protocol demanded. And nowadays, lo and behold: the seats are an unexpected, almost subversive gesture of hospitality in a public space which the tourist office has commercialized right down to the very last corner. Every traveler is aware that anyone who wants to sit down must at the very least order a cappuccino. And then they are suddenly invited to sit down on the plinth of a palace free of charge and write a postcard home...

Stay calm, be at peace, *tranquillità dell'animo*. This is how Alberti put it. Reason, reflection and responsibility He built the front of the church of Santa Maria Novella on existing medieval foundations, modified his plan wherever necessary, and designed a spectacular façade in green and white marble that truly epitomized the spirit of the new era.

EDUCATION THROUGH ARCHITECTURE

Sometimes economy, ecological thinking and respect for the history and identity of a place come surprisingly close together. For the two researchers, the benches and sacred ensemble opposite Florence railway station are only one intellectual step away from their counterpart, the Humboldt Forum in Berlin – even down to the reconstruction of a castle, the atmosphere of which is focused entirely on an idealized past. Incidentally, these constructions unwisely turn their backs on the old and new in the east of the city.

Wouldn't the Uffizi galleries have been a better model? They were built by the artist, art biographer and master builder Giorgio Vasari, interposes Hana Gruendler, who together with Alessandro Nova is one of the six co-editors of a new edition of Vasari's "Lives". Vasari had a whole city district demolished to make way for an administrative center reflecting the Commune's newly awakened Republican self-image. After all, the famous art collection was not exhibited there until much later, although the Medici expressed their passion for collecting and their enthusiasm for art early on in the Tribuna of the Uffizi.

The art historian and philosopher refers quite naturally to terms learnt in Latin lessons, to *cives* and *civitas*, the citizen and the urban community as standards for future-oriented building. This is apparently how it has always been in Florence. What was (and is) important was the moral education of humanity through architecture. Even Vasari gave due consideration to traces of the past from which the future could grow and on which it could feed. He studied and evaluated old plans and compiled them into a handbook for his guild, a *Libro de'*

disegni, used spolia (building elements repurposed from earlier times) and integrated parts of a medieval church into his brand new government center on the bank of the Arno.

The architect acted as an archivist and curator, as a legal scholar and moral philosopher. Does this mean that architecture's political and social responsibility was greater in those times? Not necessarily, claims Brigitte Soelch. But it was probably closer to its intellectual roots in ancient times. When the boundaries of the city are also the boundaries of a judicial area, the significance of the buildings is tangible. In this respect, Florence has always been something like the prototype of a modern city.

When the façade of a church such as Santa Maria Novella is built on foundations from the past, the respect felt for history is palpable; when its structure looks forward to a new era, it becomes all the more obvious that the program is directed at the civitas, the urban society. And when it uses materials from the surrounding area, as was also the case in the past, it confirms the city's identity at this location and provides a firmly anchored foundation for the new awakening. Little additional explanation is necessary: the municipality's buildings are accessible at all times.

"Don't expect us to provide finished solutions," Brigitte Soelch will say at some point. "Our group just asks the right questions." While Achim Reese, currently a doctoral student on the project, is now investigating the humanization of architecture after the end of World War II and is challenging the cliché of an allegedly "inhuman" modernity, his predecessor Nele De Raedt took a closer look at the relationship between moral behavior, palace architecture and the patronage of popes and cardinals.

One of the questions relates to what present-day architects can learn from early modernity. The researchers make it very clear that an answer will never be found without direct reference to political practice and everyday life as a building architect. Moreover, every valid answer is based on the realization that new ground can only be broken by investigating the ideas and disputes of intellectual history, and that ethical positions that go beyond a generally formulated morality always require a reference to a specific social structure, to the reality of its intrinsic possibilities.

Leon Battista Alberti called for this through the idealized character of Stoic Agnolo Pandolfini, as did his Milan-based contemporary Filarete in his *Treatise on Architecture*, and both of them drew on this for specific planning ideas. Principles of an intelligent architecture, both then and now.

