02 | 2021

MAX PLANCK *Research*

MATERIALS RESEARCH
Tuning for solar power

INFORMATION TECHNOLOGY
The architecture of the quantum internet

ENVIRONMENTAL LAW
Climate-Protecting Courts

ALL TOGETHER NOW!

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PHOTO: IMAGO / IMAGEBROKER

Exemplary teamwork: tropical weaver ants live high up in the trees, where they form large colonies. They typically build elaborate nests out of leaves joined together by the silk spun by their larvae. To start with, some of the ants join forces to pull the edges of the leaves together. Other workers carry the silk-producing larvae in their mandibles and weave the leaves together. That makes these tiny insects a prime example of team spirit!

EDITORIAL

Dear reader,

The ants on the front cover are an impressive example of what can be accomplished through collaboration: but just how did collaboration evolve in the first place? After all, living in a group always involves compromise at the expense of the individual.

To investigate the origins of communities, researchers simulate evolution in fast motion in the laboratory. Their research is focused on bacteria. When conditions are right, bacteria establish cell assemblies that can colonize new habitats and continue to develop independently. Does this represent the first step on the path to becoming a multicellular organism?

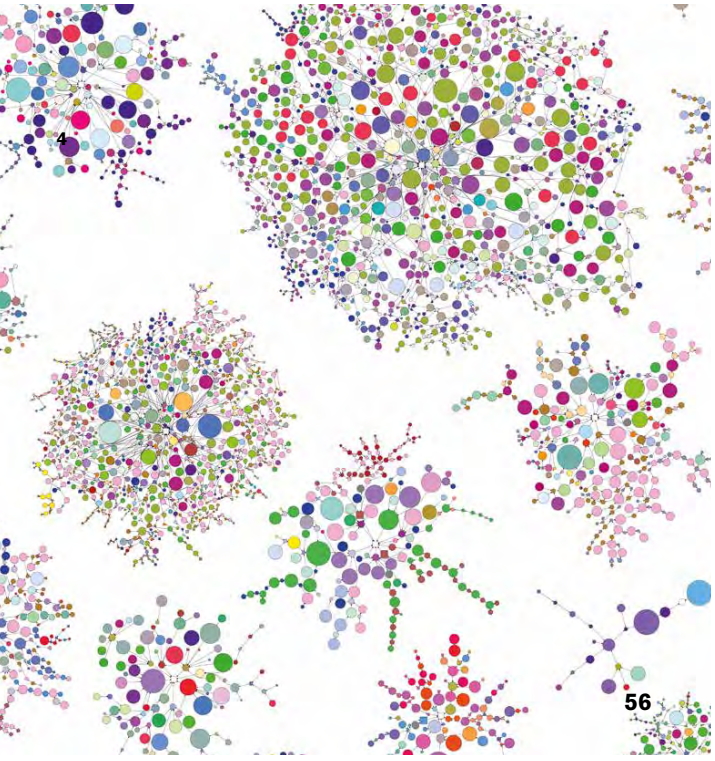
Baboons also benefit from living in groups; it helps them to forage for food and provides protection from enemies. But who actually calls the shots when deciding where to go? Surprisingly, recent findings show that it is not the alpha males who take the lead.

Humans are the undisputed champions of collaboration, yet coexistence in our society is constantly being put to the test. Civil courage is an important social glue. Scientists are striving to understand why some people have more civil courage than others and how willingness to stand up for others can be increased.

In their pursuit of new knowledge, researchers repeatedly transcend the boundaries of the known and make the unseen visible. Starting with this issue, we will be featuring a pair of images in each issue that will present a given research subject from two slightly different perspectives – encouraging you to do a double take! This image duo will reveal surprising connections or present the familiar in a new light.

We hope you enjoy reading this issue and wish you happy browsing!

Your editorial team



PHOTOS: DOROTHEA PLUTA (TOP LEFT), DAVID AUSSERHOFER (TOP RIGHT), VU BRUSSEL/MICHAEL ANSLOW (BOTTOM LEFT), PICTURE ALLIANCE / XIM.GS (BOTTOM RIGHT).

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When it comes to the crunch, only a few people have the courage to intervene.

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Majd Al-Naji wants to convert plant waste and plastic into fuel.

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Climate activists are not only taking to the streets but also going to court.

CONTENT

RESEARCH
ON THE PIANO NOBILE

The KHI (Kunsthistorisches Institut) in Florence is one of the oldest research institutes dedicated to the history of art and architecture in Italy. Founded by a group of scholars as a private initiative in 1897, it has been part of the Max Planck Society since 2002, since which time its research profile has been expanded. How would one set about renovating the premises of such a prestigious Institute without curtailing its research activities? When the KHI was confronted with this challenge back in 2010, the suggestion was made to move the photo library "Photothek" to the Palazzo Grifoni Budini Gattai for the duration of the works. The palace is located in the center of Florence between the Duomo and the Basilica della Santissima Annunziata, close to the Academy, the University and the KHI. This enabled the spatial integrity of important areas of the Kunsthistorisches Institut to be ensured during the time of the relocation.

The Renaissance-style Palazzo Grifoni was commissioned by Ugolino Grifoni and built in the 16th century. It was later refurbished in 1890 when it was acquired by the Budini Gattai family. In 2010, the Photothek was built into the reception rooms in the Piano nobile using a room-within-a-room concept, thus preserving the original structure of the listed historic halls. Every square inch was exploited to allow the photographs to remain freely accessible to researchers on open shelves, while also housing archival materials, the photo library, work desks, and a lecture hall.

With its 620,000 photographs, the Photothek is one of the most important collections for research into Italian art and architecture. The holdings and archives have long since become research objects in their own right. With projects, conferences, workshops, and publications, the Photothek plays a leading role in the international discourse surrounding the function of photo archives in the 21st century.

The KHI's online exhibition
http://photothek.khi.fi.it/documents/oau/00000072

PHOTO: BÄRBEL REINHARD, KUNSTHISTORISCHES INSTITUT IN FLORENZ – MAX-PLANCK-INSTITUT

ON LOCATION

ECOBUS IS PICKING UP SPEED

EcoBus GmbH is all about transporting people in a more efficient and environmentally friendly manner. The recently founded company aims to bring a ride pooling system developed at the Max Planck Institute for Dynamics and Self-Organization in Goettingen into widespread use. During test runs carried out in 2018, EcoBus offered mobility services to passengers in Bad Gandersheim and the Harz mountains who did not have their own car. They were collected from their homes and taken to their destinations in minibuses. At the time, the service found itself in direct competition with regular public transport services, which is why it was suspended. Since then, however, the team at the Max Planck Institute has developed the concept further. EcoBus GmbH now intends to make the underlying software ready for market and to market it accordingly. The idea is to combine the shuttle buses with existing public transport services, particularly in rural regions, to create a system with which passengers can travel from door to door for the price of a local public transport ticket. EcoBus offers its services to all transport companies and, besides allowing users to book regional trips, also intends to make longer journeys possible in the future.

PHOTO: ECOBUS GMBH

Taxi bus: passengers are collected from their homes in minibuses and taken to their destinations.

www.mpg.de/17032762

517 000

By the beginning of July, the "Interstellar" video had been viewed 517,000 times

BLOCKBUSTER ON YOUTUBE

The future is bleak; humanity has to leave the Earth, which is becoming increasingly uninhabitable, which is why a dozen astronauts are heading out into space to look for a new home. The excursion is unconventional because the intrepid explorers are being sent through a wormhole that leads to another galaxy – to a planetary system surrounding a black hole. With its thrilling action, scientific elements and visual effects, the movie "Interstellar" was not only well received by the public, but also won an Oscar. The astrophysicist Kip Thorne, who acted as an adviser during production, later went on to win the Nobel Prize. How scientifically accurate is the film? In the Max Planck Society's explanatory video series "Wissen was" with Doktor Whatson, YouTuber Cedric Engels travels into the fifth dimension with Silke Britzen of the Max Planck Institute for Radio Astronomy and Frank Ohme of the Max Planck Institute for Gravitational Physics to examine how realistic the physics is behind "Interstellar." This takes place in an informal, illuminating conversation – and viewers appear to enjoy it: the video was viewed more than 137,000 times during the first seven weeks, and the first episode of Doktor Whatson's discussion with the Max Planck experts on his own YouTube channel has been viewed more than 380,000 times so far.

www.mpg.de/interstellar01 (in German)
www.mpg.de/interstellar02 (in German)

TWO NEW MAX PLANCK CENTERS

Better treatments for diseases such as dementia and Parkinson's, more powerful computers, new artificial intelligence processes – these are the goals that will be pursued by scientists at the Max Planck – University of Toronto Centre for Neural Science and Technology. The Centre was officially inaugurated in April 2021 during a virtual event attended by Max Planck President Martin Stratmann, University of Toronto President Meric Gertler, German ambassador in Canada Sabine Sparwasser, and Canadian ambassador in Germany Stéphane Dion. Just two months later, in June 2021, the green light was given for another Max Planck Center, the Max Planck – Radboud University Center. The focus of this collaboration are free-electron lasers that emit infrared light. Their potential applications range from biomedicine to chemistry and materials science to astrophysics. Laser systems of this type are extremely complex, which is why there are only a few worldwide, including the one at the Fritz Haber Institute in Berlin and another at Radboud University in Nijmegen. The amalgamation of both facilities in the new Center will facilitate an intensive exchange of experiences and new ideas for the infrared lasers.

www.mpg.de/16760851
www.mpg.de/17048779

IN BRIEF

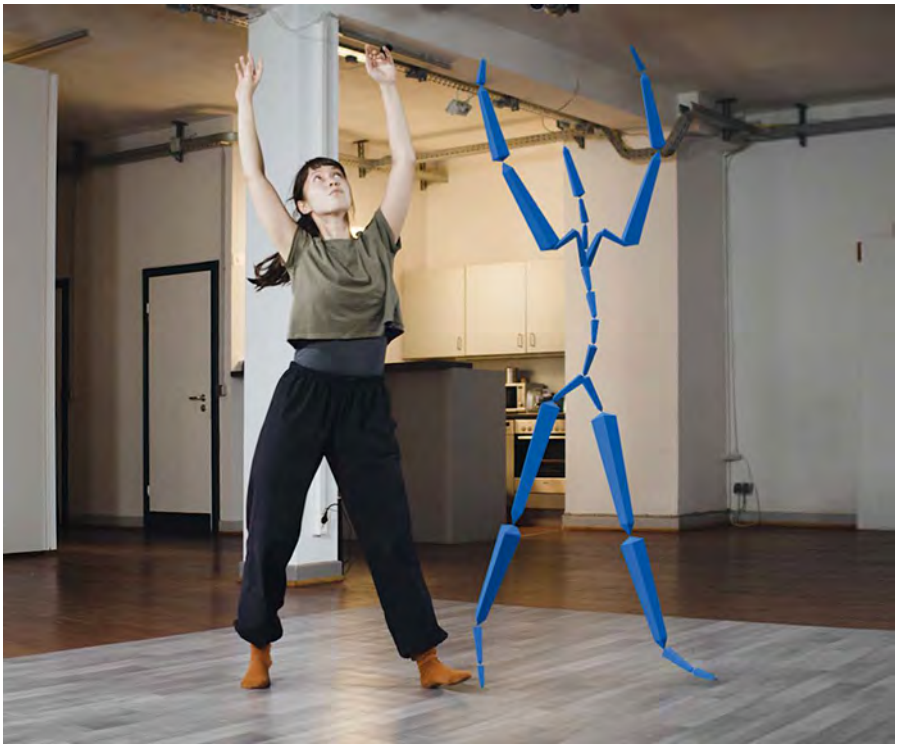


PHOTO: THE CAPTURY GMBH

Virtual dance: the motion capture technology developed by Max Planck spin-off 'The Captury' makes it possible to capture and record movements without markers or special equipment.

ANALYZING MOVEMENTS WITH EASE

Motion capture technology can capture and record movements for playback, analysis, and further processing on the computer. This technology is commonly used in movies to bring animated characters to life. In sports and medicine, it is used to analyze and optimize movement sequences and to treat diseases and the after-effects of surgery. Conventional motion capture technology usually requires special cameras and skin-tight suits fitted with special markers, which are uncomfortable to wear and can often distort natural movement. However, a method developed at the Max Planck Institute for Informatics is now making it possible to use normal cameras to record the movements of people wearing ordinary clothing. A software program analyzes the movements and transfers them to a virtual figure. A company known as 'The Captury', which was established in Saarbruecken in 2013, has made this technology ready for market and is now marketing it. The U.S. company Dari Motion has purchased The Captury and plans to bring the technology into wider use.

www.mpg.de/16777202

RESEARCH IN SIGN LANGUAGE

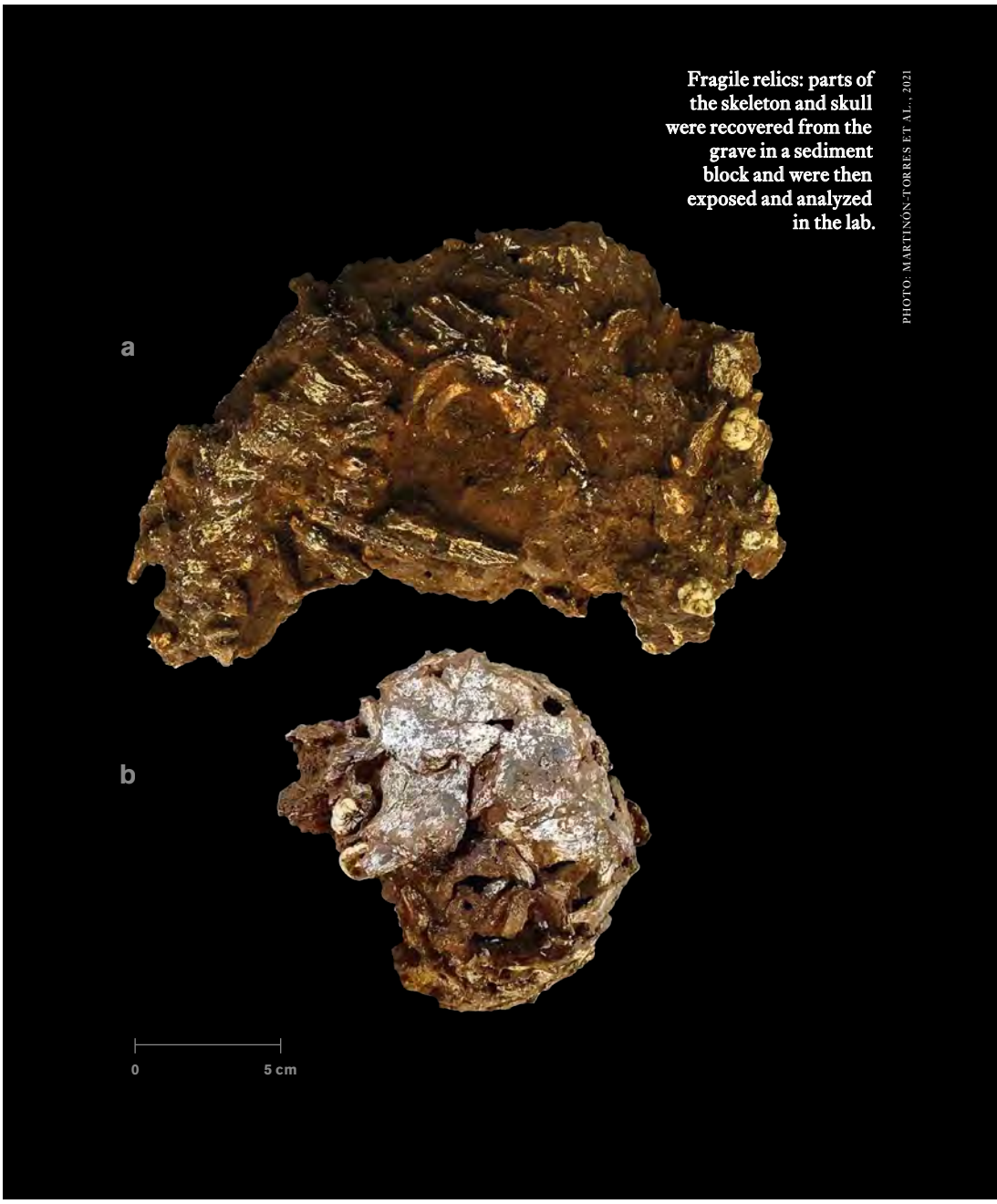
Until now, deaf, and hearing-impaired people wishing to engage in scientific discussion have found that there are often no specialized signs for specific scientific terms. Sign2MINT is now closing this gap. The specialized sign dictionary, which went online in May 2021, was co-developed by the Max Planck Institute of Microstructure Physics in Halle. Compiled in German sign language, it lists specialized signs for terminology used in mathematics, physics, the geosciences, chemistry, biology, and medicine. There is already a database of short videos showing 1,135 specialized signs, and the collection is still growing. The Sign2MINT software allows the signs to be displayed on PCs, tablets, and smartphones. This means that the sign language videos are also enabled for mobile use and can be shared on social media such as WhatsApp, Facebook, and Twitter. While working on the dictionary, the Sign2MINT team had to develop a considerable proportion of the specialized signs from scratch. The project is receiving funding from the Max Planck Foundation.

www.mpg.de/16890214 (in German)

AFRICA'S OLDEST GRAVE

Although the earliest traces of Homo sapiens were found on the African continent, evidence of early burials in Africa is extremely rare, which is why the discovery of a 78,000-year-old child's skeleton at the entrance to the Panga ya Saidi cave in Kenya was an archaeological sensation. The research team, which includes scientists from the Max Planck Institute for the Science of Human History, initially discovered fragments of bone while excavating the site in 2013. However, it was not until 2017 that the small pit containing the skeleton was fully exposed; a detailed analysis took several years. The two-and-a-half to three-year-old child was buried curled up in a shallow pit directly beneath the sheltering overhang at the entrance to the cave. Since the body was lying on its right side with its knees drawn up to its chest, the researchers assume that the burial was carefully prepared, and that the body was tightly shrouded for this purpose. The position of the head also indicates that it was resting on a type of pillow. It is assumed that the community buried the child in accordance with some kind of ritual.

www.mpg.de/16809187



Fragile relics: parts of the skeleton and skull were recovered from the grave in a sediment block and were then exposed and analyzed in the lab.

PHOTO: MARTINÓN-TORRES ET AL., 2021

CATEGORICAL THINKING

A chair is a chair is a chair. This seemingly trivial insight and the associated ability to categorize things are indispensable if we want to get by in the world, because having to learn that every new chair we encounter is a chair would be extremely inefficient. Researchers at the Max Planck Institute of Neurobiology in Martinsried have now discovered that mice are also able to categorize things. During behavioral experiments, it was found that the animals were able to classify stripe patterns either by the width or direction of the stripe. The mice learned the rules and assigned the patterns to the correct category. Whenever the researchers changed the sorting rules, the mice ignored what they had learned before and categorized the pictures using the new rule. Studies of the mice's brains revealed that nerve cells in the prefrontal cortex became active whenever the mice sorted the stripe patterns into categories. Distinct groups of nerve cells react selectively to individual categories. The results show that it is not only humans who are capable of complex thought processes such as abstraction.

www.mpg.de/16747094

NITROGEN MAKES PLANTS THIRSTY

Plants cannot live on water and carbon dioxide alone; they also need nitrogen and phosphorus. The balance between these nutrients has a critical impact on the efficiency with which plants use water and carbon dioxide. An international team including researchers from the Max Planck Institute for Biogeochemistry in Jena has found that feeding nitrogen to small plants in a semi-arid savannah made them grow better but also increased their water consumption. However, if they were fed both nitrogen and phosphorus, the plants grew more strongly and their carbon uptake increased but they did not require more water. Among other things, the fact that a nutrient imbalance makes plants thirstier can be explained by the different effects that nitrogen and phosphorus have on plant stomata. It is not yet clear whether the nitrogen-phosphorus balance also influences water consumption in trees.

www.mpg.de/16898455

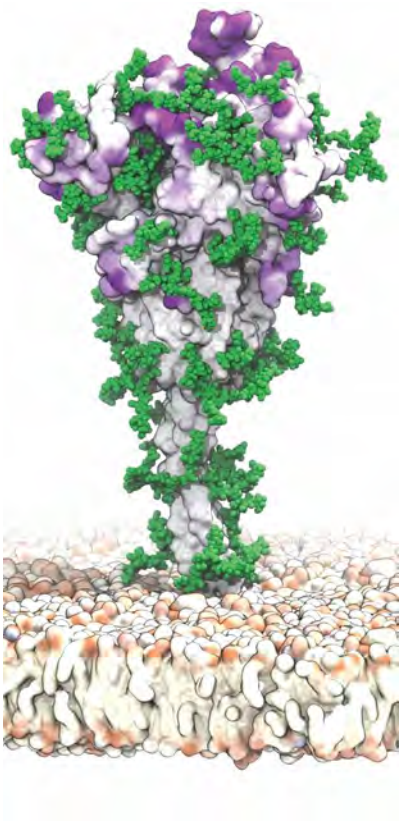
EURASIAN BLACKCAPS ARE HEADING FOR THE BRITISH ISLES

Until 50 years ago, blackcaps mostly spent the winter in the Mediterranean region. Since then, it has become increasingly common to see them in Britain and Ireland during the winter months. From there, they begin the early spring migration to their breeding grounds about ten days earlier than others of their species that spend the winter in the south, which enables them to occupy the best feeding grounds. The new migratory route is probably a consequence of the increasingly mild winters and rich supply of food found in British gardens. Researchers at the Max Planck Institute for Evolutionary Biology in Ploen have recently discovered surprising differences between the birds that use different winter quarters. The blackcaps that are fed regularly in British gardens have smaller fat reserves. Apparently, they do not need to store as much energy because the food put out in British gardens offers a reliable supply of nutrients, which also means that they are more agile and can escape from predators more easily. These birds also have longer beaks, presumably due to the wider range of food available to supplement their natural diet of insects. The tips of their wings are also rounder, probably because they are less mobile than others of their species in the south.

www.mpg.de/16715680 (in German)

PHOTO: BENEHARO RODRÍGUEZ

Blackcaps are exploring new winter quarters.



The spike protein is connected to the coronavirus membrane via a narrow bridge. The surface areas marked in violet are not protected by sugar molecules (green) and could therefore be potential targets for antibodies.

IMAGE: MPI OF BIOPHYSICS/MATEUSZ SIKORA ET AL.

A SHIELD FULL OF HOLES

Hardly any other protein has become as famous as the spike protein of the Sars-CoV-2 coronavirus. The virus uses the protein extending from its surface to dock onto human cells. While antibodies produced by the immune system can easily bond with the upper part of the spike protein, other parts of the protein are protected by chains of sugar molecules known as glycans, which prevent the immune system from recognizing them. A detailed model created by researchers at the Max Planck Institute of Biophysics shows that the glycans act like a dynamic protective shield with which the virus can evade the human immune system. These sugar molecules move backwards and forwards like the windscreen wipers on a car, thus covering a large part of the protein surface even though the coverage may only be minimal at any given time. The researchers have identified certain spots that are least protected by the glycan shields, which could be used to develop vaccines against new variants of the virus.

www.mpg.de/16652522

BEATING THEIR OWN DRUM

For many animals, it is their body size that determines how successful they are when competing with other members of their species and attracting a mate. They try to make their size unequivocally clear to their rivals in order to avoid potentially bloody fights. Male gorillas do this by rapidly beating their chests with cupped hands. The drumming sound, which can be heard more than a kilometer away, is presumably intended to intimidate rival males and attract females. Researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig recorded the chest-beating sounds of mountain gorillas in the Volcanoes National Park in Rwanda and then measured the animals' body sizes. They discovered that the chest-beating sound made by larger males is deeper than that of smaller ones, which means that male gorillas can use the sound of chest beating to make reliable estimates of their rival's body size from a distance. Because larger individuals are more dominant, they can then decide whether it is worth initiating a fight. Females, on the other hand, probably use this information when choosing a mate.

www.mpg.de/16678047

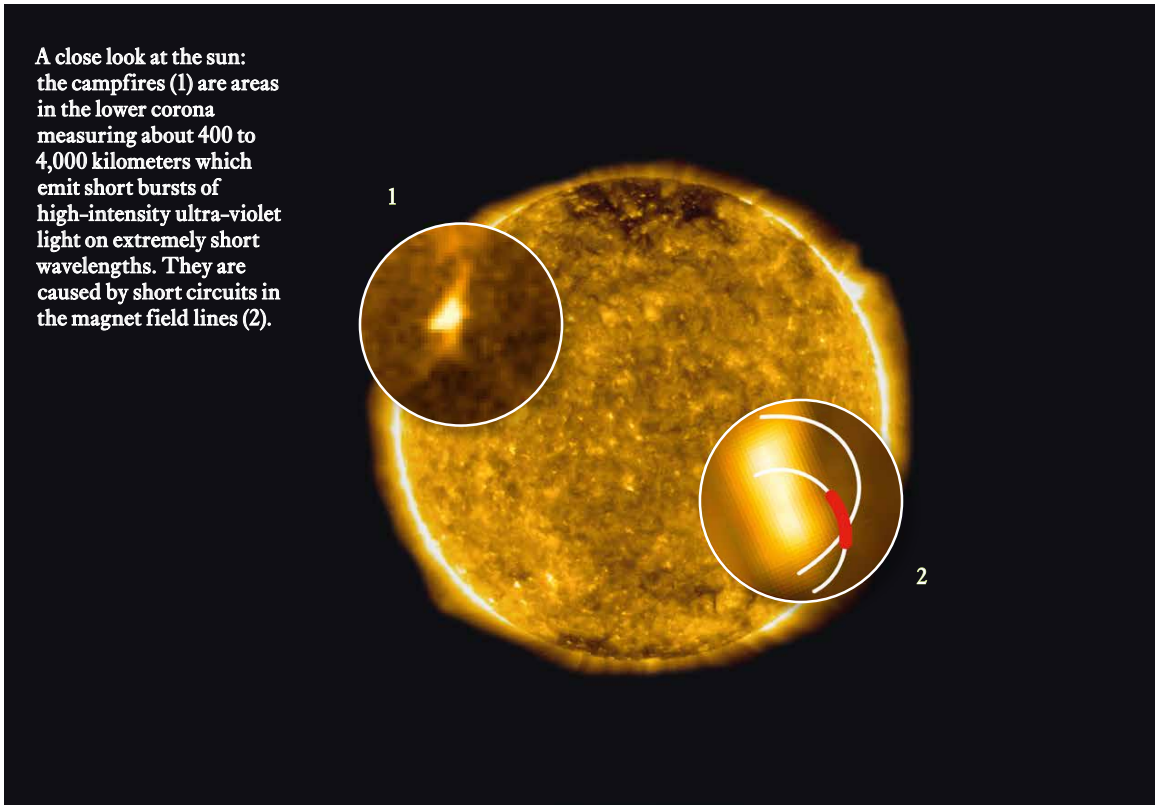
Male mountain gorilla beating its chest.

PHOTO: DIAN FOSSEY GORILLA FUND

CAMPFIRES ON THE SUN

A total solar eclipse puts a crown on the sun: a diffuse light shines around the darkened disk. This corona extends millions of kilometers into space. Researchers have been puzzling over the temperature of the sun's outermost layer for many years: while the visible surface of the sun has a temperature of around 5500 degrees, temperatures in the corona increase to over a million degrees. The European space probe Solar Orbiter has now discovered small, bright regions in the lower areas of the corona. These flares, which are only 400 to 4,000 kilometers in size, occur significantly more often than their larger equivalents, with which scientists are already familiar; like these, the smaller outbursts are caused by a kind of magnetic short circuit in the solar plasma. The scientists have studied about 1,500 of these solar campfires so far. They found that the flares only last a few minutes and reach temperatures of more than one million degrees – possibly contributing to the immense heat in the corona. However, according to Hardi Peter of the Max Planck Institute for Solar System Research, their impact depends on more than just their frequency. The amount of energy they contribute to the corona's total energy balance, he says, is equally important – this is one of the questions that computer simulations will be attempting to answer.

www.mpg.de/16788408



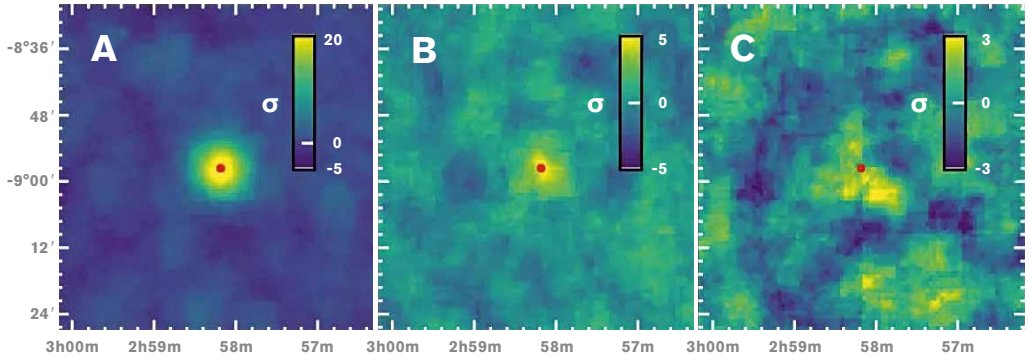
A close look at the sun: the campfires (1) are areas in the lower corona measuring about 400 to 4,000 kilometers which emit short bursts of high-intensity ultra-violet light on extremely short wavelengths. They are caused by short circuits in the magnet field lines (2).

IMAGE: SOLAR ORBITER/EUI TEAM/ESA & NASA

EVEN EDUCATED BRAINS DETERIORATE

The human brain shrinks during adulthood. The prevailing scientific opinion to date has been that higher levels of education can slow down or even stop the shrinkage. However, research carried out by the EU consortium "Lifebrain" on the basis of several large-scale long-term studies has now refuted this assumption. The team, which includes researchers from eight countries and several scientists from the Max Planck Institute for Human Development, analyzed the role which education plays in mental deterioration. The results showed that some areas of the brain were indeed larger in study participants who had spent more time at school and in higher education. However, with increasing age, people with higher levels of education experienced just as much brain shrinkage as individuals with lower levels.

www.mpg.de/16828246 (in German)



A fading burst: the H.E.S.S. sky maps of GRB 190829A shows the vanishing of the afterglow over three nights of observation (from left).

IMAGE: H.E.S.S. COLLABORATION

UNUSUAL GAMMA-RAY BURST

Gamma-ray bursts are some of the most powerful explosions in the universe, releasing more energy in just a few seconds than the sun does over billions of years. It is assumed that this elemental force is released when a massive star collapses into itself and forms a black hole. Part of the energy set free initiates a shock wave which accelerates electrons to almost the speed of light and causes a high-energy gamma-ray burst at the same time. A team of researchers, which includes scientists from the Max Planck Institute for Nuclear Physics, has now tracked the afterglow of such an ultra-high-speed gamma-ray burst using the H.E.S.S. Telescope in Namibia. Surprisingly, the gamma-ray spectrum of this event, which has been named GRB 190829A, resembles that of the much lower-energy x-ray spectrum. The afterglow in both bands also faded in parallel over a period of three days. Until now, gamma-ray and x-ray radiation had been thought to originate in different processes and to behave differently. This theory now appears to be in doubt.

www.mpg.de/16999277

KNOWLEDGE EXPANSION FOR COMPUTERS

Many guests would probably find it a matter of importance if a hotel had no elevator. For the most part, however, search queries sent to booking portal algorithms currently only return information on existing facilities, e.g., that a hotel room has a balcony or an en-suite bathroom. A team from the Max Planck Institute for Informatics in Saarbruecken has now developed a process with which statements can be made about properties missing from a search object. This method can automatically generate knowledge about missing attributes for databases, whereby it is important that the algorithm identifies the relevant statements among the countless negative statements that can be made about an object. To do so, the algorithm considers whether a specific applicable attribute is mentioned in similar search queries. If, for example, hotel elevators are frequently mentioned in corresponding responses, the algorithm concludes that it is important if the hotel has none. Access to this type of knowledge could not only improve the recommendations made by booking portals, but also those provided by online shops.

www.mpg.de/16785381

RISK FACTORS ARE LESS DECISIVE IN OLD AGE

People who smoke or suffer from high blood pressure, obesity or diabetes are not only at greater risk of suffering a stroke, heart attack or dementia, but are also more likely to develop depression or depressive moods. The more risk factors a person has, the more likely this is. Until now, however, it has not been clear whether this probability also depends on their age. For other diseases such as dementia or strokes, earlier studies had already shown that a combination of several risk factors between the ages of 40 and 65 mean that the disease is more likely to develop than if the same risk factors are present in old age. Researchers at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig and the University of Muenster have now discovered that the same applies to depression. The risk factors for depression are also less decisive in people aged over 65.

www.mpg.de/16901631

NANOPROTECTION FOR BATTERIES

Solid-state batteries could help electric cars achieve longer ranges than the lithium batteries currently in use. They are also safer; however, they are not yet durable enough. A team of researchers from the Fritz Haber Institute, the TU Munich and Forschungszentrum Jülich have now found a way to extend the life of solid-state batteries. The researchers found that irregular, nanometer-thin layers at the boundaries between the tiny crystalline grains in solid-state electrolytes can stabilize the batteries. Until now, researchers have tried to make the irregular layers as thin as possible so that the charge can be transported through the electrolytes with maximum efficiency. However, these new findings could change the way they think because the layers block the path of electrons, which could not only cause short circuits but could also contribute to the growth of metallic dendrites, which could also cause short circuits and destroy the battery. With regard to the thickness of the nanolayers, it could therefore be expedient to seek a compromise between efficient charge transport and protection against short circuits.

www.mpg.de/0220211en

Electron microscope image of a solid-state electrolyte: the crystalline grains have a regular structure (left and right), whereas the boundary layer is irregular. The central section is simulated.

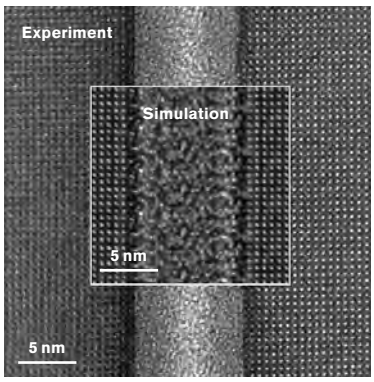


IMAGE: STEGMAIER ET AL., ADVANCED ENERGY MATERIALS 2021

PHOTO: LIZA SUMMER/PEXELS

Crying out for understanding: intensive expression of emotions can often no longer be clearly interpreted.

STRONG EMOTIONS – DIFFICULT TO UNDERSTAND

The sound of a person's voice reveals a lot about how they are feeling. But how well can we interpret the emotional communications of others? For the first time, a team comprising scientists from the Max Planck Institute for Empirical Aesthetics and researchers from New York has studied the relationship between emotional intensity and the associated vocal expressions. They recorded a number of non-verbal sounds that express various positive and negative emotions, such as screams, laughter, sighs, moans, and groans, which ranged in intensity from minimal to extreme. They then looked into how clearly listeners understand these sounds depending on their emotional intensity. As expected, emotions initially became easier to interpret as their intensity increased. However, the more intense the expression of feelings became, the more difficult they were to understand. In the case of extreme emotions, the ability to interpret them correctly fell dramatically. Expressions of the most intense emotions were therefore the most difficult to interpret.

www.mpg.de/0220212en

CHINA – A PARTNER IN TRANSITION

The Max Planck Society has maintained close relations with China for almost 50 years. The country has undergone a rapid development in recent years and is currently on a par with Europe and the U.S. in terms of research. As the Max Planck Society's Vice President Klaus Blaum explains, this poses entirely new challenges for collaborative research.

A black and white photo shows two men sitting side by side on a sofa below an image of Mao Zedong, the "Great Chairman" of the Chinese Communist Party. Taken in Beijing in April 1974, the photo shows Reimar Lüst, the then President of the Max Planck Society, in conversation with Wu Youxun, Vice President of the Chinese Academy of Sciences (CAS). That meeting laid the groundwork for an extraordinarily successful collaboration during the following decades, which undoubtedly contributed to China's scientific rise.

In the beginning, the collaboration primarily involved educating and providing advanced training for scholarship holders, who initially came to Germany in small numbers. By the early 1980s, the Max Planck Society already had its own guest laboratory at the CAS' Institute of Cell Biology in Shanghai, which gave numerous German researchers an opportunity to collaborate with their Chinese colleagues and to teach young Chinese researchers. The first independent junior research groups were then established in 1995 and were modeled on Max Planck research groups. Their purpose was to encourage young Chinese researchers living abroad to return to China. The program introduced a range of important elements such as international calls for tenders and independent peer reviews by

→

VIEW POINT

KLAUS BLAUM

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Klaus Blaum studied physics at the University of Mainz, where he received his doctorate in 2000. He then went on to conduct research at CERN, where he was project leader for "Mass Spectrometry of Exotic Nuclei" between 2002 and 2004. In 2004 he took over a Helmholtz Research Group for Young Investigators at the University of Mainz and habilitated in 2006 with a study on high-precision mass spectrometry with Penning traps and storage rings. Blaum was appointed Director and Scientific Member at the Max Planck Institute for Nuclear Physics in Heidelberg in October 2007. He has been Vice President of the Max Planck Society since July 2020 and is responsible for collaborations with China among other things. For many years, Klaus Blaum has personally maintained close scientific collaborations in the Asiatic region.

international scientific advisory boards. Young Chinese researchers were then willing to forgo promising career prospects in the U.S. in favor of management roles in these groups. About a third of all Chinese research and development management positions are currently held by people who received their scientific training in Germany.

At the celebrations held to mark the 40th anniversary of the Max Planck Society's collaboration with China, Peter Gruss, then President of the Max Planck Society, said that: "Conditions were anything but stable in the early days of our collaboration, because it began in the middle of the Cold War and at a time when Chinese life was dominated by the Cultural Revolution. It took a great deal of courage and foresight to build a partnership between Germany and China at that time." Later, I would like to say more about the courage and foresight we need once again in the present, as the political framework conditions are changing once again. But first I would like to review the changes China has undergone during the past decade, particularly in the field of research.

China now has the second biggest economy in the world after the U.S. Whilst China's share of world trade only totaled 2.3 percent in 1995, it had already risen to 10 percent by 2019 (UN estimates). According to Bloomberg, China invested $377 billion – or 2.4 percent of its GDP – in research and development in 2020, which puts them on a par with the eurozone. And this development is set to accelerate in the coming years.

CHINA IS INCREASING ITS SPENDING BY ALMOST ELEVEN PERCENT ON BASIC RESEARCH ALONE

According to the five-year plan for 2021 to 2026, which was recently signed off in Beijing, China will increase its research and development budget to match that of the U.S., thus establishing the course for coming scientific developments. This year, spending will rise by almost eleven percent in basic research alone, with the primary focus on future technological innovations in fields such as quantum information technology and artificial intelligence. They will also be focusing on information and communication technologies, semiconductor technology, biotechnology particularly in relation to brain and genetic research, space, deep-sea and polar exploration, as well as novel and raw materials.

This major research investment is also reflected in other figures: there are currently 1.82 million active researchers in China, which is more than any other country. However, this only equates to about 0.1 percent of the overall population. In comparison, the number of researchers in Germany equates to 0.5 percent of the population. Moreover, the level of education is not uniform throughout China, being extremely low in large swathes of the country (in the hinterland in the west and north of China), which is why the government is concerned that the backwardness of the rural regions could have a negative effect on China's rise in the near

future. China has also caught up in terms of the number of scientific publications: the country produced 19 percent of all scientific publications worldwide in 2017 – more than the U.S. However, the EU member states, which together account for 26 percent of scientific publications worldwide, continue to lead the field. More importantly though, China's output has long since ceased to be a question of volume alone: for example, the CAS now ranks first – ahead of both Harvard University and the Max Planck Society – in the renowned Nature Index, which evaluates the number of top scientific publications. According to the Index, nine out of the ten most improved universities are in China, in addition to which, China already accounts for the majority of the most cited scientific publications. This applies to computer science and cybernetics (80 percent) and to automation control, nanoscience, nanotechnology and electrochemistry (50 percent).