DEBATES ABOUT THE FUTURE OF CONSTRUCTION ARE ESSENTIAL

In order to breathe life into these ideals, the researchers permit themselves a kind of utopia, according to which a serious architect should still be able to think, argue and write extremely well today. Like the great authors and master builders of the Renaissance, with their manifestos, treatises, polemics and policy papers. What is important is to challenge building owners to engage in dispute on an equal level and initiate large-scale, fundamental debates on the future of building. At issue here are questions of sustainability, habitability and ethics. Gruendler and Soelch say that one example of such a combination of practice and theory is the Dutch designer Rem Koolhaas, with his in-depth analyses and carefully developed theses on architecture. His counterpart would be an ordinary star architect who merely elevates his personal style to the status of a trademark. With a rather short expiry date.

Florence is hard to endure. Particularly for its inhabitants. They have become accustomed to the fact that tourism dominates every aspect of life and business in the city. After all, they too are responsible for this development. However, the researchers report that over the last two or three years, residential space in the city center has become almost unaffordable for the local population – because even the smallest room promises quick, barely controllable profit through online portals such as Airbnb. Florence is drowning in tourism.

So off to Scandicci! For the Ethics & Architecture group, the western suburb is confirmation that the Florentine talent for bringing forth new ideas on the basis of an evolved identity tempered by constant debate is still alive and well. In Scandicci, the city has been experiencing a kind of Futurism 2.0 since 2016. The British architect Richard Rogers, who built the Centre Pompidou in Paris, and who was incidentally born in Florence, made the bold move of completely redefining this urban area as a metropolitan region with functions and structures expanded to the scale of a network. A modern concept is reduc-

Linking a variety of interests: the research project led by Hana Gruendler and Brigitte Soelch (from left) unites architectural and social questions, philosophy and psychology, politics and art history.

ing the crush on the streets, while supplies and administration have once again been brought closer to the local inhabitants. Perhaps this will help Florence find itself again.

The best thing (here Brigitte Soelch waxes positively lyrical) is that Rogers sought and found expression wholly in keeping with the spirit of the great master builders, expression that adopts, invokes and integrates the surrounding forms and aesthetics sensitively and respectfully – not the distant domes and loggias of the city center, but rather the local residential architecture of the 1950s and 1960s, the typical façades given structure by light grids and red tiles, and in the middle of it all, a town hall dating from earlier times that was made of béton brut (raw concrete), and which unexpectedly gives a whole new lightness and dignity to the region. Very clever, says the art historian. This is how architecture can guide the present into the future. Tourists are never seen out there. Unfortunately, architects and architectural historians are also rare visitors.

Supposing they had taken part in the competition to design the area on which Berlin city palace had stood until it was destroyed by the GDR regime? What would they have built there? The two researchers barely hesitate; this topic is obviously familiar from their congresses and ongoing dialogues. The Palace of the Republic has disappeared, a formative phase of history has been rudely obliterated. So why not use this physical, historical empty space to invite the world to Berlin?

To build a vertically layered urban space in these narrow confines, taking China or Brazil as a model, Le Corbusier or the Dutch architects MVRDV with their Expo pavilion as intellectual sponsors. They imagine the area as a mixture of public amenities, with a sports arena on the first floor, above it cinemas, bars, libraries, open areas and forums. And there has to be space with cultural and subcultural potential on the open ground floor. Undefined, and constantly open to rethinking.

This would probably have been the best solution, because it would have confirmed what the classical thinkers repeatedly postulated and substantiated: the city belongs to its citizens. ◀

SUMMARY

- **Architecture and urban planning reflect the concept of humanity and the idea of citizens coexisting in the respective epoch in question. Conversely, building design influences the lives of both the individual and of society as a whole.**
- **The "Ethics and Architecture" project at the Kunsthistorisches Institut in Florenz – Max Planck Institute is exploring these interactions and their development from the Renaissance to the present day.**
- **A key role is played by public spaces as places of intellectual and political dialogue. Another important factor is the challenge of amalgamating new and existing buildings to form an integrated whole.**
- **As in the Renaissance, architects today should put their planning-related and social ideas on paper and open them up to discussion.**