So there is no longer any doubt about it: from a scientific perspective, China is on par with the U.S. and Europe. For decades, Chinese governments have been promoting science by looking extremely closely at the factors that have made the West and other parts of the world successful – by observing, adopting, and adapting them to Chinese conditions, and by doing so with a very long-term perspective. Whereas only 20 percent of Chinese studying abroad returned home after completing their studies in the year 2000, the figure now stands at 80 percent. China is attractive to its own people. Both the CAS' 100 Talents Program, which primarily recruits highly promising young people from China and abroad, and the Chinese government's 1000 Talents Program, which provides resources to permanently recruit top talents to Chinese universities, as well as to temporarily appoint international experts from leading universities or research facilities abroad, have also contributed to this development.

Every year, the Max Planck Society welcomes around 1400 research fellows from China, which represents the largest contingent of foreign researchers out of a total of 9000 research fellows per annum. Fifteen percent of our postdoctoral researchers and PhD candidates are from China. Many postdocs return to China and, in the case of particularly distinguished young researchers, continue their association with the Max Planck Institute at which they carried out their research for a further five years via a partner group. To date, 32 of the current 36 former partner group leaders have been appointed to senior scientific positions in China. These researchers form part of a network in China, established over many years, upon which we can draw. We are also currently participating in almost 200 collaborative research projects with China, which include research by the Max Planck Institute for Chemistry on the impact of air pollution and climate change in the Yangtze River Delta, the Max Planck Institute for Solid State Research's joint search for new materials with novel properties, and projects being carried out by the Max Planck

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Institute for Psycholinguistics involving the synthesis of mechanistic and neurobiological language models. The CAS continues to be our most important collaboration partner. Teams from the Max Planck Society enjoy privileged access to the CAS' excellent infrastructures, some of which are globally unique, in such fields as radio astronomy and gravitational wave research, biophysical chemistry, ecology and behavioral sciences. Both sides benefit from these collaborations.

CHINA IS INCREASINGLY INVESTING IN ITS SOPHISTICATED SCIENTIFIC INFRASTRUCTURE

China is increasingly investing in its own sophisticated scientific infrastructure, such as a high-energy synchrotron radiation source for materials science, which is roughly equivalent to what will be achieved at the Deutsches Elektronen-Synchrotron (DESY) in Hamburg by the mid-2020s, which the state has been constructing for around two years. In astrophysics and astronomy, China has already put the world's largest radio telescope into operation, with a primary reflector measuring 500 meters in diameter. In comparison, the diameter of our radio telescope's reflector in Effelsberg is about 100 meters, although ours is fully steerable. A new interferometer facility for gravitational wave detection, based on a completely new technique, and a heavy ion accelerator facility to generate radionuclides for basic research and medical applications, similar to the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, are also under construction. And in the field of particle physics, a Circular Electron Positron Collider, with an acceleration length of 50 to 70 kilometers, is being planned in Hebei Province. Again, to put that into perspective, the Large Hadron Collider at the European Organization for Nuclear Research (CERN) in Geneva is 27 kilometers long.

It is evident that China is pushing for the global lead in numerous fields of research with large-scale research facilities whose developers frequently received their training in the West, many at Max Planck Institutes. But China is also aware that scientific progress requires transnational collaboration and is therefore dependent on acceptance by the global science community. Nor must we ever lose sight of the fact that we are facing many global challenges that we will only be able to overcome together, with the aid of international scientific collaboration, a fact that the global pandemic has recently brought into sharp relief. Knowledge has rarely been shared so rapidly and comprehensively among the international scientific community, as occurred in the development of solutions to contain the pandemic. The other major challenge that we will only be able to meet by joining forces on a global scale is climate change and the problems involved in supplying the world's burgeoning population with CO_2-neutral power. Against this background, a strategic collaboration with China in certain research fields is essential. Yet, as fruitful as the collaboration with China in the natural sciences may be, especially in those fields covered by the Chemical-Physical-Technical Section, for which I am responsible as

Vice President, collaborations in other research areas, such as the social sciences, is more challenging and we have witnessed a considerable worsening in recent years. For example, research into the living conditions of Uyghurs in Xinjiang, which began in the 1990s, has been increasingly restricted; virtually no research has been possible on the ground since 2016, since which time our researchers have been denied research permits for this region. We will, however, continue to publish the research results, even if the Chinese government does not like it: we at the Max Planck Society will not submit to any kind of self-censorship. So we are not optimistic about every development in China. Whilst the emphasis in the natural sciences is on excellence in compliance with international standards – which is very much in line with Max Planck Society principles – researchers in other disciplines, such as the social sciences, are encouraged to work on "Chinese theories" and to carry out applied research primarily aimed at solving national problems, which makes it difficult to find any common ground internationally. It has also become more difficult for some of our colleagues in the arts, social sciences, and humanities to carry out effective field research, because their counterparts in China have become more cautious about researching subjects such as political processes, as a result of which the number of contact partners is decreasing as are opportunities for on-site discussion and for accessing data and materials.

The tightening of the European Union's foreign trade legislation and sanctions imposed against China by the U.S., which have resulted in a ban on supplying certain technologies from the U.S. to China without approval, may also significantly restrict collaboration opportunities for German researchers in China. China's legislative processes on research and development are another issue we are closely monitoring: the People's Republic is planning a raft of legislation, for example on the use of research data generated in joint projects carried out in China, that could potentially have a direct impact on research collaborations. Research collaborations with our Chinese partners would certainly become much more difficult were such laws actually to come into force in their present form.

SO WE ARE NOT OPTIMISTIC ABOUT EVERY DEVELOPMENT IN CHINA

So how should we engage with this emerging China at this point? First, we will have to accept the ambivalence and, in spite of everything, seek collaboration in all those areas in which it makes sense and is mutually beneficial. As was the case in 1974, we need courage and foresight – the courage to defend our own values and standards, and the foresight required to pursue the partnership with China in a prudent and fair manner. We need transparency in terms of the organization and management of our partnership. We must avoid any unilateral knowledge transfer. And we need to ensure that we share a common understanding of "good scientific practice," especially as it pertains to research ethics

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(for example, in relation to the collection of personal research data), dual use risks, and the protection of intellectual property. Nor should we be afraid to repeatedly stand up for our concept of academic freedom. It was not for nothing that the campaign carried out by the German science organizations to mark the 70th anniversary of the principle of academic freedom was conducted under the maxim "freedom is our system!", as is instituted in the Basic Law of Germany.

The Max Planck Society Senate adopted a set of guidelines to shape international collaboration in a meeting held in March 2021. These are intended to provide our researchers with guidance in relation to foreign collaborations where conflicts arise between academic freedom and legal and ethical responsibilities. Two of the Max Planck Society's in-house governing bodies – the Ethics Council and the Committee for Ethics in Security-Relevant Research – provide advice to all Max Planck researchers. We need to address dual use issues, i.e., research that could produce results or technologies that could be misused by third parties, such as research that could contribute to surveillance technologies. The purpose of these guidelines is to sensitize people not to naively enter into collaborations and to think carefully about what they want to achieve through a given collaboration and, if necessary, to say no if the conditions are not appropriate or if too many compromises would be required.

WE NEED TO FURTHER STRENGTHEN AND CONCENTRATE OUR CHINA EXPERTISE AT ALL LEVELS

We also need to further strengthen and concentrate our China expertise within the Max Planck Society at all levels and to ensure that we communicate about the current state of play of our collaboration with China. This would involve discussing our experiences and evaluating current developments. To this end, the Max Planck Society has established a "China Round Table" under my chairmanship, an internal council of experts, which, among other things, assesses best practice examples for collaborations with China. Starting in summer 2021, we will also be offering lectures and workshops for all of the Max Planck Society's scientific staff aimed at boosting their China expertise. Additionally we intend to put more effort into motivating our young researchers to spend time in China for research purposes. After all, far more young Chinese are familiar with Europe and the U.S. than young Europeans with China. All too often we only set our sights on the U.S. We need to increase interest in China as well as collaborating with China and familiarize ourselves with China's cultural idiosyncrasies. Over around 50 years, our collaboration with China has seen some very good times but also more difficult periods. While the events in Tienanmen Square in June 1989, for example, placed a strain on relations, that did not lead us to suspend our contacts with China, in contrast to certain other international organizations. We were guided by the idea that the sanctions imposed by the international community were

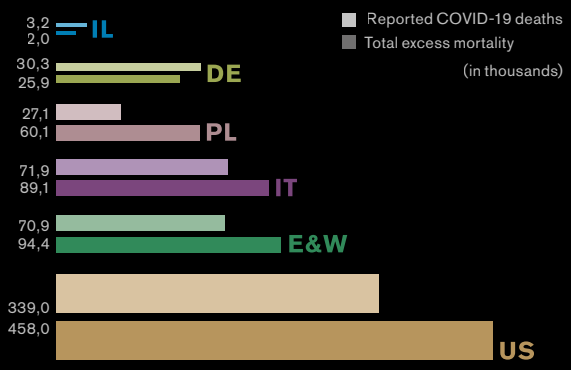
having a negative impact on precisely those people who were already suffering from what was happening in China at the time. We initially avoided official contacts but continued our involvement in scientific programs and projects as far as possible. This created trust, which is an important social basis for collaboration, especially in China.

Moreover, the only way in which we will be able to influence further developments in China will be through collaborative endeavors. Scientific contacts can keep doors open that, for good reasons, have to remain closed in other areas, or which are completely locked. The Max Planck Society has gained a great deal of experience in this area, and I am optimistic that individual contacts among researchers in particular will continue to serve as a driving force for German-Chinese collaboration.

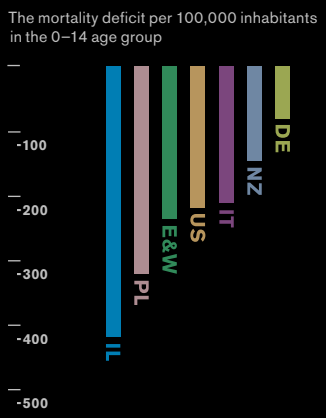
THE DEAD OF THE FIRST YEAR OF THE COVID-19 PANDEMIC

The COVID-19 pandemic is costing millions of lives. The true extent of the pandemic is revealed by "excess mortality": the difference between total reported deaths in 2020 and those expected to occur on the basis of previous years. A team at the Max Planck Institute for Demographic Research compared these figures, and their results show that the mortality rate not only depends on the rate of infections and the protective measures implemented, but also on such factors as the capacity and efficiency of the health care system, as well as the aging structure of the population.

REPORTED AND ACTUAL DEATHS



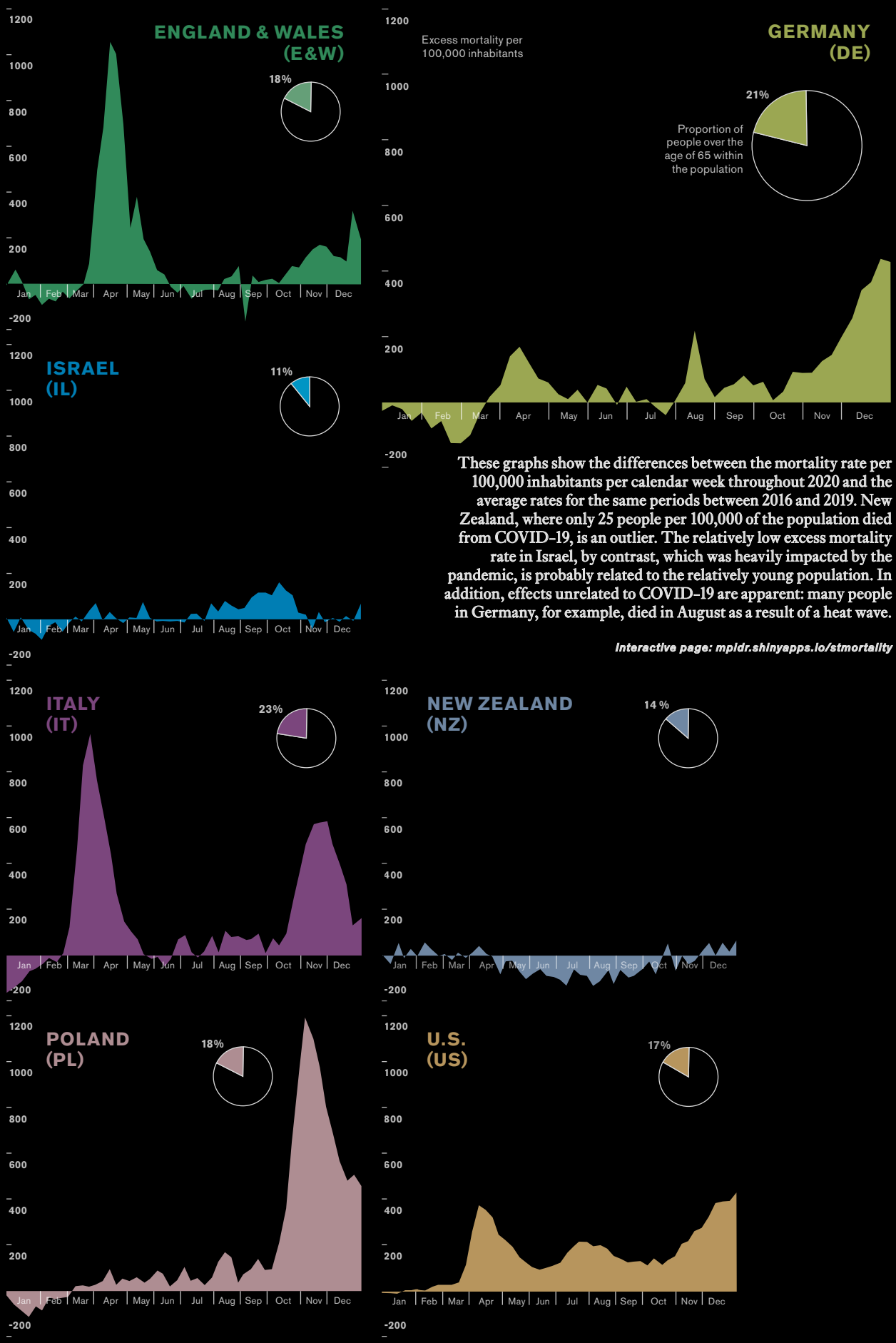
FEWER CHILDREN DIED



GRAPHIC: GCO BASED ON N. ISLAM ET AL.: BMJ 2021; 373: N1137

In many places, the pandemic has claimed more victims than reported, due, for example, to overstretched health systems. On the other hand, measures such as mask-wearing, social distancing and restrictions on travel have also prevented deaths from other infections and accidents. This can be seen in Germany and Israel, for example, where the number of reported COVID-19 deaths was higher than excess mortality (above). This probably also accounts for the decreased mortality rate among children and adolescents (right).

2020 MORTALITY RATES IN COMPARISON



These graphs show the differences between the mortality rate per 100,000 inhabitants per calendar week throughout 2020 and the average rates for the same periods between 2016 and 2019. New Zealand, where only 25 people per 100,000 of the population died from COVID-19, is an outlier. The relatively low excess mortality rate in Israel, by contrast, which was heavily impacted by the pandemic, is probably related to the relatively young population. In addition, effects unrelated to COVID-19 are apparent: many people in Germany, for example, died in August as a result of a heat wave.

Interactive page: mpidr.shinyapps.io/stmortality

FOCUS

ALL TOGETHER NOW!

Female olive baboons with young. The females usually stay in their troop for their whole life. They have a fixed position within the hierarchy, which they pass on to their daughters. Until the age of three months, the young hold on to the belly of their mothers, later they ride on their backs like jockeys.

PHOTO: KATHY WEST ©2013, TANZANIA

THE MONKEY TROOP IS ON COURSE

TEXT: CARLA AVOLIO

Baboon troops are famous for sticking together as they traverse the savannah in search of food. For almost a decade, Meg Crofoot, Director at the Max Planck Institute of Animal Behavior in Konstanz, Germany, has been studying a group of olive baboons in Kenya to understand how they do this – how they overcome their individual differences to band together, make a decision, and move forward as one.

It's five in the morning at the Mpala Research Centre in Kenya and the baboon troop is nowhere to be seen. A lingering cold in the pre-dawn air is keeping them high above the ground in their sleeping nest in the trees. Huddled in groups, the troop of 50 olive baboons stays warm and safe from the leopards who stalk them below. But soon enough morning comes. As the sun spills over the horizon, the troop begins to stir. And the game of compromise begins. Compromise is not a word that usually springs to mind when thinking of baboons. More commonly, images of the group-living primates focus on the dominant male – with his extra-large body and shaggy mane of fur – who wields a despotic sway over his tight-knit group. He gorges himself at the best food patches while the rest watch on. He enjoys access to the best sleeping sites, the most mating opportunities and grooming sessions. He keeps the group in check with aggressive tactics.

The majority decides

But in recent years, scientists including Meg Crofoot have built a body of research that adds color to this black and white picture. By studying a troop of olive baboons at the Mpala Research Centre, Crofoot and her team have discovered that the levers of power do not lie solely with dominant individuals.

Far from it. When it comes to choosing where to go, the group can decide democratically. To help the troop stay together, baboons of all sizes will compromise on their preferred pace of movement. Features in the landscape and subtleties of the social group also play a role in shaping the decisions that individuals make. All of this points to a far more nuanced portrait of baboon societies. "It isn't that we have a strictly despotic or democratic decision-making species," says Crofoot. "What we anticipate is that these decisions are flexible and highly context dependent."

Understanding the nuance in these results also requires understanding the technology at the heart of the science: GPS tracking devices that record the position of animals at very high accuracy. Before high-resolution trackers, biologists studying the behavior of social primates in the wild had two choices: "Either you observe one animal through time, but miss out on what's going on in the periphery that sets the social stage for that individual's behavior," says Crofoot. "Or you can do slices through time and record what everybody is doing but miss out on the sequence of events."

GPS trackers changed that. Now, a single researcher can know with centimeter precision where every animal in the group is, and what they are doing, at the same time. In 2012, Crofoot and her team attached GPS collars to 25 olive baboons in a troop, becoming the first scientists ever to do so on a social primate. The collars, which logged one GPS point per second for weeks, have yielded a staggering amount of data. Study by study, these data are allowing the team to fill in the pages of knowledge about the inter-dependencies of baboon societies. "How what I'm doing effects your behavior; how our interactions shape the choices of other group mates," says Crofoot.

The findings of the first study, which asked the question – who does the group follow? – came as a surprise: in a society marked by despotic leadership, rank matters very little. Troop members didn't follow dominants any more than they did subordinates, overturning assumptions about who affects whom in this highly hierarchical society. "Why the dominant males can't, or don't, translate their social power into leadership ability remains a mystery – and one we are actively working to understand," says Crofoot. The team, which included Iain Couzin, Damien Farine and Ariana Strandburg-Peshkin, then showed what happens when the troop has to choose between following two baboons moving in different directions. Their choice, it turns out, hinges on the angle between the two paths. If that angle is less than 90 degrees, then follower baboons

PHOTO: ROB NELSON

"It isn't that we have a strictly despotic or democratic decision-making species. What we anticipate is that these decisions are flexible and highly context dependent."

MEG CROFOOT

Roland Kays (left) and Meg Crofoot preparing GPS collars. The researchers equipped a group of 25 baboons with these tracking devices and recorded the positions of all the animals to the second for several weeks.

will compromise and head off down the center. If the angle is bigger than 90 degrees, the followers choose whichever direction is preferred by more members of the group.

This finding, which the team termed "majority rule" showed that the baboons could incorporate democratic decision-making. But without the backdrop of the physical and social environment, the picture of baboon decision-making was incomplete. To help, the team turned again to tech, this time to an unmanned aerial vehicle that flew above the plateau in Kenya collecting high-resolution imagery. With the photos, Strandburg-Peshkin generated a 3-dimensional reconstruction of the landscape with a precision of five centimeters. By overlaying the baboon location data on the 3D landscape, the team could essentially see through the baboons' own eyes how the hills, trees, roads, and other features in the habitat influenced their decisions. They discovered that roads are key to baboon decision-making. So much so that roads override the "majority rule". If a troop is moving along a road and another baboon wants to pull off into the surrounding vegetation, it takes not just a majority but a super majority to make the troop budge.

"Walking on the road is easier, so trying to pull your group mates into a situation that requires them to work harder will justifiably take you more effort," says Crofoot. The baboons also care about where the group has been – preferring to visit locations where other baboons had visited in the last five minutes.

Studies that combine the natural environment with collective movement are surprisingly rare. "What's so fascinating to me is to see how the animals are integrating social and habitat information over different spatial and temporal scales," says Crofoot. "It also illustrates the way results prompt new questions about what matters and why it matters." These new questions began to coalesce around the physical capabilities of the animals. After watching hundreds of hours of baboon videos – standard practice for those studying animal behavior – the researchers noticed a striking pattern. "You would see the troops constantly speeding up and slowing down, having to modulate their own pace as the group is moving," says Crofoot. This got the team wondering how societies like baboons – in which animals of different ages, sizes, and capabilities move together – bear the cost of this cohesion.

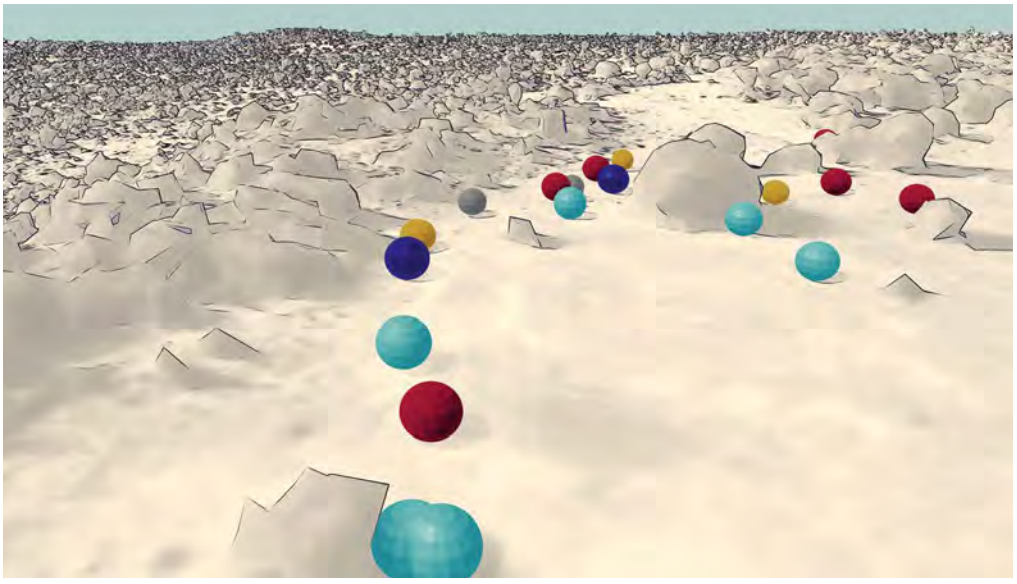
To find out, Crofoot tapped an untouched stream of data. Back in 2012, she had integrated accelerometery sensors into the GPS collars "because they didn't cost anything in terms of battery life." In the background, these powerful sensors had been collecting information about the performance, behavior, and energetics of the wild animals. "We had this pile of accelerometery data that nobody had dared to look at," she remembers.

PHOTO: MEG CROFOOT

This page:
The thick mane is the typical feature of the adult males of the troop. They weigh up to 40 kilograms and have longer canines than a lion.

Next page:
A group of olive baboons in the savannah of Kenya. The animals like to follow roads, probably because they can travel faster that way. To keep the troop together, the animals have to adjust their speed to each other.

PHOTO: CARTER LOFTUS



GRAPHIC: GCO ACCORDING TO MEG CROFOOT

Linking GPS location and landscape reconstruction: the spheres indicate the positions of the members of the baboon troop:

- Adult female
- Sub-adult female
- Adult male
- Sub-adult male
- Juvenile

Then COVID-19 happened. International travel was banned, fieldwork ground to a halt, and scientists were stuck at home with just their computers to keep them company. It was the perfect time to mine the data. Roi Harel led the investigation into the locomotor consensus costs of the troop's cohesion. He found that the mixed size of the troop members does pose an obstacle to collective movement. Each size class is compromising on their optimal speed in order to keep the group together. However, Harel also found that the costs fall most heavily on the youngest members who, by virtue of their smaller size, also have the most to gain by safety in numbers.

If the accelerometery data was complicated, it's just the beginning. With computer science collaborators, the team have incorporated wrist watches on baboons that add an additional array of sensors: magnetometers, gyroscopes, temperature loggers, and acoustic recorders to name a few. The goal is to create an electronic ethogram for each animal – a digital description of its behavior rendered in exquisite detail.

With that toolkit, researchers studying sociality in nature can begin to grasp at questions that once seemed out of reach, but which are essential to an integrative understanding of social behavior. Questions such as: how do wild animals sleep when they are together? "Sleep is usually studied in labs using single subjects," says Crofoot. "One of our next projects is to move this into an ecologically relevant setting that also captures the collective dynamics of this mysterious behavior."

Sleeping together, moving together, deciding together. It's easy for the mind to wander and to arrive at another, extraordinary ape.

"It's wonderful to watch baboons in the wild as they argue, make up, help each other, and sometimes trick each other," says Crofoot. "It inevitably makes you draw parallels to humans and think about our own evolutionary path."

"How did we come to be such an unusual ape? The answer to this question lies in understanding the similarities, and differences, in how we and other socially complex animal species overcome conflicts of interest to achieve shared goals. My lab tackles this problem by using powerful remote-sensing technologies to escape the limitations of the human observer, and attain a novel vantage point from which we can understand how animal societies emerge and function."

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

SUMMARY

Thanks to modern GPS tracking, researchers can see where every animal in the group is and what they are doing, at the same time. Using this and other environmental data, they want to find out what determines the animals' behavior.

Rather than always following the dominant male, the members of a baboon troop often choose the direction that more group-mates are moving in. The choice of direction is then effectively made in a democratic manner.

Troop members have to compromise on their preferred speed of movement to ensure that the group remains together, whereby the younger ones have to adapt more than older ones.

RARELY COURAGEOUS

TEXT: MARTIN TSCHECHNE

Civil courage is essential in a free society. Yet, when it comes to the crunch, few people dare to protect the victims of crime or to take an active stance against hatred and racism. Psychologist Anna Baumert of the Max Planck Institute for Research on Collective Goods is conducting research into the motives and conditions for civil courage – a work in progress.

DOROTHEA PLATZ

Imagine a young person walking into a research laboratory with bare walls, ceiling lamps, and seminar tables. Some of the Institute's friendly staff explain the procedure of the study, take down personal details, and hand out some questionnaires. They then ask whether the visitor would like to accept a small payment as a thank you for his or her time and effort, or whether he or she would prefer the study to count as credits for their degree. No, he or she replies: forget credited hours; I'll take the payment.

Shock, outrage or silence

So let us assume that the test subject had worked through a stack of test questions, then in a second session two weeks later, had untucked their top and put on a strap to measure their heart rate. Following the researchers' instructions, he or she has memorized a text, answered questions about it, and willingly provided information about his or her own feelings – nervous, anxious, bored, each of which rated on a scale of zero to five – and then, at some point during the experiment, overhears a conversation between two of the project staff. Although they are whispering with their heads close together, our test subject hears a short but unmistakable proposition: "Some of our test subjects do have their work credited to their studies; so if we also issue a receipt for payment in their names, then we could collect the money ourselves and no one would be any the wiser ..." How would such a study participant react? With shock? Outrage? Embarrassed silence?

Psychologist Anna Baumert of the Max Planck Institute for Research on Collective Goods has come up with some sophisticated, differentiating hypotheses. According to her, the test subject's reaction depends on his or her personality, the presence or absence of others, the subject's experience of dealing with authority, and the expectation of being able to take the initiative rather than being at the beck and call of others. During the course of her research, Baumert has developed a system of concepts in collaboration with many colleagues, representing a guideline for distinguishing between character types: whether one's perspective of the world is as a casualty or a beneficiary of events, whether he or she observes and analyzes situations solely from the outside or experiences him- or herself as playing an active role, and with pride and satisfaction or with guilt and shame. It is a question of moral courage – whether to stand up for the interests of others, even if one's own suffer as a result. It is about the whistleblower's determination to bring secret data and practices into the public domain for the communal good, even under the threat of imprisonment. It is about standing against discrimination and prejudice, racism, sexism or hatred, especially when it affects others, or standing up in the subway to put a bully in his or her place or intervening when someone is being hassled. It is also about protesting when many people are doing their best to protect public health, while a small minority get together to party in spite of everything. Baumert interviewed people who had been awarded crosses of merit for their civil courage. One woman had driven off a gang of hooligans who were kicking a man while he lay on the ground. A man had chased after someone who had burgled a neighbor's house, keeping in cell phone contact until the police arrived on the scene. Are such people different? Yes, says the psychologist. They get angry about things more intensely and perhaps more readily and they may have a lower tolerance for unresolved situations. "I suspect that sensitive observers are also more likely to clarify a situation for themselves and then to intervene in a more decisive manner. I'm extremely interested in this approach to dealing with uncertainty or ambiguity."

"Those who tend to look into a situation themselves will probably take more decisive action to intervene."

ANNA BAUMERT

For decades, the Kitty Genovese case has been considered a textbook example of the failure of all virtues within a community. The young woman was stabbed, raped, and murdered outside her house in the New York borough of Queens on March 13th, 1964. As a reporter for the New York Times discovered, 38 people in the immediate vicinity witnessed the crime. They had been awakened at 3:15 am by the woman's screams but had stood at the window, hesitated and waited – for almost an hour! One had even turned his radio up to drown out the horror. Finally, one had ran out the door to hold the dying woman. But no one really came to her aid.

The search for courageous personalities: psychologist Anna Baumert heads the Max Planck Research Group "Civil Courage" at the Max Planck Institute for Research on Collective Goods and teaches at the University of Wuppertal.

PHOTO: FRANK VINKEN FOR MPG

Of course, Baumert is aware of the literature relating to the case; it is standard reading in her field. A few years later, for example, Bibb Latané and John M. Darley, both social psychologists, founded an entire research tradition relating to the question of when and why people fail to intervene. "There is clear evidence," she says in summary, "that the presence of others who fail to take action can cause people to not intervene themselves." And yet, she remains skeptical, explaining that the evidence in many of the studies is too anecdotal, and the explanations, which are often collated in a rather random manner, are too speculative. "We have to define a given context ourselves," says Baumert, explaining her approach: "Only in the context of a controlled study can the relevant personality traits be recorded and subjects be interviewed in parallel with events. It's about causality."

Victim, observer, perpetrator, beneficiary: in the course of her studies, the psychologist has identified four perspectives on everyday perceptions of injustice, each of which results in a distinct level of sensitivity – a disposition to confront challenges to public morality. These represent the conditions necessary for active civil courage – or for inactivity. Victim sensitivity, for example, initially arises when someone experiences an injustice firsthand, which may lead to anger and rage or else hesitancy, mistrust, and a tendency to withdraw. "Both are plausible," Baumert confirms, "and we have observed both in our studies." In one project she carried

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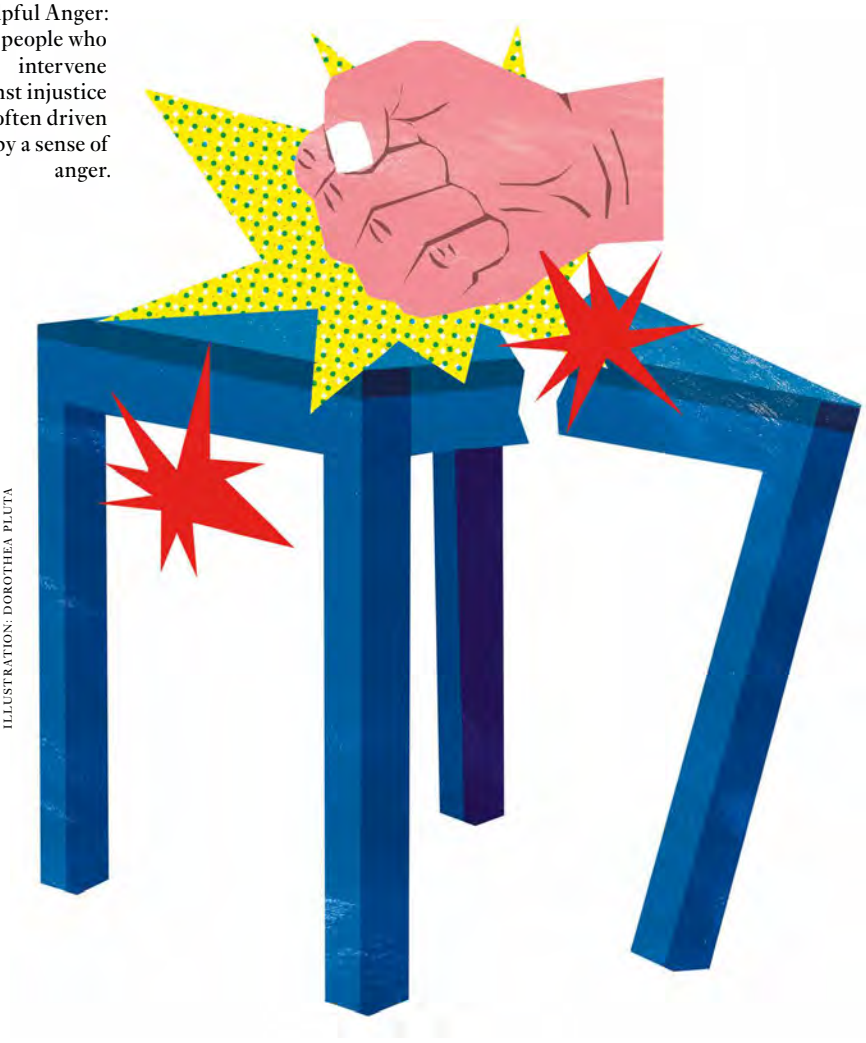


Helpful Anger: people who intervene against injustice are often driven by a sense of anger.

ILLUSTRATION: DOROTHEA PLUTA

SUMMARY

It is difficult to gauge people's willingness to take action that requires civil courage under controlled conditions.

Clear predictions cannot be made based on personality traits.

People who tend to anger more rapidly or more violently are more likely to exhibit civil courage.

out in collaboration with South American researchers in Chile, for example, she found that it was the direct victims of exploitation and oppression whose angry determination made them stand out during the protest movement.

And, what is to prevent uninvolved observers from becoming keenly aware of the unjust nature of a particular situation, or people who develop a special empathy precisely on the basis of an introspective awareness of their own behavior, or undeserving beneficiaries, who become aware of the privileges they enjoy and question them? "Yes, that happens too," Baumert laughs. "Just think of the elderly white man who stands up for women's rights – perhaps there should be a few more of them."

In her empirical studies, Baumert collects and dissects various contexts and narratives that influence an experience and stimulate an interpretation. She surveyed students and was surprised to discover that their sensitivity to injustice seemingly tends to diminish when they start a university course. That was until she realized that their lives really had changed in one particular respect: their new circumstances were less regulated, freer and less structured, at least in comparison to the parental home and school, so they simply presented fewer opportunities to experience anything like injustice in their immediate environment. Baumert realized that any analysis of such complex conditions requires equally complex strategies, so she organized her study like a conspiracy, comprising an extensive battery of psychological tests, which she evaluated in detail, and the task of memorizing a text, whose result was irrelevant to her subject and simply served as camouflage. She recorded certain physiological parameters, which if they deviated from the norm provided her with proof that her performance shocked subjects and asked assistants to whisper to each other, while in fact ensuring that the genuine test subjects actually

overheard these seeming "secrets". The entire experiment was designed around deceiving the participants (although, just to clarify, she explained everything to them later).

In spite all of this, however, unambiguous results failed to materialize. "The thing is," she says, "none of our four personality traits actually predicts, with any great accuracy and in accordance with our theoretical expectations, who will intervene and who won't." Yet, she's not discouraged: it may be that a truly functional analysis of morally guided action may have to be based even more closely on everyday life. It may be that the path between recognizing a given situation and deciding to take action to counter it needs to be traced in a more consistent manner. Perhaps even broader collaboration is required. "I would be extremely interested in collaborating with developmental psychologists," she says. "Unfortunately, that hasn't yet been possible."

One in four objected

At least the anger factor has been confirmed. Angry people tend to speak out. As the psychologist explains, this emotion is triggered when goals are thwarted or values violated. The signals for the observers were clear enough. And a quarter of the test subjects experienced feelings of anger and objected to the supposed attempted fraud, most of them spontaneously and directly to the staff members involved in the sham. "That's what you find in this kind of study," Baumert explains: "25 percent will say something while the rest keep quiet." Where were they when Kitty Genovese was murdered? Where are they when vandals go on the rampage, strangers or women are threatened, children abused and neglected, when district administrators smuggle their families past the queue to get vaccinated, or protesters against coronavirus restrictions rip the masks off other people's faces? Anyone who reads the papers can judge for themselves: 25 percent would be a remarkably high proportion in real life.

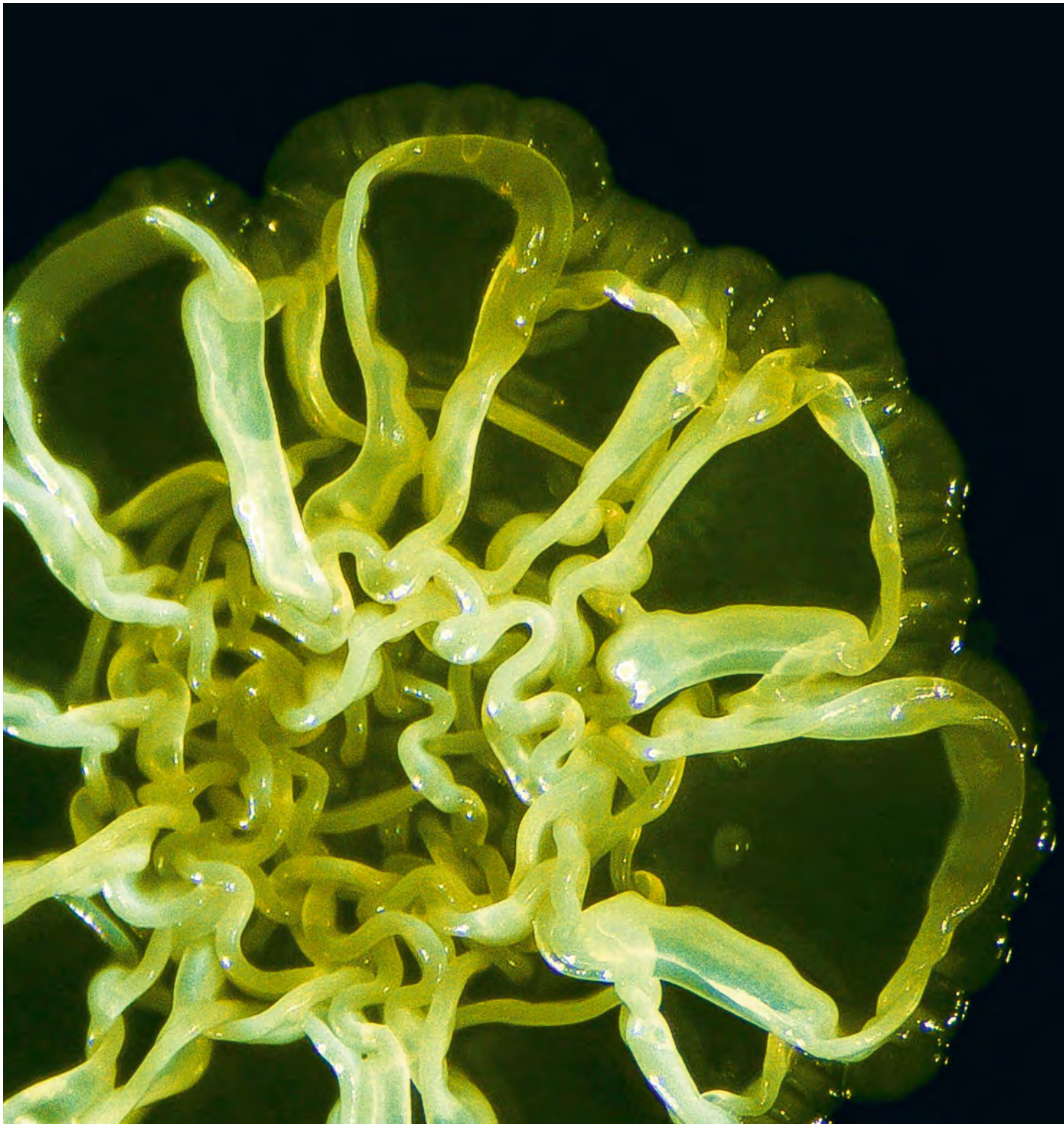
But there are limits, she believes, beyond which her research should not stray. All the effort is essential, she says. The laboratory, the staging – "there is no other way to record psychological differences and dispositions." Not to mention blood pressure or breathing rate. But just how realistically should she shock her subjects in the name of science? Where are the ethical boundaries between curiosity and responsibility? Researchers find themselves in a dilemma. It's something else Anna Baumert attempted to ascertain, as follows. One group of participants in her study was presented with the attempted deception solely by means of a video recording, while another group was provided with a description of events in a written text. And, low and behold, all of the participants were outraged – the sensitive ones, the angry ones, the committed, timid, and indifferent – all joined in the chorus: yes, we would intervene to prevent that, immediately and decisively! Cost-free courage, as Baumert clarifies. "You can't use hypothetical questions to predict behavior. What they reveal is how one sees oneself. How one would like to be."