Photo: Denise Vernillo

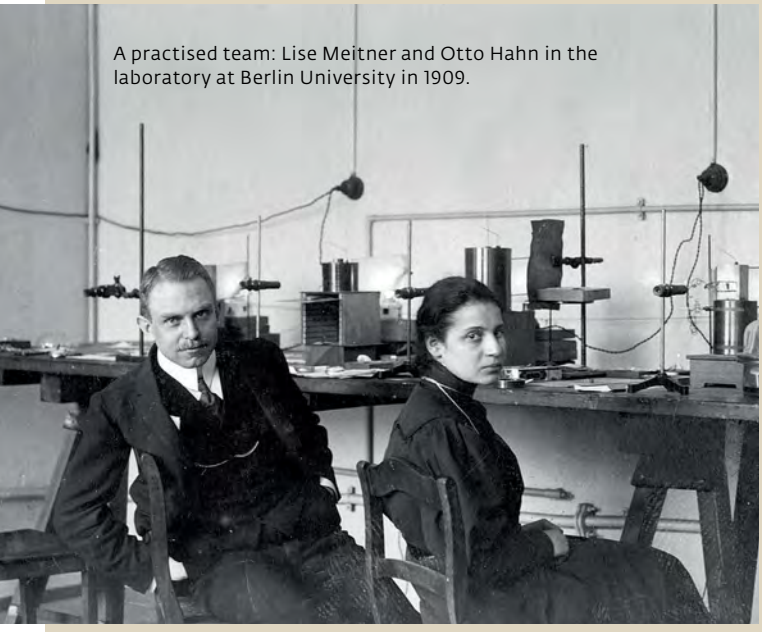
A fateful year for a physicist

For **Lise Meitner**, 1938 is something like a turning point in her life. She flees the Nazis and goes to Sweden, where she tries to establish herself as a scientist and finds the solution to a problem that Otto Hahn told her about in a letter. As a result, the former researcher at the **Kaiser Wilhelm Institute for Chemistry** becomes one of the co-discoverers of nuclear fission.

TEXT **SUSANNE KIEWITZ**

July 1938. Lise Meitner flees from Germany, her adopted country since 1907. After the annexation of her native country of Austria, she is at grave risk of falling victim to the anti-Semitic persecution in the Third Reich. At the urging of friends and colleagues – most notably Otto Hahn – Meitner finally decided with a heavy heart to emigrate to Sweden. For her, it is the end of an era. In resigning from the Kaiser Wilhelm Institute for Chemistry in Berlin, the almost sixty-year-old scientist is giving up a hard-won, prestigious position in her profession.

Since 1912, Meitner had worked with Otto Hahn to make the Institute one of the world's leading research facilities in the fields of radiochemistry and nuclear physics. From 1923 on, she was in charge of the Department of Radiophysics and thus held a leading position that only a very few women attained in those times. The Institute had unique research opportunities, first-rate equipment and a motivated team of staff, which until 1937 included Max Delbrueck, who went on to win the Nobel Prize.



A practised team: Lise Meitner and Otto Hahn in the laboratory at Berlin University in 1909.

The scientific community tries to support Lise Meitner as best it can, but ultimately with little success. As the best option offered is a temporary job at the Nobel Institute in Stockholm, she decides to go to Sweden. Yet the disappointment is great. "At the Institute, I have a workroom which is also my study and experiment room with lots of people coming and going," writes Meitner in frustration to her friend Gertrud Schiemann in Berlin at the end of October 1938.

In this situation, her written correspondence with Otto Hahn becomes a vital link with a familiar world. This is all the more important as her escape has torn her away from another phase of intensive collaboration. It is also why Meitner's Christmas parcel contains a letter in which Otto Hahn gives her strictly confidential information about the most recent experiments.

Lise Meitner, who had been a fascinated observer of Enrico Fermi's experiments on transuranes using the newly discovered neutrons, had in 1934 proposed a joint research program exploring how atoms react when bombarded with slow neutrons. In Stockholm, Meitner follows her colleagues' work from a distance and is the first to hear of the unexpected results of the latest series of experiments. "There is something about the 'radium isotopes' that is so remarkable that for now we are telling only you," writes Hahn to Lise Meitner on 19 December 1938. "Our Ra[dium] isotopes do not act like Ra but like Ba[rium]," in other words, like an element with a significantly lower nuclear mass than expected.