A myth changed reality

The case of Kitty Genovese deserves an addendum. On March 27th, 1964, two weeks after the crime, the *New York Times* ran an article, and it was this article that first elevated the case to the level of a social phenomenon. "38 Who Saw Murder Didn't Call the Police"; Apathy at Stabbing of Queens Woman Shocks Inspector. Stimulating public outrage was intentional, but no one could have foreseen its enduring character. Psychologists and sociologists took up the subject and were soon to be joined by urban planners, architects, and political consultants. What they found was that the murder confirmed the alienation and anonymity of life in the Moloch of a major metropolis, the stress caused by space restrictions, noise, and social tension, and in some studies even the limits of perception – being present but seeing nothing.

Only in 2015 did a documentary directed by James Solomon entitled *The Witness* reveal how the nocturnal murder had been stylized into a myth right from the start, a narrative of a cold and heartless city, and a cold and heartless society. It was a journalistic disaster: the original reporter confessed that there had not been so many witnesses after all – perhaps just twelve or only two, and not a single one of them had been able to witness the entire course of events. A year later, the *New York Times* also distanced itself from the article. Yet, the questions raised by the case are real as are the research projects that have taken up and studied the phenomenon. Anna Baumert continues to study the necessary conditions for productive anger and moral vigilance. At the same time, she is collaborating with computer scientists to look into potential ways of averting the devastating effects of online bullying and baiting – through courageous objections perhaps or through censorship? While the Kitty Genovese case did portray one, albeit distorted reality, it also created another reality: 911 was introduced as a nationwide emergency telephone number throughout the U.S. just four years after the murder.

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



BIRTH OF COLLECTIVES

TEXT: MAGDALENA NAUERTH

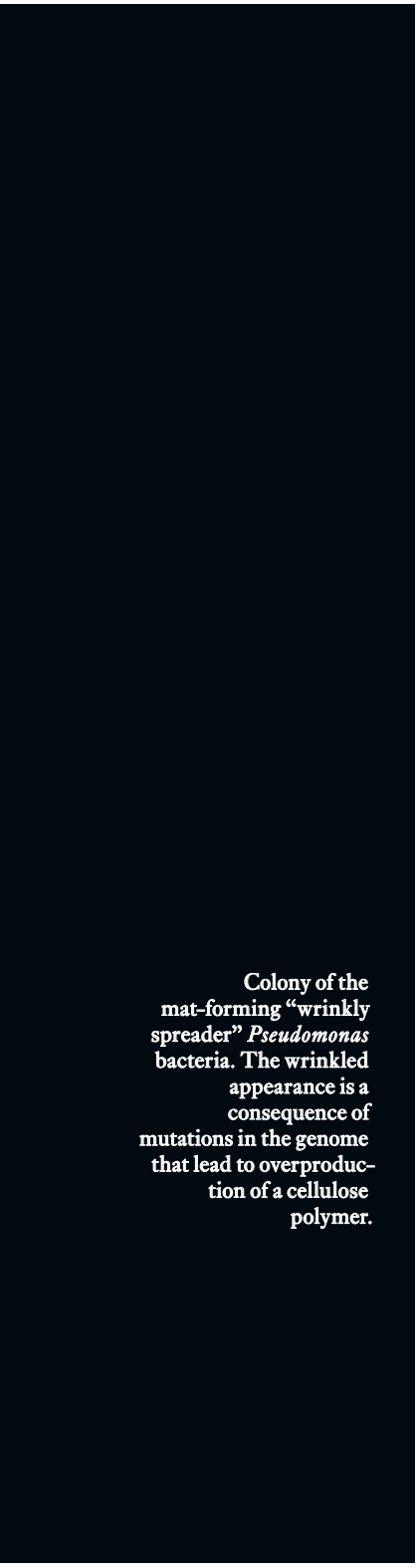


PHOTO: MICHAEL SCHWARZ / MPI FOR EVOLUTIONARY BIOLOGY

Colony of the mat-forming "wrinkly spreader" *Pseudomonas* bacteria. The wrinkled appearance is a consequence of mutations in the genome that lead to overproduction of a cellulose polymer.

Cheaters can leave. In the case of the bacteria in Paul Rainey's lab, that's exactly what is wanted. In his laboratory at the Max Planck Institute for Evolutionary Biology in Ploen, the evolutionary biologist studies how multicellular life emerges from individual cells. Their findings show that too much cohesion can be counterproductive.

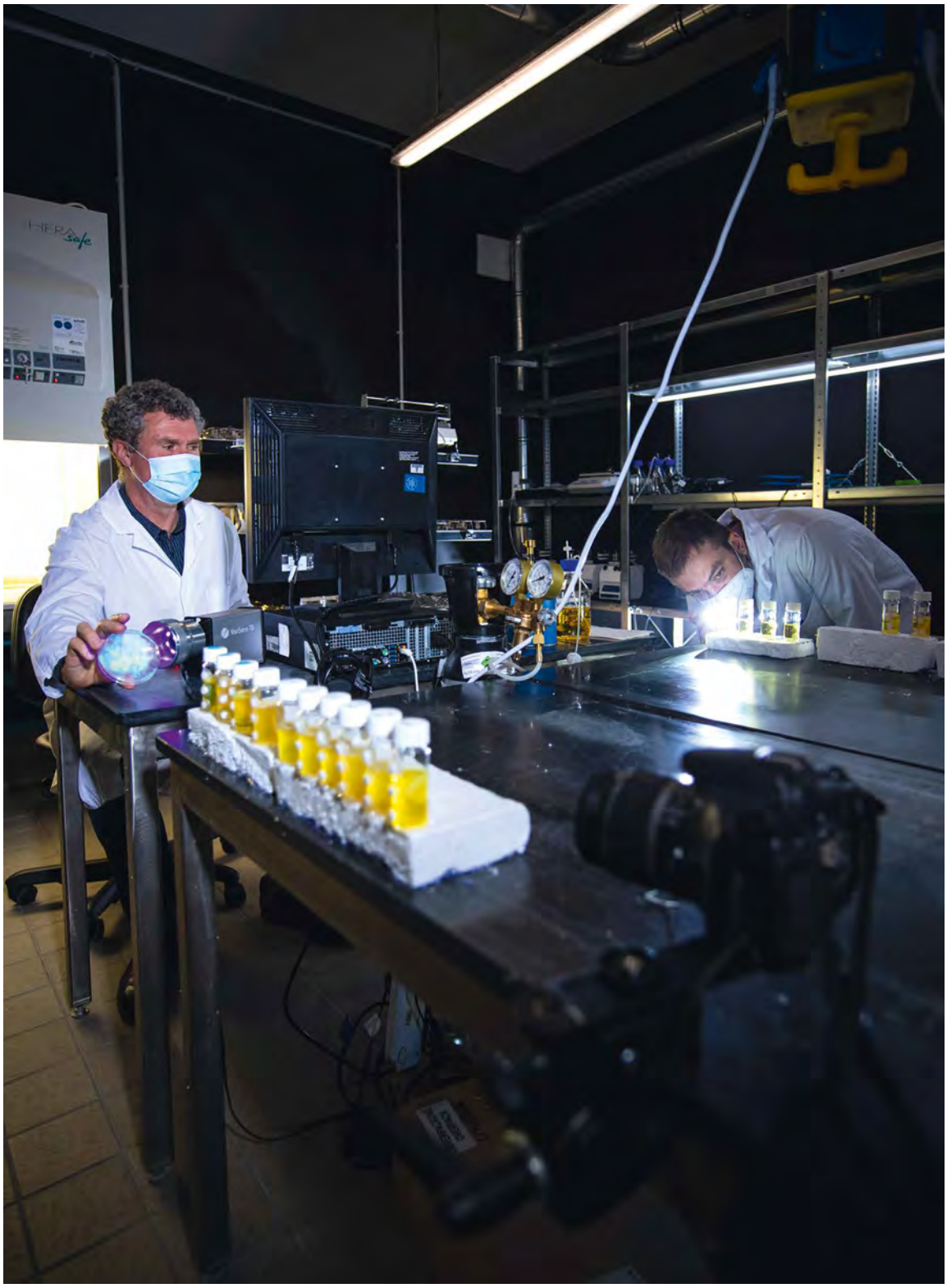


PHOTO: TOM PINGEL FOR MPG

Paul Rainey (left) in the laboratory with Loukas Theodosiou. Rainey is holding a Petri dish containing bacteria that produce a fluorescent pigment that gives its name to the species *Pseudomonas fluorescens*. Microbes floating around in test tubes at different stages of their life cycles.

When life emerged, there was not yet much in the way of cohesion. The first cells were "lone warriors" that had to adapt to the harsh living conditions on Earth 3.8 billion years ago. Just 300 million years later evidence of the first multicellular life emerged in bacteria, famously preserved as stromatolites in Western Australia. The first cells with a nucleus appeared 2.7 billion years ago and multicellular eukaryotic life 1.7 billion years ago. Paul Rainey and his team aim to understand how single cells might have made the transition to multicellularity.

Rainey majored in biology. After completing his studies, the New Zealander decided that he needed a break. For several years, he toured the world with his saxophone as a jazz musician. After returning to New Zealand, he worked as a sales manager for a dairy company. But after a while, he decided to return to his passion of biology and enrolled in university. For his master's thesis, he was supposed to study fungi.

But he soon became aware of a species of the mushroom pathogen, a bacterium called *Pseudomonas tolaasii*. It is able to propel itself forward with the help of its thread-like flagella. Rainey noted that the bacterium was able to adapt to changing conditions in his culture vessels. Some cells lost their capacity to produce the toxin responsible for brown-blotch disease.

His interest in *Pseudomonas* continued to grow. In addition to his actual research projects, he was always conducting side experiments with *Pseudomonas*. This enormous scientific curiosity coupled with perseverance would pay off in the end. But it also sometimes got him into trouble.

"We have observed for the first time how cooperative behavior emerged from scratch."

PAUL RAINEY

When Rainey moved to the UK for a post-doctoral fellowship, he observed that in addition to the typical round, smooth colonies, the bacteria in his cultures produced colonies of various other types.

One type was characterized by deep furrows on the cell surface. Rainey therefore called them "wrinkly spreaders". These cells formed a dense mat on the surface of unshaken liquid media. The other type were marked by a fuzzy appearance. He called these "fuzzy spreaders". Like the "wrinkly spreaders", they also formed thin mats – albeit short-lived ones – due to electrostatic interactions among cells.

Environmental complexity promotes diversification

Rainey's tests revealed that the colonies not only looked different but were formed by cells that had different properties. Was that evolution? "At that point, I didn't fully understand the significance of what I was looking at," says Rainey. As his research progressed, it became apparent that the variants appeared only when the culture vessels were not shaken and thus were ecologically complex. Shaking ensures the supply of oxygen in the nutrient solution. In unshaken vessels, the microbes quickly consume the vital gas, creating gradients from high (at the surface) to low (beneath). This is when the wrinkled and fuzzy spreaders came into play: the ability of cells of the different colony types to adhere to one another allows them to form mats at the meniscus and take advantage of the high oxygen content at the surface.

Rainey repeated the experiment many times but always observed the same result. After a few days, a mixture of smooth, wrinkled, and fuzzy cells emerged. In fact, they always appeared in the same order: first the wrinkled ones prevailed; only later did the fuzzy ones appear. "That was the breakthrough: *Pseudomonas* had thus adapted to oxygen deprivation," says Rainey looking back. As exciting as these results were, they did not go down well with his supervisor. After all, his research was supposed to be directed elsewhere. He was therefore forbidden from continuing his experiments. But Rainey continued anyway – albeit in a more discrete manner.

Pseudomonas bacteria are an ideal model for studying evolution. In the laboratory, unlike in nature, researchers

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can precisely control the living conditions of their experimental organisms. There is also another advantage to working with bacteria. Because evolution proceeds rather slowly, in most populations, the changes in genetic material that influence survival can be observed only over many years. This is not the case with *Pseudomonas*: there is less than one hour between generations. Evolutionary adaptations can be studied as if they were occurring in fast forward. "We were thus able to study evolution in a test tube."

Rainey's experiments made him one of the co-founders of a new sub-discipline of evolutionary biology: experimental evolution. Scientists around the world are now conducting experiments to investigate how organisms adapt to changes in living conditions. This works particularly well in artificial laboratory environments in which researchers are able to precisely control every parameter. Darwin's original theory of evolution by natural selection has thus been scientifically proven many times.

Glue holds cells together

But how do solitary bacteria become team players? First, they must stay together. The genetic analyses of Rainey and his colleagues revealed that as the result of mutation, mat-forming cells produce excess amounts of an adhesive cellulosic polymer. "This polymer acts like a glue that allows the bacteria to adhere to the vessel wall – and to each other," explains Rainey. This allows them to form a mat on the surface of a liquid, where they can take advantage of the higher oxygen content. For the group, this is clearly a great advantage. But for the individual cells? After all, they have to expend energy to produce the adhesive polymer and this comes at a measurable cost to individual cells.

Pseudomonas thus fulfilled the classic definition of cooperation: a behavior by which an individual contributes something to the benefit of others – at cost to self. "This was the first time that the evolution of this behavior had been observed de novo," says Rainey. Cooperation is found in many social colonies in the animal kingdom. For example, worker bees take care of raising their sisters without reproducing themselves. However, because they are genetically similar, they still contribute to the transmission of their genes. This allows the colony to produce new bees. However, for the behavior to take hold, the members of the colony themselves must also reproduce. In spring, a young queen leaves the old hive with part of the colony and starts a new colony. Can the bacterial mats produce offspring? "At first glance, they didn't seem to be reproducing," says Rainey. Without reproduction, no selection is possible: mats of cells are not units of selection. In other words, while cells that make mats replicate, mats themselves are evolutionary dead-ends.

But Rainey and his team did not give up and continued to monitor the system. Over time, further classes of mutant cells evolved within the mats. These no longer produced the adhesive polymer and were able to move freely. They thus benefited from the cohesion of the colony – and a plentiful supply of oxygen – without contributing anything themselves. "In some ways, they are cheating their colleagues. Because they do not expend energy to produce the adhesive polymer, they can multiply more quickly. At the same time, they weaken the cohesion of the mat and gradually cause it to disintegrate," says Rainey.

The prevailing view is that such free-riders are a problem that must be eliminated, or controlled, because otherwise cooperative actions cannot be maintained. However, Rainey and colleagues found that "cheaters" can have an important evolutionary function: under certain ecological conditions, they can help the collective of cells to replicate. "In some ways, the cheater cells play the role of reproductive propagules that multicellular organisms use to reproduce themselves. The cooperating cells of the mat are analogous to soma, or body cells. With this separation between cells that remain in the colony and the cells that disperse, the bacterial mats begin to resemble a multicellular organism," explains Rainey.

Of course, the bacterial mats have a hard time spreading in test-tubes. In nature, the mats might attach to the reeds of a pond. When reeds become free of mats, because mats detach and sink to the ground, the free-moving dispersing cells of other mats can colonize the new niche. It is now no longer individual cells that compete for space and resources but rather mats – they become units of selection. The best-adapted mats are able to displace inferior competitors. "This means that selection no longer works solely at the level of individual cells but also at the level of mats," says Rainey. "Such group-level selection underpins the emergence of complex organisms," explains Rainey.

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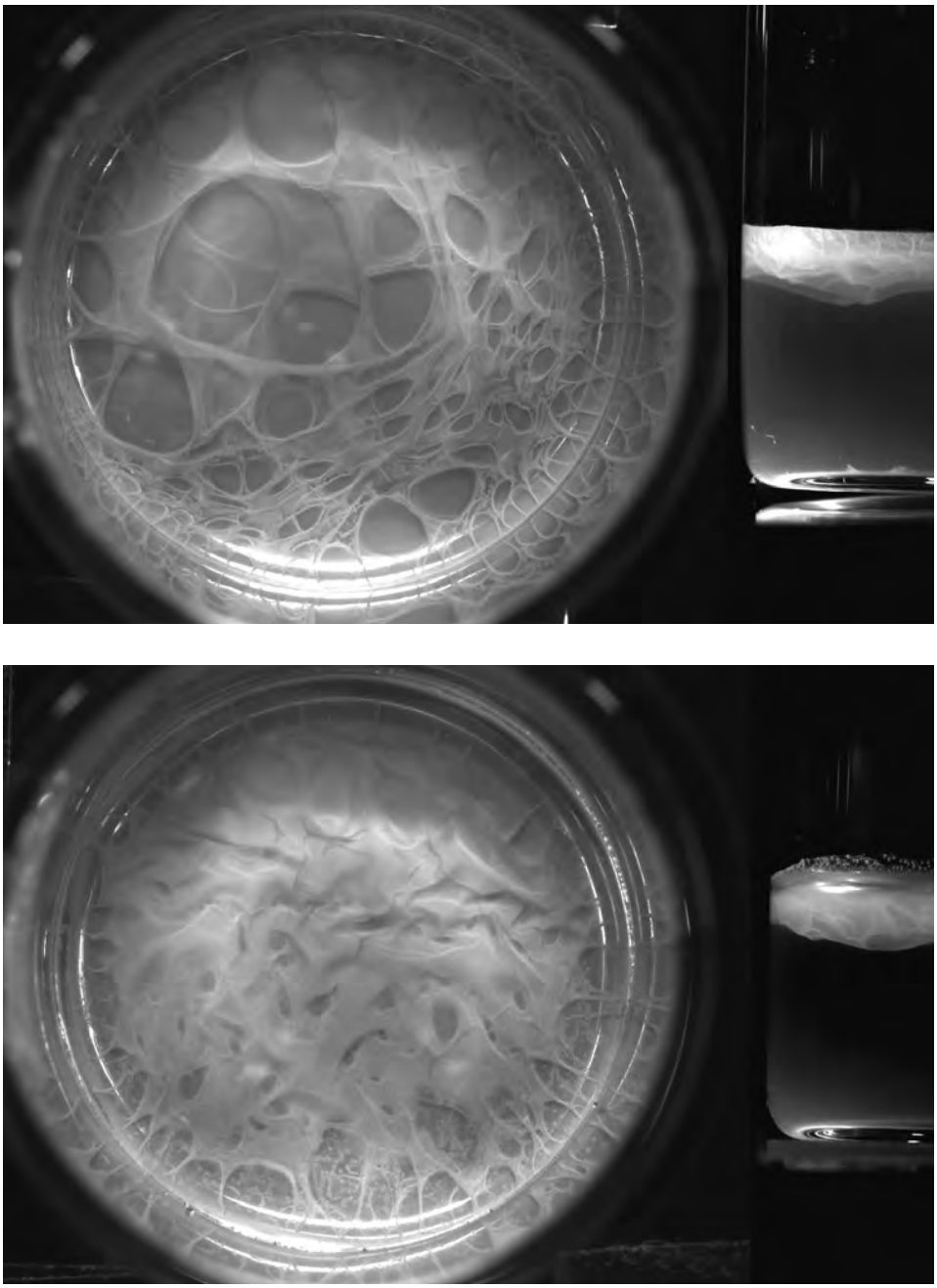
Mats of *wrinkly spreader* mutants developing at the meniscus of liquid medium. Over-production of cellulosic polymer allows cells to adhere to each other, and the edge of the culture vessel, and remain at the air-liquid interface where they are rewarded with a plentiful supply of oxygen. Using a 45° angle mirror, it is possible to record growth of the mat from both the top-down and lateral perspectives. Images were taken at 12 (top) and 24 hours (bottom).