This suggests that the radium nucleus could have split. Hahn is more than cautious about propounding this possibility and requests Meitner's support. He is an expert in chemical fractionation but not in nuclear physics. "Perhaps you can come up with some sort of fantastic explanation," he suggests to his colleague. "We know ourselves that it can't actually break apart into Ba." And Hahn, who is already preparing to publish the results of his work, adds: "If there is anything you could propose that you could publish, then this would still in a way be work by the three of us." The third researcher is Fritz Strassmann, who is conducting experiments with Hahn in Dahlem. In order to give Meitner a head start, Hahn does not tell even his own Institute of the astonishing discovery.

Lise Meitner and her nephew Otto Robert Frisch – a physicist at Niels Bohr's renowned institute in Copenhagen – spend the

Photo: Archives of the Max Planck Society, Berlin

Christmas holidays of 1938 in deep discussion of Hahn's report during long walks in the deep snow. Based on Bohr's nuclear drop model and Einstein's formula for the transformation of mass into energy, they calculate all the possibilities of nuclear disintegration with mathematical precision.

More letters are sent back and forth between Sweden and Berlin, until Meitner finally confirms Hahn's cautious theory on 3 January 1939: "Now I am almost sure that you have indeed discovered decay into barium, and I consider this result beautiful indeed. I cordially congratulate you and Strassmann." Hahn's report appears in the prestigious publication Die Naturwissenschaften (The Natural Sciences) very shortly afterwards, on 6 January 1939. Meitner and Frisch likewise rush to complete their paper, which is published in February by the no less prestigious journal Nature. A joint project would be practically impossible in the current political situation, especially as Hahn and Strassmann have already drawn negative attention from the Nazi regime.

A close friendship: Lise Meitner and Otto Hahn on his 80th birthday in 1959.

However, the paper by Meitner and Frisch goes unheeded in the scientific world, as Niels Bohr has taken the sensational results of the measurements with him to the U.S. at the beginning of January and given a spontaneous report on them at a conference. Other nuclear physicists also quickly produce an explanation for the chemical findings and calculate the enormous quantity of energy released by nuclear fission, as Meitner and Frisch have already done. Everyone is sure that this is one of the most far-reaching discoveries in physics of the 20th century. Something that had previously only been given hypothetical consideration by a few bold spirits and was at most the stuff of science fiction now turned out to be scientifically proven and in principle therefore technically feasible. Six months later, when German troops invaded Poland and started World War II, the idea of using nuclear energy to construct a new type of bomb quickly took shape.

The Observer, 13 December 1946

» Lise Meitner did it with mathematics.

The events of 1938/39 were a watershed for Lise Meitner: a watershed, but not a peak, as the scientific world withheld its ultimate accolade for the role she had played in the discovery of nuclear fission. In 1945, the Nobel Committee awarded the 1944 Nobel Prize for Chemistry to Otto Hahn alone, while in 1953, a paper written by physicist Werner Heisenberg demoted his former colleague in Dahlem to Hahn's "assistant".

However, the public paid extensive tribute to Lise Meitner's contribution to the discovery of nuclear energy after the war. An array of honors including the order Pour le Mérite, together with German and international reports on the "chief witness of the nuclear age", testified to her reputation after the end of World War II as the most important person in contemporary history.

Initially, the atomic bombs dropped on Hiroshima and Nagasaki in August 1945 catapulted the publicity-shy researcher into the public spotlight rather abruptly. The American tabloid press were not the only ones to celebrate Meitner as the "mother of the atomic bomb" and claimed that the "Jewish refugee" had collaborated on the Manhattan Project. Meitner did actually receive offers of this kind in the 1940s, but refused them all. In 1946, she told the Evening News: "I hate all bombs."

That same year, Meitner traveled to the U.S. to meet relatives and old acquaintances. She gave lectures at universities and was voted "Woman of the Year" by the Women's National Press Club. Having carved out a career driven by stamina and curiosity in the male-dominated field of physics, she became a role model for many female students.

Looking back, Meitner emphasized that this would have been impossible without the support of her parents and academic teachers. These included Ludwig Boltzmann, who was her supervisor when she obtained her doctorate in physics at the University of Vienna in 1906, and Max Planck, who despite initial reservations made her his assistant at Berlin University in 1912, thus giving her a sound financial basis.

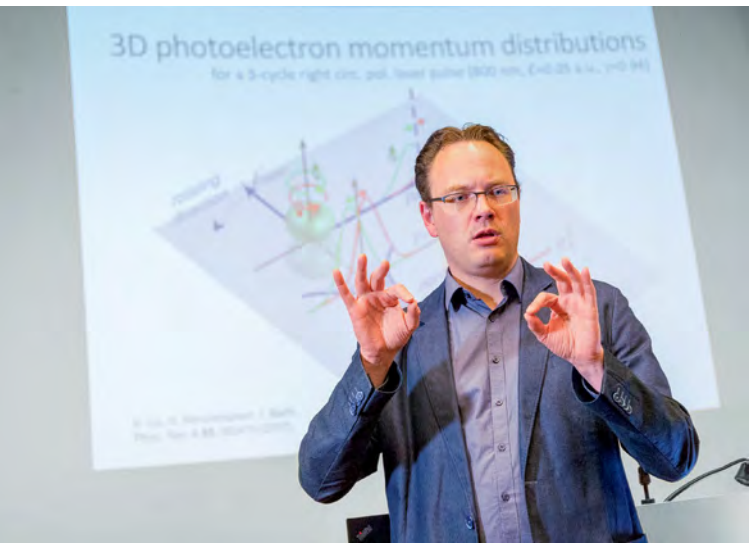
However, the most vitally important events of her life were her meeting with Otto Hahn and their collaboration from 1907 until the discovery of nuclear fission in 1938. Their friendly relationship continued even after the war. What made this possible was Meitner's big-hearted willingness to forgive the injustice and rebuffs she received, although she did not hesitate to reproach those of her friends who had remained in Germany for being partly responsible for the atrocities of Nazism. Meitner first went back to Germany in 1948 to attend the memorial service for Max Planck.

In 1953, the Frankfurter Rundschau published a profile of her to commemorate her 75th birthday. Asked about the beginnings of their collaboration, Hahn and Meitner showed a friendly camaraderie to the press: "'I was delighted to have found someone who could teach me about the chemistry of radioactive substances,' she [Meitner] admitted with an engaging smile; 'I had hardly any idea of chemistry!' Hahn promptly countered, 'And as a chemist, I had even less idea of physical and mathematical problems. Yet Ms. Meitner always kindly worked out everything I didn't quite understand – and in this way we were always able to help each other!'"

Photo: Archives of the Max Planck Society, Berlin

Many hurdles lead to success

How a deaf Max Planck Research Group Leader forges his path in science



Ingo Barth presenting his report at the MPG 2018 staff meeting. His signing was interpreted simultaneously.

For Ingo Barth, the thought that he would one day be a quantum physicist at a Max Planck Institute was even more challenging than it already is for others. In the former East Germany, the deaf could achieve no more than a simple school-leaving certificate and faced the prospect of completing one of only ten rather simple apprenticeships. Then came the fall of the Berlin Wall – and Barth was given the opportunity to obtain his secondary education diploma at a special school for the deaf in Essen. This was already an achievement, but then he faced the next hurdle: how is it possible to study at a university? What offers and opportunities are available for the deaf to participate in lectures and seminars?

These were only the most pressing questions that needed to be answered. The profession of sign language interpreter was just gradually developing at the same time. Ingo Barth therefore decided to tackle the first semesters of his physics studies at TU Berlin with the help of note takers. Parallel to this, as a sign language teacher, he taught other students, providing an abundance of communication and interaction.

Ingo Barth relied on sign language interpreters for every oral examination and every lecture. This created additional hurdles: there was nobody available for physics with English as the working language. For his dissertation defense, he thus had to sharpen not only his own knowledge, but also that of his interpreter. And he succeeded: he completed his dissertation summa cum laude and was awarded the Carl-Ramsauer Prize for it in 2009. In 2013, the German Association of University Professors and Lecturers and the academics portal honored him as Junior Scientist of the Year in recognition of his research achievements and his dedication in translating technical terms into sign language, as well as his ideas for establishing a European university for the deaf.