PHOTOS: MICHAEL SCHWARZ/MPI FOR EVOLUTIONARY BIOLOGY

“Specific ecological conditions are required for the evolution of collectives.”

PAUL RAINEY

SUMMARY

Because of their short generation time, bacteria can quickly adapt to new living conditions. Bacterial cultures can therefore be used to observe evolution in the laboratory as if in fast forward.

When oxygen becomes scarce in nutrient solutions, individual bacterial cells produce an adhesive polymer that allows them to form cellular mats. In this way, they can take advantage of the higher oxygen content at the surface.

Some cells save on the costs of collective living. While harmful to the short-term persistence of mats, they can serve as propagules for mat reproduction.

Ecological factors as simple as patchily-distributed resources and a means of dispersal allow the process of Darwinian evolution at the level of collectives to become established.

The results put Rainey on the trail of a new idea. They recognized the central role that ecology can play in effecting major evolutionary transitions, including the transition from cells to multicellular life, the transition of matter to the first self-replicating chemistries, or the evolution of chromosomes from genes. The idea is referred to as "ecological scaffolding" and it solves a long-standing chicken and egg problem.

Evolutionary milestones

Evolutionary transitions begin when lower-level particles join forces. They complete when collectives of particles participate in the process of evolution by natural selection. For this to happen three properties must exist: collectives must be individually distinct and vary, they must reproduce, and they must be able to pass on their traits to offspring. However, early manifestations of collectives invariable lack these properties. As a consequence, arguments that posit their evolution by natural selection are not tenable. So, how do we explain the origin of these most fundamental Darwinian properties (variability, replication, heredity)?

Together with his colleagues Andrew Black and Pierrick Bourrat, Rainey has developed a model that simplifies and generalizes his team's experimental findings and shows how Darwinian properties can be exogenously imposed (scaffolded) by particular ecological conditions. In terms of the bacterial mats in the pond, this means that. Returning to the pond-reed-mat analogy, the spatially separated reeds on which the mats settle allow for discrete variation between mats. When mats fail, newly available reeds can be colonized by dispersing cells. Dispersal and re-establishment of a new mat is akin to mat-level reproduction. And if the new mat is formed from a single propagule from a parental mat, then the newly formed mat inherits properties from the parent.

"The mats themselves have no 'intention' of participating as evolutionary units in the process of natural selection," explains Rainey, "but ecological conditions cause a Darwinian process to unfold at the level of mats." Of course, these externally imposed properties must, if evolution is to proceed in an open-ended way, become endogenous features of the new life form. But, as shown in experiments, and more recently via simple and general models, this is well within the scope of possibility. Rainey and his colleagues at the Max Planck Institute observed for example that the bacterial cells evolve a simple genetic switch that enables the transition between adhesive (mat) and non-adhesive (propagule) cells. They thus no longer rely on random mutation but rather have separate life cycles for growth and reproduction. In nature, the mats could eventually acquire the ability to float on the surface of the water. This would free them from the need for restrictive ecological conditions. The bacterial mat would thus resemble multicellular life forms that release their propagules into the water.

With this new way of thinking – one that recognizes the continuity between organism and environment – the researchers have helped shift attention not only to the importance of ecology, but to environments in which Darwinian properties might be exogenously imposed on otherwise unwitting particles. This opens the door for new opportunities to experiment and solve each of the major evolutionary transitions, including the most challenging: the origins of life.

Whether the first cells actually came together like they did in Rainey's test tubes is an open question. Life has had to adapt to many changes since then. There have also been many different pathways to multicellularity – depending on the environment in which an organism has evolved. Thus, in the course of evolution, multicellularity has evolved independently on numerous occasions. "It is thus plausible that one route resembles that observed in our experiments," says Rainey.

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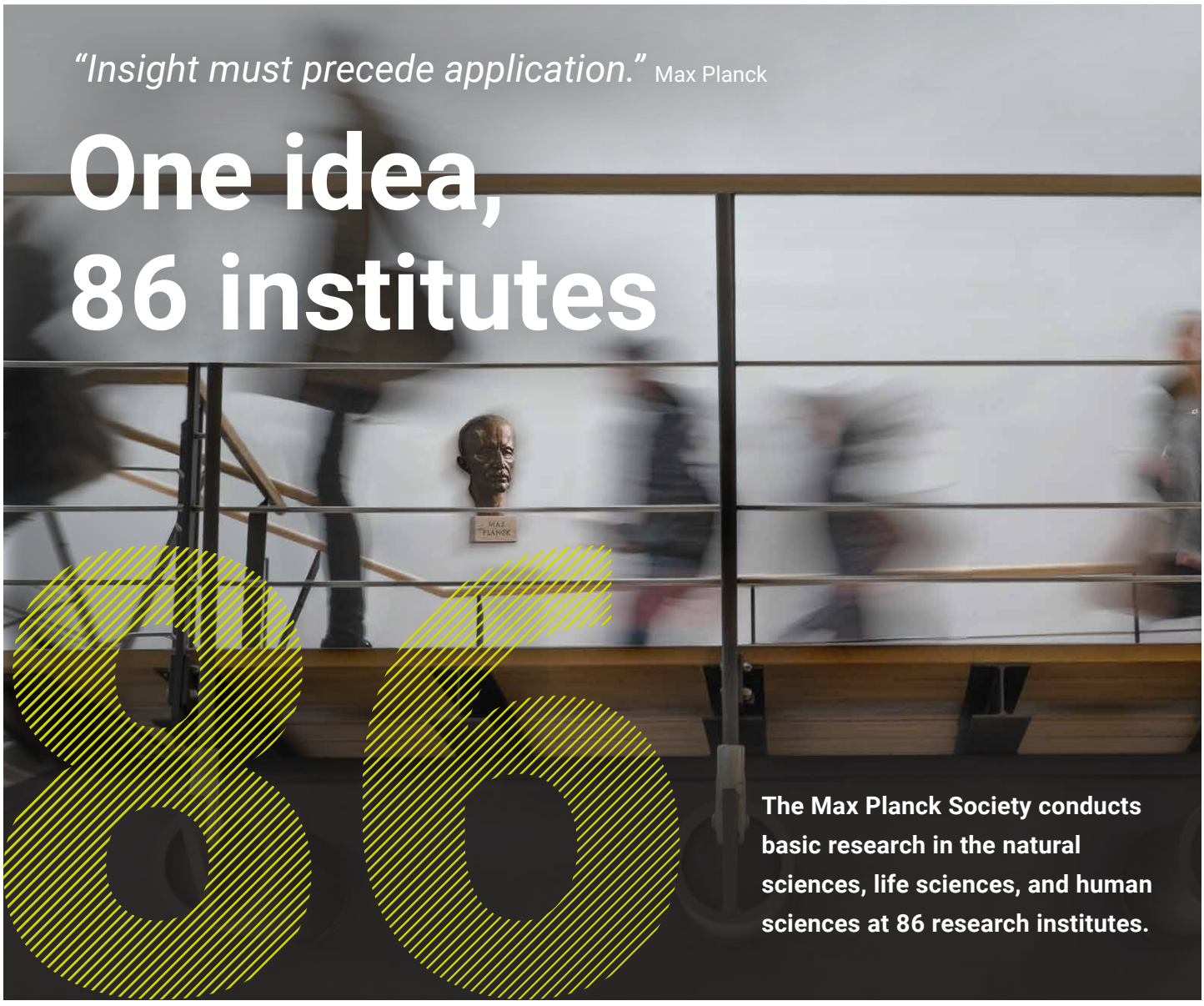
"Insight must precede application." Max Planck

One idea, 86 institutes



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MAX PLANCK GESELLSCHAFT

ON THE LEAP TOWARDS GREEN CHEMISTRY

Among his many talents, it took a while for Majd Al-Naji to discover his current passion for chemistry. He is currently searching for solid catalysts for the production of fuels and other chemical products from plant waste or plastic at the Max Planck Institute of Colloids and Interfaces in Potsdam, and he can already look back on his extraordinary career.

TEXT: KLAUS JACOB

Al-Naji speaks several languages, is interested in art and culture and has been a theater actor as well as a professional show jumper. After graduating from high school, he developed a passion for many and varied subjects – but not for chemistry. But that is what he has now become: a chemist, who has been leading a team at the Max Planck Institute of Colloids and Interfaces in Potsdam, developing catalysts for sustainable chemistry since 2018. His journey to becoming a Max Planck researcher was anything but preordained, both in terms of his choice of discipline and his background story, as his future prospects seemed to be anything but promising when he was born. But, spurred on by his optimism to which his frequent bursts of laughter attest, he refused to be deterred. He is convinced that: "You need luck in life, and I have been very lucky." Essentially, Al-Naji was born stateless. He could be considered to be Syrian, because his parents lived in Syria for a long time, or Saudi, because he was born in Saudi Arabia. He has traveled extensively around the world, but he has no homeland where his family is rooted. His grandparents fled from Palestine to Syria in 1948. Many of his relatives still live there but are still refugees to this day. His family members were only given travel documents rather than passports. A Palestinian, as he soon learned, is at home throughout the world – or nowhere. But he has been lucky. Just what this means can be seen in a small Polaroid photo pinned on the bulletin board in his office, which shows him standing between two friends, Baris Kumru and Paolo Giusto, clutching an official document in his hand: his Certificate of Naturalization. "Having German citizenship makes my life easier," he says. The 17th of August 2020, the day he became a German, is a date that he can recall with ease. But the journey that led to his citizenship was beset with obstacles and required tenacity, fortunately a trait that Al-Naji has demonstrated on many occasions.

His first career is a case in point. At the age of four, his father sat him on a horse. His father, a horse lover himself, was working in Saudi Arabia, where Majd spent much of his childhood and youth. Not a day went by on which he did not clear obstacles mounted on a horse. The rhythm of his days was set by his school and stable timetable. What began as a hobby soon became a profession and, as a professional show jumper, Majd trained ten hours a day, from 6 to 11 in the morning and 4 to 9 in the evening. "I was nuts," he says looking back. At the age of ten, he was already earning prize money at show jumping competitions and was also working as a trainer. He traveled through many Arabic countries, going from one tournament to the next and competing with adults. Of course, the occasional fall came with the territory: at the age of 13,

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VISIT TO

MAJD AL-NAJI

PHOTO: DAVID AUSSERHOFER FOR MPG

A focus on renewable materials: Majd Al-Naji has developed a catalyst that converts lignin extracted from sawdust into the raw materials for biofuel and other chemical products.

he fell onto a metal fence and woke up in hospital, where doctors diagnosed a kidney hemorrhage. After that, his father came close to banning him from show jumping, but his son's successes made him change his mind. So Majd Al-Naji kept at it – and successfully: he competed in the qualification for the Olympics in 2008, by which time he was already studying at university. Ultimately, however, he was unable to compete in the Games due to lack of funding.

His attitude towards equestrian sports changed when he moved to Germany. Instead of pursuing prizes and success, he rode for pleasure, preferring to ride in the countryside rather than in the arena. Nevertheless, he bought himself a young show jumper in Leipzig, his first point of call in Germany. Only when work came to dominate his schedule did he finally close that chapter. However, he still has not completely given up on the sport and hopes to buy another horse at some point in the coming years. Show jumping in Germany opened up a completely new path for him. During his time in Leipzig, he worked for a number of years as a commentator on international tournaments for Arabic television stations. He would interview the riders in English or German and moderate in Arabic.

Majd Al-Naji hopes to end our dependence on oil – and above all, to combat climate change: "That's the future."

Picking up a microphone was no coincidence. He had always felt drawn to journalism. After graduating from high school, he initially flirted with the idea of media studies. "I wanted to study anything except chemistry," he says. Of all the subjects he took in high school, chemistry was the one for which he received his worst grade. Maybe he was trying to emancipate himself from his family and was mentally resisting their expectations. His two uncles Mahmoud and Omar Al-Naji were chemistry professors, one having studied in Russia and the other in France. In the end, they convinced him to study chemistry, but his first steps at university did not go as planned at all: "I didn't pass a single module in my first semester." Only after his father had had a serious talk with him did he pull himself together and finally start to enjoy the subject. Practical laboratory work, in particular, was something he developed a passion for. So, he decided to continue his studies after earning his bachelor's degree in Damascus in 2009. That would have been all but impossible in Syria, where only a fraction of the many students had the chance to take a master's degree. Research was also all but out of the question, at least not at the cutting edge, due to the lack of equipment. So, Al-Naji applied for a master's degree in Germany via the German Academic Exchange Service (DAAD). He is deeply grateful for the opportunity, he says. But here, too, luck was required. "Obtaining a visa was a difficult and lengthy process." The only people who were granted a visa were those who could demonstrate that they could finance their own studies. His cousin, Bassel El Nagi, who had been living in Germany since the 1980s, guaranteed his monthly fees. It was also fortunate for Al-Naji that the civil war had not yet erupted and that it was easier for Syrian students to come to Germany than it currently is.

His move from Damascus to Leipzig, where he studied for his master's degree, was a leap into the unknown, because he spoke no German. Cosmopolitan by nature, Al-Naji finds learning languages easy. This talent helped him through his subsequent career: for example, he spent one academic year at the University of Cordoba in Spain and later, after completing his doctorate with Roger Gläser at the University of Leipzig, he spent a year conducting research in Belgium, where he learned French. He now speaks five languages: Arabic, English, German, Spanish, and French. He came upon his current research focus – green chemistry – while studying for his master's thesis. He now heads the "Biorefinery and Sustainable Chemistry" working group at the Max Planck Institute. With enthusiasm and creativity, Al-Naji explains what this involves. In fact, it is illustrated on his of-

fice wall, which is strewn with framed graphics that once appeared in periodicals. He sketched them himself and had them completed in detail by artists who are his friends. One depicts a piece of wood that is transformed into a plastic object. "Art is the best tool for conveying knowledge," says the scientist.

Al-Naji wants to make fuels and other chemical industry products from plant-based materials, thus ending our dependence on oil, specifically with a view on combating climate change: "That's the future," he says. As such he has set himself a highly ambitious goal, as oil has shaped many aspects of our daily lives for over a century and employs an entire sector of industry – the petrochemical sector. Sophisticated technology has emerged during this extended period of time to facilitate the production of a wide range of products. Petrochemicals have an enormous lead over green chemistry. For the most part, fuels are made of crude oil, which powers cars, airplanes, and ships in the form of gasoline, kerosene and diesel. However, oil can also be found in many everyday products where one would hardly suspect its presence, such as chewing gum, candles, cleaning agents, and in many cosmetic products including body lotions and shower gels. The synthetic fibers found in many garments are also products of the petrochemical industry. The majority of plastics in particular are also derived from crude oil – and are now infamous, among other things, for the harm they cause to the environment. Plastics accumulate in the oceans in horrific quantities as they are

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Fearless of obstacles: as a show jumper, Majd Al-Naji in the Olympic Games Qualification. He also had to overcome a number of obstacles to become a research group leader in Germany.

PHOTO: RABIH MOGHRABI/AFP VIA GETTY IMAGES

PHOTO: DAVID AUSSERHOFER FOR MPG

Chemical recycling: Qisong Hu, Francesco Brandi, Majd Al-Naji, and Jose Chacon (from left) are searching for ways to extract useful substances from plant waste such as sawdust, straw and from plastic waste.

all but non-degradable and when it does degrade it disintegrates into ever smaller pieces that have been contaminating the entire ecosystem for many years in the form of microplastics.

Al-Naji is looking for ways to make such products from natural materials – entirely oil free. To minimize harm to the environment, he has set his sights even higher. In stark contrast to currently available biofuels, one of his precepts is that the raw materials should not originate from crops that could be used to feed people or that are grown specifically to produce fuels or fodder, because food is already in short supply in many countries, as is land that could be used for agriculture. Al-Naji is focusing exclusively on waste that would otherwise end up in incinerators or as compost, such as sawdust or kitchen scraps, which is why he has been gathering bark in the forest and collecting grass trimmings from the soccer field, where he plays with colleagues. And that is not all: he always bears the question of costs in mind and avoids using expensive materials. Everything he needs in addition to organic waste products is cheap and abundant in nature – that is his second precept.

One can view his raw materials and the way he processes them when one accompanies him through his laboratory. The lab contains equipment that you might expect to find in a kitchen rather than a chemistry lab: a pasta machine, a pizza oven, and a blender. Likewise, many of the chemicals he employs are natural substances, just like the ingredients found in a kitchen – albeit in different containers and labeled differently: olive oil, salt, palm oil, vitamin C and amino acids. Chemists, it is said, are good cooks. Al-Naji and his colleague Francesco Brandi take this literally and employ a "kitchen laboratory" founded by Markus Antonietti.

Al-Naji's team produces catalysts in the so-called KitchenLab. Most chemical reactions require these solid catalysts to get going, but the catalysts used in the petrochemical industry are ill suited to green chemistry. Others are too expensive because they contain precious metals such as platinum and gold or are not sufficiently stable. Among other things, Al-Naji is working on catalysts that can depolymerize the lignin contained in wood, in other words break it down into smaller, chemically usable units. Together with his colleagues, he has developed a simple recipe to achieve this: take eight parts of protein-rich waste and two parts of zinc oxide, mix everything in a blender with glucose from waste wood and a dash of urea to form a homogeneous mixture, before adding water to make a spreadable paste. Feed this into a pasta machine to form thick strands of spaghetti. Put these in a pizza oven for a day at 120–250 °C until the water evaporates. Finally, place the hardened strands

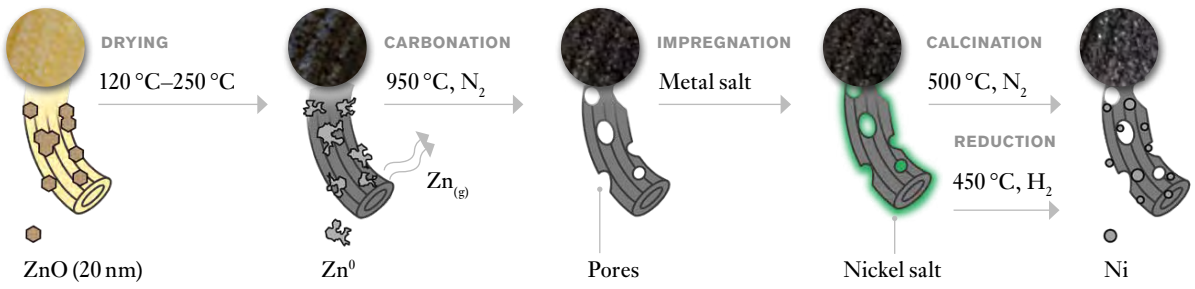
of spaghetti in a high-temperature furnace, roasting the flour at 950 °C to form carbon. The process causes the zinc oxide to evaporate, leaving behind countless tiny pores. The finished spaghetti is now placed in a nickel solution for another six hours – and the catalyst is ready.