These topics still inspire Barth today. With his Max Planck Research Group, in which he has included two more individuals with disabilities, he works on ionization dynamics in strong circularly polarized laser fields and on quantum hydrodynamics in vibrating molecules. In addition to this, he teaches natural sciences sign language in workshops for both interpreters and deaf scientists.

For him, it is essential to have a pool of experienced interpreters who can also travel to conferences. “Sign language interpreters are very expensive,” says Ingo Barth. “But these costs are funded by the Integration Agency. The MPI supports me perfectly; for example, it organizes everything in such a way that questions can be clarified when the interpreters are also at the Institute. And we not only have representatives for employees with disabilities, but also an inclusion representative, who serve as designated contacts.” Ingo Barth has achieved a great deal on his career path so far, but he also has many more plans and ideas – for example about equal opportunity: “It would be good if there were permanent jobs for those with severe disabilities. For me, for example, a move to a distant city or another country would be almost impossible to manage, as I’m dependent on my interpreters. They know my scientific work, they’ve developed specialized vocabulary to interpret from German sign language into English. Anywhere else, I would have to start from scratch,” says Barth, whose career and CV make him a role model – not only for other deaf scientists.

From Lindau on Lake Constance to the MPG’s world of research

The MPG traditionally gives around a dozen junior scientists from the MPI the opportunity to attend the Nobel Laureate Meeting. This time, however, 14 participants unconnected with the MPG were invited on a flying visit to Munich and one of the Institutes in order to promote further network expansion.

The 68th Nobel Laureate Meeting in Lindau at the end of June was yet again an exciting week, which this time brought together 39 Nobel Laureates and 600 junior scientists to focus on physiology and medicine. For 24 of them, the program continued after the conference had officially ended – at the post-meeting event organized by the MPG. This event, which is financed by the Max Planck Foundation, was established last year with the objective of giving highly-qualified young international scientists an exclusive in-

Photo: Axel Griesch

Biodiversity, tropical disease and health

Tandem Research Groups meet in Colombia to share experiences

Group photo with researchers: representatives of ten Tandem Groups spent two days together in Bogotá.

In Colombia, there are ten Tandem Research Groups at universities in Bogotá, Cali and Medellín. The leaders of these groups, all of whom are researchers selected by means of international calls for applications, have now met for the first time to share their experiences.

The first Scientific Symposium for all Tandem Groups took place at the Universidad de los Andes in Bogotá at the beginning of June and was attended by almost 50 junior scientists. The 26 presentations given at the two-day conference divulged not only the progress made on their research projects, but also the increase in external funding and the growing number of international publications, collaborative endeavors and last but not least doctoral and other students. The groups, each of which contains between five and seven young scientists, have been granted five years of funding by their home university or the Colombian Administrative Department of Science, Technology and Innovation (Colciencias), and cooperate closely with the respective Max Planck Institutes.

Nine groups are carrying out interdisciplinary research in the fields of tropical disease, biodiversity and health, investigating the metabolism and microbiome of plants, animals, insects, bacteria and viruses in laboratory experiments and using innovative biosensors and computer modeling. One other Tandem Group is researching the transformation of public law, particularly with regard to land grabs in Colombia.

Photos: MPG (top); Ch. Flemming / Lindau Nobel Laureate Meeting (bottom)

sight into the MPG's world of research. A total of 24 talented young people from all over the world were hand-picked from among 80 applicants and invited to familiarize themselves with the support and research conditions provided by the twelve participating MPI.

At the start of the event, Max Planck President Martin Stratmann welcomed the group of young scientists at the Administrative Headquarters in Munich and talked to them about career opportunities in the MPG and their personal goals. The accompanying cultural program consisted of an introductory weekend in Munich including a Bavarian-style dinner, an entertaining tour of the city and a visit to the Deutsches Museum. Afterwards, the scientists traveled to the MPI of their choice. During their two-day stay there, the guests gained an impression of their respective Institutes, spent a day working with one of the working groups, and introduced themselves and their own research as part of a presentation. They were supervised not only by the Directors and Research Group Leaders, but also by MPI "mentors" who had also attended the Lindau Nobel Laureate Meeting. The visitors first met these mentors during this conference.

Informal gathering in Lindau. Bianca Verlinden (left) and Shireen Mentor in conversation with other participants in the MPG's post-event program.

Quiz night in the cafeteria

The Max Planck House hosted a special event for external guests

At the first quiz night in the Administrative Headquarters in Munich, nine quiz teams are solving major and minor research questions and puzzling over everyday trivia. Along the way, they are learning about the Max Planck Society, its history and some of the Institutes.

"How many of you have taken part in a quiz night before?" A couple of hands are hesitantly raised. Most of the 45 or so guests still have no idea what awaits them in the cafeteria of the Max Planck House at the Hofgarten in Munich. It is evening and the staff have gone home. As expected, most of those present are visitors from outside who have come together for the Max Planck Society's first quiz night.

The two hosts for the evening, Tom Zimmermann and Darren Grundorf, quickly make their guests feel at ease. None of those who raised their hands are made to sit in a "hot seat" or come to the front. Instead, they are expected to work in teams to find solutions. They sit together, are given a series of questions, and everyone can contribute what they know.

And so the quiz starts. The theme of the night is a bus tour of the Max Planck Society, starring bus driver Klaus and humorously described by the two hosts. Klaus takes his guests on a trip to the various Max Planck Institutes in Germany, with detours to Florida and Nijmegen. During the trip, they not only find out about the MPG as an organization for basic research but are also asked a large number of different questions, with answers to be provided by the nine quiz teams: which household pest is Nobel Laureate Christiane Nuesslein-Volhard researching? What was Max Planck's famous statement on the importance of basic research? The correct answer to the first question is "fruit flies", while for the second question, points are awarded for the answer "Insight must precede application". These questions are not multiple choice, and smartphones may not be used. On stopping at the "MPI for Empirical Aesthetics", the teams have to complete a couple of lines from Helene Fischer's song "Atemlos..." – the question is about which texts and melodies are perceived as beautiful. The origins of the petrified objects investigated at the MPI for Evolutionary Anthropology are explained in a completely different way, with a film clip from "Star Trek".

A good two hours and four rounds later, the winning team is delighted to receive the original Max Planck bath duck and other essential MPG accessories. Moreover, all the other guests are so enthusiastic about the new quiz night that a repeat event is being considered for next year.

An evening of questions and answers about the MPG – this was what the first quiz night had in store for around 45 guests. In the background: hosts Tom Zimmermann and Darren Grundorf.

Photo: Denise Vernillo / MPG

The "Eugen Seibold" sets sail

New ship named after the pioneer of German marine research

In the fall of 2018, the research ship operated by the MPI for Chemistry in Mainz will be heading to the North Atlantic on its first expedition. The launching ceremony took place in May during a conference in Kiel.

Leaders in the field of German marine research convened at the Kunsthalle in Kiel on 11 May. Together they paid tribute to the achievements of Eugen Seibold, who would have celebrated his 100th birthday on that day. In his address, Gerald Haug, climate geologist and Director at the MPI for Chemistry in Mainz, honored the pioneering work of Seibold, who died five years ago. It is largely due to him that "a high-performing, internationally recognized marine research program has been established in Germany," said Haug. The ship was christened by Seibold's widow, the micropaleontologist and science historian Ilse Seibold.

Gerald Haug is likely to have been awaiting the christening of the ship particularly eagerly – after all, it is his Institute that will be operating the research vessel in the future. The ship is expected to be ready for service by the beginning of September, when it will be embarking on its first research expedition to the North Atlantic to investigate the upper 500 to 1,000 meters of the ocean. The "Eugen Seibold" will be voyaging south of the Azores in order to avoid the stormy conditions in the North Atlantic. At these latitudes, the vessel can "sail with trade winds that measure five to six on the Beaufort Scale," explains Haug, himself a keen amateur sailor.

First, however, the "Eugen Seibold" will be cruising back to the Michael Schmidt dockyard in Greifswald, where it was built at a cost of EUR 3.5 million and where the final precision work will be completed. The construction of the 22-meter research ship was financed by the Werner Siemens Foundation.