The beauty of this method is that it requires much less nickel than conventional catalysts of this type. This is because the pores created when the zinc oxide evaporates are extremely small, which provides the metal, the actual catalytic substance, with a very large surface area. His spaghetti catalysts are not just cheaper and more sustainable than competing products, they are also more efficient. However, that is not enough for Al-Naji, who has now set his sights on the entire production chain, from natural materials to the finished product. He is experimenting with small biorefineries in which the catalysts are only one component.

To make these plants work as efficiently as possible, he has developed a continuous system into which supplies are constantly fed on one side while the finished product is delivered on the other. Proven on the laboratory scale, he has also proven the technology can be successfully scaled up. A pilot project involving several companies has successfully generated 300 liters of depolymerized lignin in a single day. Al-Naji is confident that his method will enable him to produce the raw materials for many products that are currently still based on oil – from fuels to plastics. Such biorefineries could also operate on a small, mobile scale unlike petrochemical plants.

For example, Al-Naji hopes to use the technology to enable farmers to process straw and other lignocellulose-containing waste into a useful product. He is also currently developing catalysts that convert plastic waste into the raw materials for a variety of chemical products, such as fuels and plastics. It is conceivable that such facilities will be installed on ships collecting plastic waste from the world's oceans and processing it on the spot. These are no mere pipe dreams. Al-Naji has applied for patents stemming from his work into sustainable chemistry and the biorefinery. He can envision himself launching his own start-up, but also accepting a professorship at a university where his research could allow him to make a real contribution.

Majd Al-Naji now feels at home in Germany; it has become his home. He emphasizes his gratitude to so many people for their support throughout his scientific and personal development, especially Markus Antonietti, who also believes in thinking outside the box. It was he who not only taught him how to implement a big idea from a simple experiment but also to enjoy life to the fullest. When Al-Naji and his colleagues join the Director for a glass of wine occasionally in the evening, the conversation meanders through art, politics, philosophy, sports and, of course, a little bit of chemistry.



GRAPHIC: GCO ACCORDING TO MAJD AL-NAJI

Pasta catalyst: the researchers prepare the catalyst by roasting noodles composed of simple ingredients at 950 °C, causing the organic components to transform into porous carbon. They then load the carbon noodles with a nickel salt, before calcinating them (i.e, thermally treating them), and reducing the nickel salt to pure nickel.

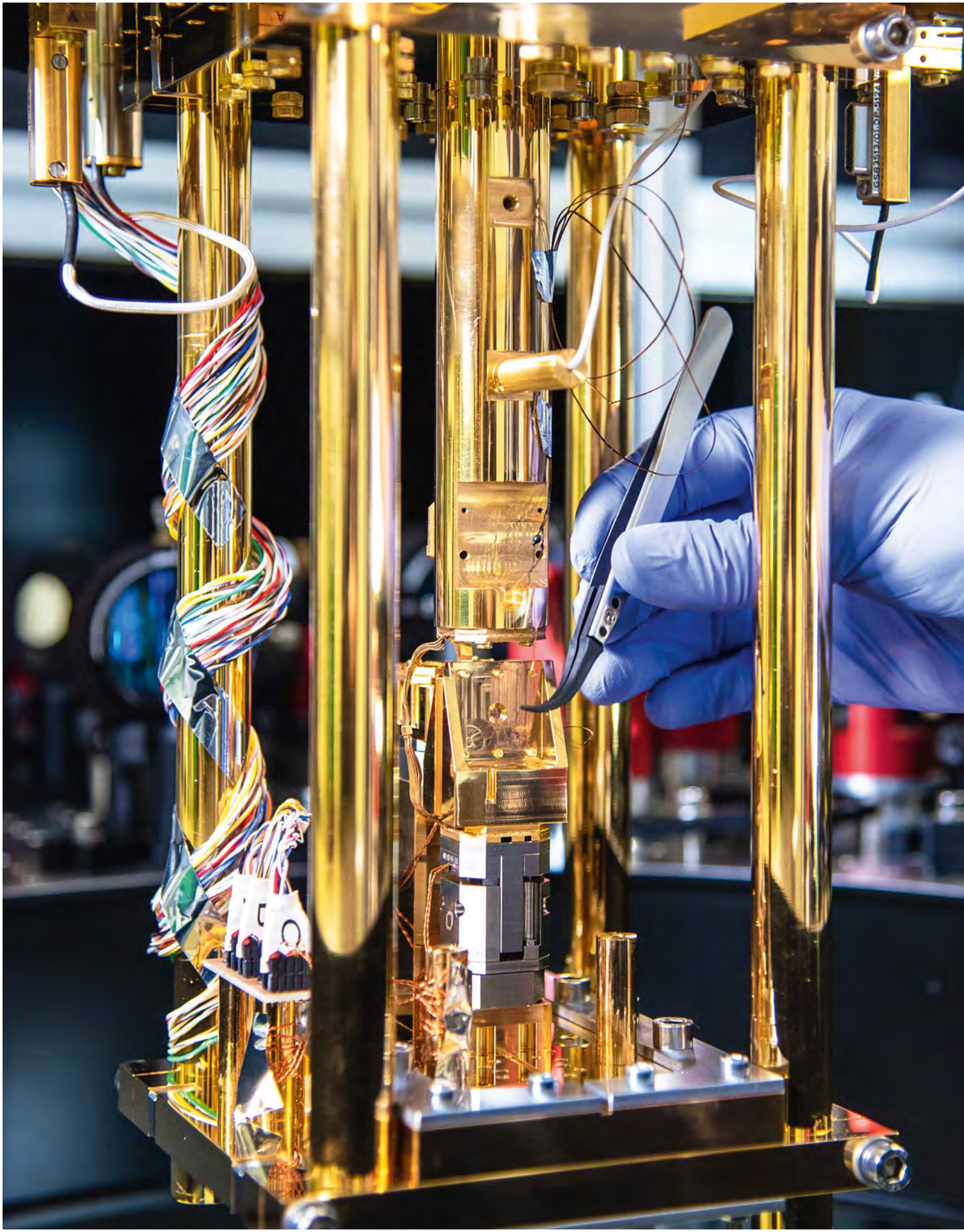


PHOTO: FRIEDERIKE HERGET / MPI FOR THE SCIENCE OF LIGHT

DOUBLE TAKE

MAX PLANCK INSTITUTE FOR THE SCIENCE OF LIGHT

In the cryostat (left), physicists work with the coldest liquid in the world, a special mixture of liquid helium, that reaches temperatures down to –273.14°C, almost absolute zero. In these conditions atoms nearly stand still. This also applies to the dye molecules embedded in the thin crystal layer (right). The researchers can then use laser light to excite vibrations of individual molecules in order to transfer information from the light to them. That way these quantum emitters could be used for photonic circuits or quantum information processing.

PHOTO: JOHANNES ZIRKELBACH / MPI FOR THE SCIENCE OF LIGHT (NANO-OPTICS SANDOGHDAR DIVISION)

IN THE GEARS OF THE OPINION MACHINE

TEXT: PETER HERGERSBERG

Nowadays, political debates often turn into verbal brawls – especially on social media. In order to counteract this, Eckehard Olbrich and Sven Banisch of the Max Planck Institute for Mathematics in the Sciences in Leipzig and Philipp Lorenz-Spreen of the Max Planck Institute for Human Development are investigating how polarization occurs and how opinion formation in groups works.

To explain why he studies political developments, mathematician Sven Banisch describes an experiment with rats. Biologists observed that the same ratio of cooperating, solitary, and bullied animals always emerged in small groups of the rats. The same order also emerged when animals of only one type, (e.g. solitary animals) where brought together in a new miniature society. "I want to understand such forms of social self-organization," says Banisch.

The formation of a consensus or else polarized viewpoints in a debate also involves a self-organizing process. Experts refer to the dynamics of opinion, which is something being studied at the Odycceus (Opinion Dynamics and Cultural Conflict in European Space) project, which Banisch initiated in collaboration with Eckehard Olbrich, who heads a research group at the Max Planck Institute in Leipzig. In this four-year project (2017–2021), which Olbrich is now coordinating, researchers from eight institutions in six countries have been studying, among other things, how we position ourselves in controversies or how populism drives opinions to the edges of the political spectrum, particularly now that online and especially social media are shaping political disputes. Debates in social media are rarely moderated and often degenerate into a heated verbal exchange.

"Digitalization," as Olbrich explains, "means that we have much more and faster-moving information at our disposal. And comment functions and social media mean that even more people have the opportunity to express an opinion. It's almost impossible to follow debates in detail and understand why conflicts arise." That is why some of the Odycceus partners have developed mathematical tools to help manage the flood of information. "We hope to help make debates more transparent and disputes more objective," says Olbrich.

To this end, his colleague Sven Banisch is developing models that depict the conditions under which a debate leads either to a common viewpoint or to irreconcilable differences. The mathematical parameters and starting conditions with which the models realistically reproduce these processes enable the researchers to conclude which social factors play a role. Banisch and his colleagues use empirical data to verify the models. This works particularly well with experiments conducted under defined conditions. Together with economist

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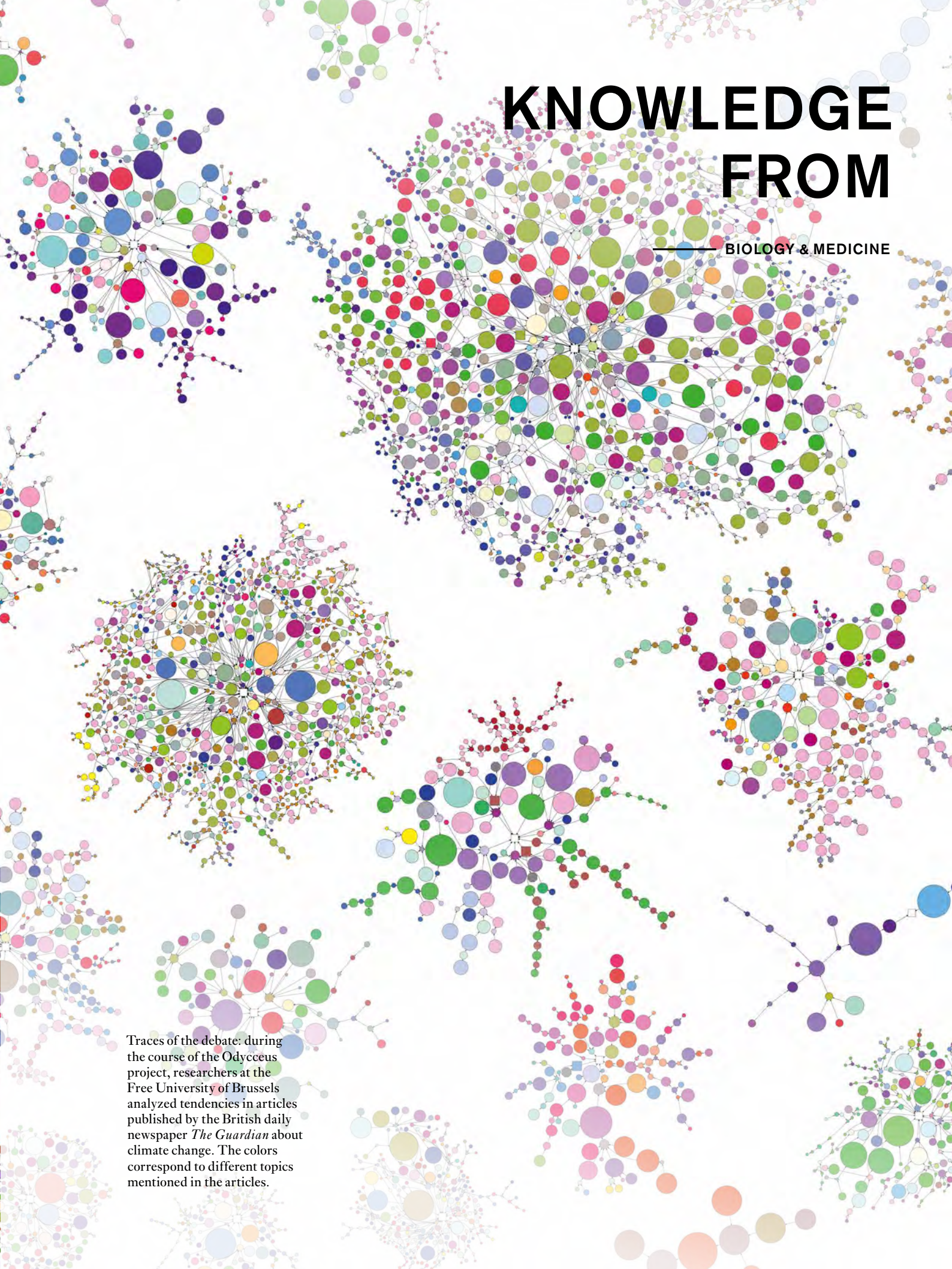
GRAPHIC: VU BRUSSEL/MICHAEL ANSLOW

KNOWLEDGE FROM

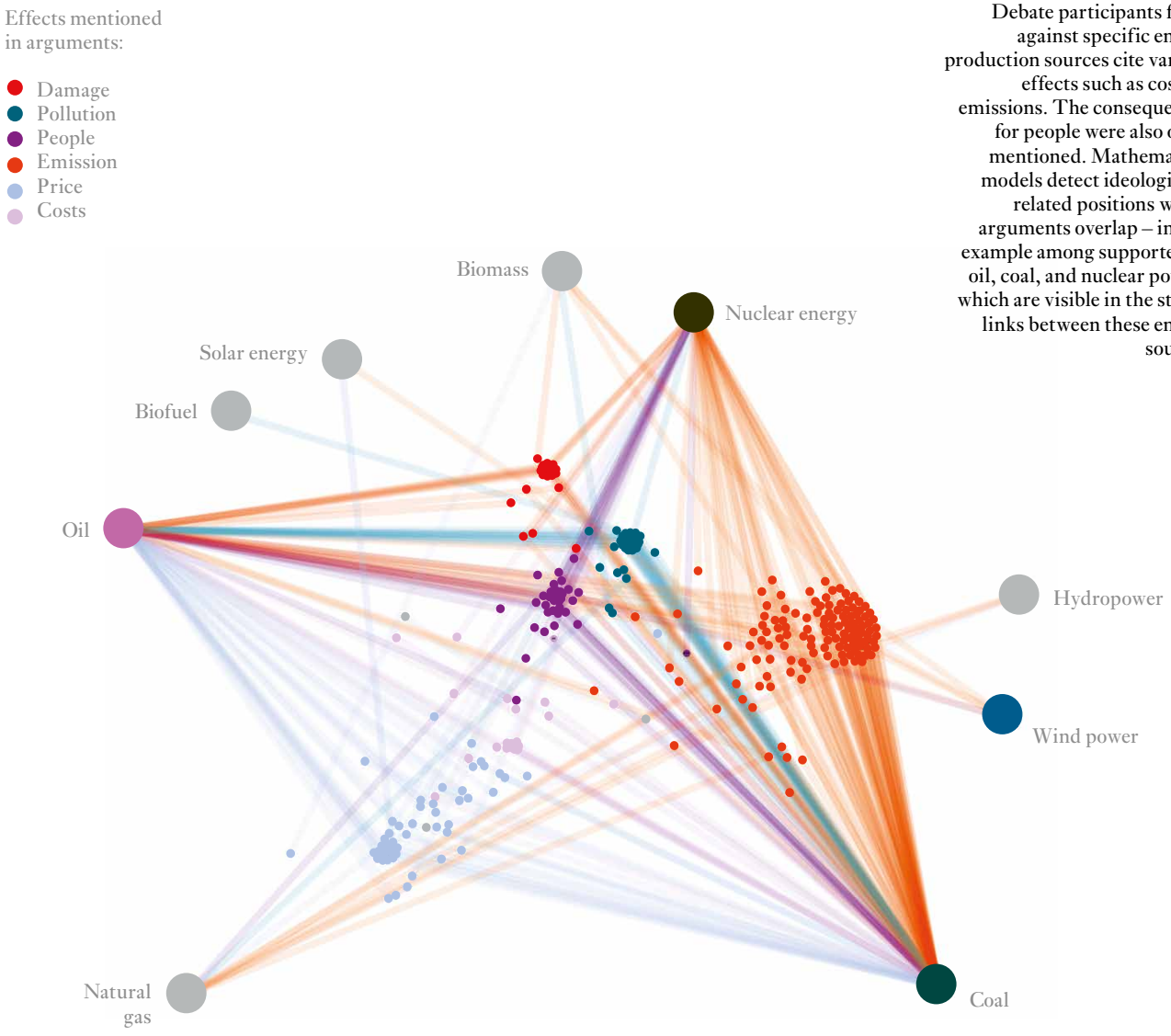
BIOLOGY & MEDICINE



Traces of the debate: during the course of the Odycceus project, researchers at the Free University of Brussels analyzed tendencies in articles published by the British daily newspaper *The Guardian* about climate change. The colors correspond to different topics mentioned in the articles.

Hawal Shamon of the Research Center Jülich, Banisch investigated how strongly the biases held by various test subjects towards different energy sources determines the formation of opinion within a group. This cognitive bias causes ardent supporters of coal or wind power to find the arguments in favor of their preferred energy source to be more compelling, which is hardly surprising. However, the collective impact is surprising, as a strong cognitive bias can result in polarization within a group. However, a different effect occurs if people simply prefer one form of energy less strongly: "We were also surprised by the fact that when the bias was weak, the group quickly agrees on a stance," says Banisch. This was the case with energy sources such as biomass and gas, which are not discussed as prominently and heatedly in public. Groups also reach a consensus in the complete absence of biases, although the consensus remains undecided between pro and con and also takes a long time to reach. "Our hope is that debates will be more constructive if we demonstrate the effects of evolved cognitive apparatus at the collective level," says Banisch.

This bias cannot even be overcome through discussions with others – on the contrary. This was demonstrated by a team in which Philipp Lorenz-Spreen was involved. The physicist, who works at the Max Planck Institute for Human Development in Berlin, relies on models as well as data from social media. Together with German-Italian partners, he has shown how social discourse can divide opinions. The more avidly users post comments, the more extreme their views become. In this way, the researchers reproduced the divide that emerged on Twitter in rela-



Debate participants for or against specific energy production sources cite various effects such as costs or emissions. The consequences for people were also often mentioned. Mathematical models detect ideologically related positions where arguments overlap – in this example among supporters of oil, coal, and nuclear power – which are visible in the strong links between these energy sources.

GRAPHIC: SVEN BANISCH/MPI FOR MATHEMATICS IN THE SCIENCES

tion to three issues that dived opinions in the U.S. – Obamacare, gun control, and abortion – although the positions predicted by the model were less widely divergent. "The initial hope that the Internet could facilitate constructive discourses between people with different opinions has not been fulfilled," says Lorenz-Spreen. The disintegrating effect of the discourse is due to psychology: we find it difficult to put up with opinions that differ from our own. We tend to be social homophiles and prefer to discuss things with like-minded people.

Discourse promotes polarization

This creates echo chambers in which one opinion clearly predominates and people can push each other toward increasingly extreme views, which do not even need to be supported by substantive arguments; pro and contra comments are sufficient: "No way is that possible" or "Yes, I totally agree" are among the more civilized statements; support can even be shared by simply clicking the "like" button. Social scientists refer to such comments as social feedback. Banisch and Olbrich have shown that posts in favor of or against a particular viewpoint rapidly help to create unity in a group. Again, the reason is homophily: most people enjoy pats on the back and fear slaps in the face even if these are only verbal, which is why group members increasingly rally behind a particular opinion which may only have been expressed as a tendency at first. This makes perfect sense from an evolutionary point of view, as this is how our early ancestors quickly reached decisions when it came to spontaneously gathering the group for hunting and taking up arms or fleeing in the face of hostile hordes. "But in larger groups," Banisch explains, "social feedback on differences of opinion quickly leads to polarization and the creation of echo chambers." The extent of the social consequences of the echoed opinions is still under debate. Studies from the U.S., for example, show that even the most active opinion leaders rarely spend time exclusively in echo chambers. Most people also consume other media – even if the reporting might be as unbalanced as Fox News.