The "Eugen Seibold" has already made a name for itself as the world's "greenest" research vessel. The ship is especially environmentally friendly, with a plastic hull, two electric engines and a specially developed hybrid drive. This means that sea water, air and plankton samples can be collected from depths of up to 2,500 meters with no risk of contamination. These samples can be analyzed immediately in the clean room laboratory on board. As a result, new possibilities are opening up for the projects being implemented in cooperation with various partners.

The ship was ceremonially christened in Kiel. The "Eugen Seibold" is equipped with two electric engines and a specially developed hybrid drive.

Photo: Thomas Eisenkraetzer

This also applies to the Department of Climate Geochemistry led by Gerald Haug, in which the scientists' work includes analyzing the biochemical processes that take place in the oceans. These processes regulate oceanic heat transport, biological productivity and the oceanic nutrient reservoir, for example. They also have an immense influence on the concentration of CO2 in the atmosphere, which is why they are also important for understanding climate change.

The vessel will normally be manned by "three scientists and two or three crew members," says Haug, who does not want to pass up on the opportunity "to sail with one of the expeditions," although he finds the yacht quite formidable. He himself sails on board "a wooden Dragon built in 1953 with a sail area of 22 square meters," while the Eugen Seibold has 300. "You have to know exactly what you're doing."

Talent, tools and a tenor

The Harnack House – a magnificent venue for the Chefsache Conference

In mid-June, Max Planck Society Vice President Angela Friederici welcomed 16 board members and executives from major companies to the Harnack House. As a member of the Chefsache Initiative, the Max Planck Society was hosting the Chefsache Conference, at which more than 300 guests had the opportunity to find out about current trends in the development of talent.

Women have the same career opportunities as men – this is what 68 percent of the approximately 400 executives questioned in a survey conducted by the Chefsache Initiative believe. However, the reality looks somewhat different. On closer inspection, it was found that less than half of those questioned were able to confirm that their company actually adopts a systematic approach to the development of talent. Moreover, more than half had not yet addressed the existence of unconscious bias or explored it in any depth. It is therefore hardly surprising that the proportion of women continues to grow smaller with every rung up the career ladder.

"The talent of tomorrow has to be recruited today," emphasized Angela Friederici in her welcome speech. There are also still far too few female scientists in Germany's topmost management circles. Professional talent management based on objective criteria could help create equal opportunities for men and women besides making talented women more visible.

Janina Kugel, Chief Human Resources Officer and member of the Management Board at Siemens, went on to explain the importance of diversity within the company. "The mind is like a parachute: it only works when it is open," is her argument in favor of a diverse corporate culture, in which Siemens even publicly supports the LGBT community.

The highlight was the presentation given by Swiss behavioral economist and Harvard Professor Iris Bohnet, who teaches in the U.S.. She used numerous experiments to explain how unconscious bias can be outsmarted. It is important to apply this knowledge when making personnel-related decisions. Her advice included interviewing job applicants individually in a structured manner – a procedure that should also be followed by the persons in the company responsible for making the selection. This is the only way to make independent judgements of the candidates that can then be brought together.

Ruth Werhahn, Labor Relations Director TUEV Rheinland, studies the display in the Harnack House featuring information about famous guests.

Participants had the opportunity to test how far they are free from bias by means of a musical interlude. Quite a few of them may have perceived the singing of countertenor Georg Bochow as an intermezzo sung by a female singer, as they were at first not permitted to see the performer. This was where true fans of Baroque music had a clear advantage...

Various workshops gave conference participants the opportunity to discuss the ideas put forward during the morning session in practical terms, share what they had experienced in their own companies and familiarize themselves with new tools. The workshops focused on the following questions: how can managers be motivated to focus more intensively on developing talent? What form would a talent program have to take to appeal to women? What makes a talented person successful?

The one-day conference was rounded off by two panel discussions between carefully selected guests which also spanned the sports and entertainment industry. The most unconventional arguments were put forward by former professional footballer Katja Kraus from the advertising agency Jung von Matt/sports and feminist Robert Franken. Kraus asserted that having a career did not automatically mean wanting to rise through a hierarchy, while Franken had a request: "Do not see it as presumptuous if people want flexibility in their working lives." His judgement: despite verbal openness, there is still far too much rigid behavior. The Chefsache Initiative still has plenty more to do.

Photo: Phil Dera/Chefsache

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

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