SUMMARY

Researchers at the Max Planck Society want to uncover the mechanisms that lead to the polarization of debates in social media. They initiated the Odycceus project to counteract this.

Bias and social discourse can lead to polarization, in the course of which a loud minority can silence the quiet majority.

Artificial intelligence can help to deduce opinions and lines of argumentation from texts.

Analysis of Tweet battles

The fact that the societal implications of the modeled effects are not yet clear is not the only reason to treat the model results with caution – even by the modelers themselves: "We simulate mechanisms of opinion formation – but not real behavior," says Lorenz-Spreen. Real behavior is also determined by environmental influences and individual differences, which the current models do not consider. Olbrich also thinks that the simulations could be more realistic: "There's still a lot of room for improvement." Nevertheless, the model calculations are helpful even in their current form. "They help us develop theories about how opinion formation works," says Banisch.

For example, a theory about how opinions on various topics result in a closed view of the world and why camps are formed in the process. Why, for example, are proponents of rigid climate protection often also more open to immigration – and vice versa? Banisch and Olbrich were able to use a model to illustrate this with an example relating to energy policy where advocates of coal-fired and nuclear power are comparatively close whilst the distance between them and advocates of renewable energies is significantly greater. This is because some arguments such as the need for a stable energy supply or the opinion that wind turbines and solar parks disfigure the landscape speak in favor of both coal and nuclear power. In contrast, there is less overlap with the arguments in favor of renewable energy. So, different ideologies are formed on the different argumentative foundations.

The team also uses empirical data to research the political clashes between ideological camps. Social networks, especially Twitter, are ideally suited for this purpose because they contain a wide range of information. In the case of Twitter, conflict lines and alliances can be identified by who retweets which tweets (i.e. shares them with their own followers) and who replies to whom. The team has therefore written software that creates and visualizes networks of Twitter users and their tweets. Each node represents a user, and each line between two nodes represents a retweet or a reply. The program also arranges strongly linked nodes close to each other. To enable interested parties to analyze debates themselves, the researchers have put the software online under the name Twitter explorer along with instructions on how to install it. They then used the algorithms to examine two tweet battles in more detail: one about the 2019

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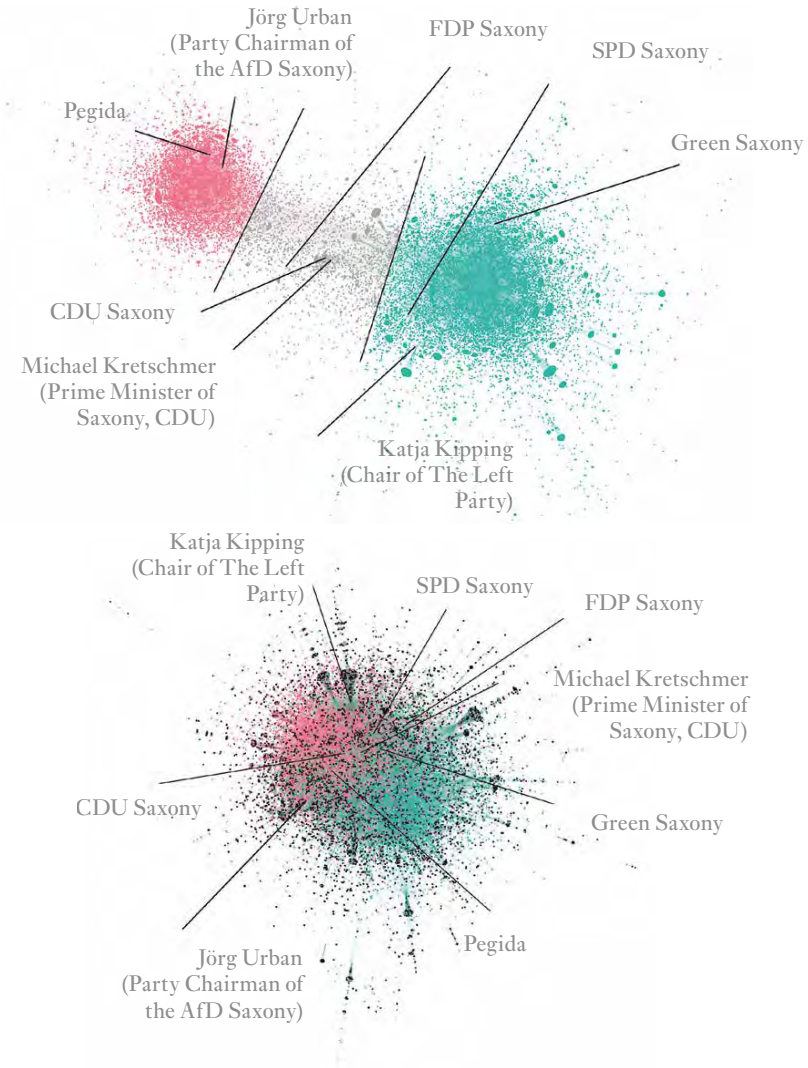
state elections in Saxony and one about riots in Leipzig on New Year's Eve 2019/20. In both cases, two poles of opinion formed in the retweet network along with a much weaker area in between. But the poles were also occupied to varying degrees. The majority group, which included politicians from the SPD, the Left Party, and the Greens and certain media outlets such as MDR Sachsen and Bild Leipzig retweeted each other's post more frequently and had almost three times as many followers as the minority group, which consisted mainly of representatives of the AfD and Pegida (very right wing paties). The middle ground was occupied by politicians from the CDU and FDP as well as other media such as MDR aktuell or Bild Dresden.

Psychological spiral of silence

A completely different picture emerged for the network of replies: the two clusters now seemed to be virtually wedged into each other – the right-leaning minority in particular sought confrontation. It responded as often as the majority, which was three times larger. This is where psychology comes into play. Because most people fear criticism – especially insults – they refrain from making statements in the case of doubt. "This can lead to a spiral of silence," says Felix Gaisbauer, a doctoral candidate at the Max Planck Institute for Mathematics in the Sciences: "A loud minority can silence a quiet majority to such an extent that the public may perceive it as a majority." The main danger arises when the traditional media portrays events on Twitter, for example, thus providing the minority with an even bigger platform on which to vent their outrage.

To make disputes more constructive, the Odycceus partners are developing mathematical tools for text analysis. "We want to extract opinions, lines of argumentations, and how people make causal connections from texts and process them in such a way that they are easier to comprehend," says Olbrich. The researchers are relying on artificial intelligence (AI), or more precisely, on machine learning. For example, a team led by Katrien Beuls, and Tom Willaert of the Free University of Brussels has developed an opinion facilitator that recognizes causal relationships in texts and catalogs causes and effects. As an example, the group applied the tool to articles on climate change that appeared in the Guardian newspaper in England. It shows whether different causes are discussed for an effect such as global warming (e.g., human greenhouse gas emissions or increased solar activity). Olbrich also specializes in machine text comprehension. In doing so, he combines his mathematical skills with his own political interest. He is working specifically on computational rules – primarily topic models – that are designed to extract opinions from



Visibly divided: supporters of an AfD-affiliated (pink) and a more left-liberal (turquoise) camp mainly shared like-minded posts about the 2019 elections in Saxony. This appears as polarization in the retweet network (above). There are fewer users (gray) between the two camps. In the reply network (below), the two clusters move closer together because it was mainly the AfD-affiliated faction that replied to tweets published by the opponents.

GRAPHIC: FELIX GAISBAUER, ARMIN POURNAKI, SVEN BANISCH, ECKEHARD OLBRICH – IDEOLOGICAL DIFFERENCES IN ENGAGEMENT IN PUBLIC DEBATE ON TWITTER

press reports, posts, and other online publications. To do this, the programs must first recognize the topics – even if they are not explicitly named. The algorithms learn from training data (e.g., how likely a text is to be about mobility if it contains terms such as traffic, train, highway, and airport) after which they recognize such correlations independently, even for new topics such as the environment or law and order.

Olbrich based the formulas on the election programs published by political parties in Germany and other European countries as well as the U.S. in the past decades. The Berlin Social Science Center (WZB) has digitalized the political declarations of intent in the Manifesto project. "We can identify topics quite well using the topic models," says Olbrich. This helps to compare the programs. The goal now is for the AI program to recognize attitudes toward the relevant issues, whereby the researchers are always trying to understand how the algorithms arrive at their results, which is by no means self-evident: "Practical users, such as the Google team, are much more advanced when it comes to text interpretation," says Olbrich. But it is difficult to discern which criteria the algorithms use to assign meanings. It remains unclear whether the algorithms actually recognize a real connection or only construct it. Clearly, the latter can distort debates just as much as fake news can.

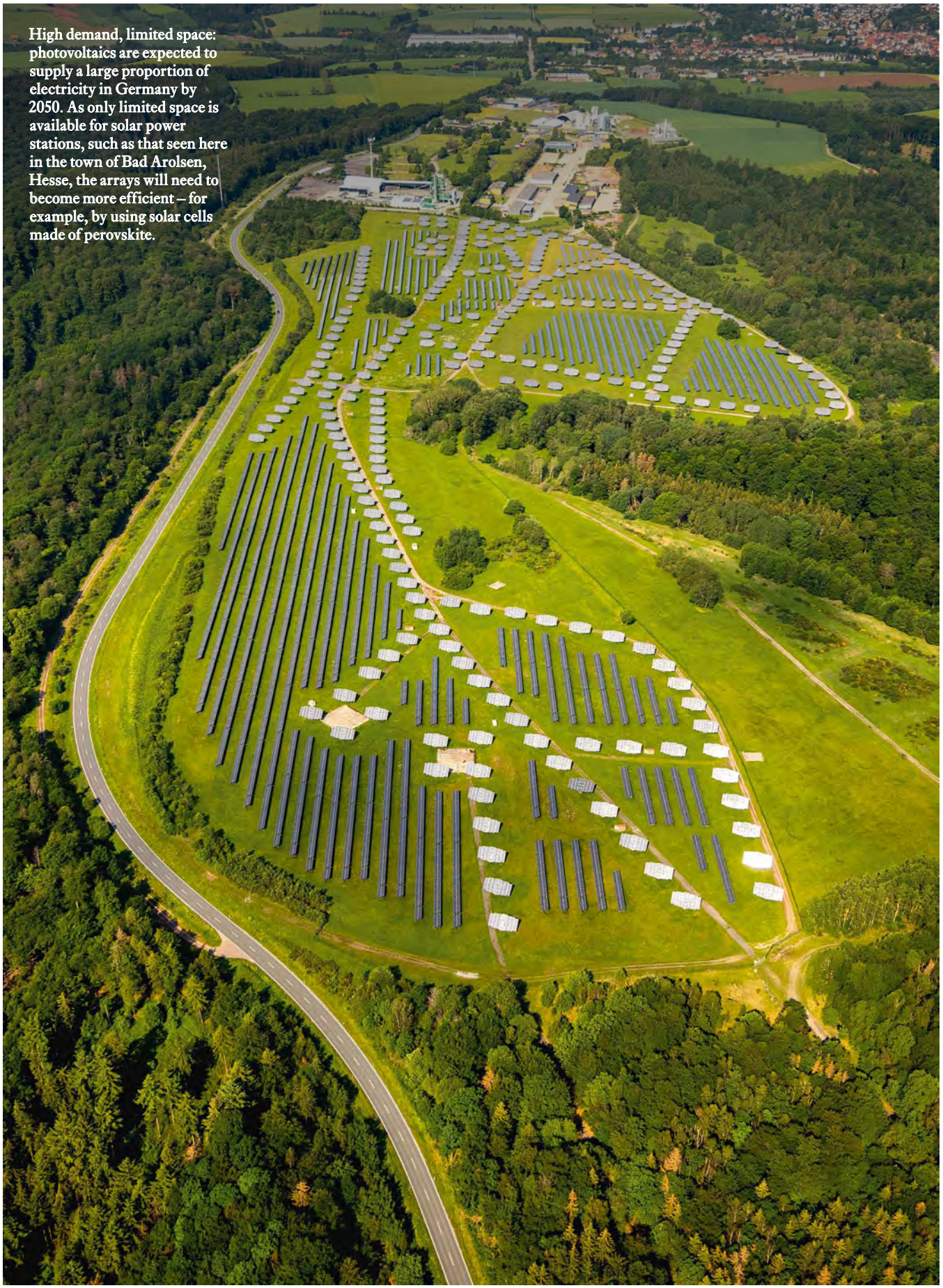
Quality inspection through nudges and boosts

The Leipzig team also wants to use mathematical tools for text analysis to help answer questions that the social sciences are currently working on. This was also a major motivation for Olbrich to initiate the Odycceus project in 2015. Specifically, the aim was to uncover the background of the Pegida movement, which gained significant popularity after 2014. Were the demonstrations against Muslim citizens just another right-wing populist movement? Can Pegida still be classified in the traditional left-right scheme, which is strongly influenced by economic criteria, with the proponents of the free market on one hand and those who argue for more government intervention and redistribution on the other? Many sociologists currently tend to identify the line of conflict along cultural differences associated with open-mindedness and patriotism. Olbrich is working on using algorithms to deduce this reconfiguration of the political space from relevant texts.

Social media can act as a lubricant for such a transformation. One example is the rift that Donald Trump's Twitter rage has continued to widen for years whereby his most important tool consists of alternative facts. If fake news could be more easily identified as such and less easily disseminated, the common factual basis that many debates currently lack could re-emerge. Lorenz-Spreen would therefore like to encourage social media users to pay more attention to the robustness of the claims people make. Together with an international team led by Ralph Hertwig, Director at the Max Planck Institute for Human Development, he has developed proposals based only on external characteristics rather than substantive criteria: a content presentation that makes its credibility easier to recognize based on the sources or senders is just as much a part of this as attempts to slow down the sharing of posts, for example, by requiring additional clicks if users want to forward a message without having read it. Social scientists refer to such interventions as "nudges". "We are fully aware that nudging can be paternalistic," says Lorenz-Spreen, "so, it would therefore always have to be made transparent that these are nudges."

Boosts, which refer to the ability to judge the quality of a piece of information, are less paternalistic intervention mode. Navigating through a decision tree with corresponding (again external) cues before or after reading could give users such a systematic quality check boost. "Boosts require a relatively large motivation. But unlike nudging, they are likely to work even when they are removed," says Lorenz-Spreen. However, all of the team's proposals would have a profound impact on the business model of YouTube, Twitter, and similar platforms, as they are likely to slow down the dissemination of information thereby depriving the platforms of attention "which," as Lorenz-Spreen explains, "means less profit." The only way out he sees is for users themselves to demand more transparency and, for example, to migrate to alternative platforms that could work along the same lines as Wikipedia. "In the long term, I can even imagine public institutions operating such platforms along the lines of public media," says Lorenz-Spreen. However, for now it does not work without rules.

The European Commission has demonstrated its openness to regulation with the Digital Service Act, which aims to establish security and liability rules for digital services. Germany too has already taken a step against criminal digital content with the Network Enforcement Act. Whichever additional standards should be applied to social media is still open to public negotiation. "Regulating digital presences down to the smallest detail is difficult. But design details definitely play a big role," says Lorenz-Spreen. Going forward, he would also like to work with Olbrich's team to study which measures could lead to a more careful handling of information arising from social media, because although the Odycceus project is now coming to an end, the road to a fair, fact-based exchange of opinions is still long – and not just in the digital world.



High demand, limited space: photovoltaics are expected to supply a large proportion of electricity in Germany by 2050. As only limited space is available for solar power stations, such as that seen here in the town of Bad Arolsen, Hesse, the arrays will need to become more efficient – for example, by using solar cells made of perovskite.

PHOTO: PICTURE ALLIANCE / ZB/EUROLUFTBILD.DE | EUROLUFTBILD.DE/HANS BLOSSEY

TUNING FOR SOLAR POWER

TEXT: ANDREAS KNEBL

Germany's objective of achieving carbon neutrality by 2045 will require a massive expansion of solar energy and improved photovoltaic modules. New materials such as perovskites promise to deliver more cost-effective and more efficient solar arrays. To pave the way for their development, Stefan Weber and Rüdiger Berger of the Max Planck Institute for Polymer Research in Mainz are clarifying the processes that take place inside perovskite solar cells.

There is a good chance that the future of solar power will be black – jet-black! Most of today's solar cells are a shade of blue because they are still produced from silicon, which only generates electricity from part of the light spectrum. But these modules could soon be superseded by perovskite solar cells, which are less expensive to produce and, more importantly, have the potential to deliver higher energy yields: 7 kilograms of perovskite could produce as much power as 35 tonnes of silicon, not least because perovskite allows a larger section of the solar spectrum to be converted into power. That is also why the modules are jet-black in appearance.

Many countries are backing the widespread expansion of solar energy with a view to achieving climate neutrality. This includes Germany, which – according to a study by the think tank Agora Energiewende – is expected to meet up to 40 percent of its electricity needs from photovoltaics by 2050. Even small improvements in electricity yield and reductions in material and manufacturing costs have a significant effect. Although today's silicon photovoltaic elements are far more cost-effective, more powerful and less energy-intensive to manufacture than they were 15 years ago, the avenues for their development have largely been exhausted. Researchers around the world are therefore turning their attention to other materials, including those with a perovskite structure. For a number of years, Stefan Weber and Rüdiger Berger, both of whom are Group Leaders at the Max Planck Institute for Polymer Research, have been investigating exactly how solar cells made of or containing perovskite work and how they could be further improved.

"Perovskite" originally referred to a mineral made up of calcium, titanium, and oxygen. First discovered in the Ural Mountains, the compound was named after the Russian mineralogist Lev Alekseyevich Perovski and eventually lent its name to a whole class of materials with a specific crystal structure. These include numerous compounds made up of metals and nonmetals that have a wide range of properties and potential applications. A little over ten years ago, scientists discovered a group of semiconducting perovskites known as lead-containing methylammonium halides that are suitable for use in photovoltaic elements. Armed with this information, researchers around the world made rapid progress: whereas the first perovskite solar cell had an efficiency level of approximately four percent, the latest modules achieve levels of over 20 percent and are therefore approaching the standard of silicon solar cells, whose maximum efficiency is currently 27 percent. Theoretically, a perovskite cell can even achieve an efficiency in excess of 30 percent.

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The principal argument for the widespread use of perovskite solar cells is that the material can be produced cost-effectively and with little energy. This is possible because, in principle, the semiconductor produces electricity efficiently even in very thin layers with a thickness of just 300 to 400 nanometers. Moreover, as the composition of perovskites can be tweaked so that they convert a certain portion of sunlight into electricity, it is also possible to access the energy-rich blue and green sections of the solar spectrum. In contrast, silicon has to be used in thick layers with a depth of several hundred micrometers and primarily exploits infrared and red solar radiation, whereas most of the blue portion is left unused. With this in mind, a combination of silicon and perovskite, or different perovskites, could soon be used to generate electricity from the entire spectrum of sunlight. These perovskite solar cells would then be even more efficient and economical than modern modules based purely on silicon. It is not surprising that the German daily newspaper *Frankfurter Allgemeine Zeitung* described perovskite as the "wonder material of photovoltaics." But before perovskite solar cells can be used on an industrial scale, the materials still need to be optimized in various ways including in terms of their durability and electricity yield. Their chemical composition is a key factor in this context: "In the past, the fabrication of perovskite solar cells was more like alchemy than chemistry, as no one had a proper scientific understanding of the material." Rüdiger Berger explains: "Using our methods mean we can now clarify some of the fundamental processes – and the understanding we've gained will pave the way for systematic improvements."

Looking inside solar cells

He and Stefan Weber are actually experts in scanning probe microscopy, which is the technique they use to examine the interfaces. This technology utilizes the interaction between a very fine probe tip and the sample surface to image it. Additionally, SPM can correlate the structure with the electronic properties at resolutions in the nanometer to picometer range. For comparison, atoms have a diameter of up to 100 picometers. While the research team is steadily refining the scanning probe microscopy methods they use to examine a wide range of materials, they arrived at the perovskite solar cells in something of a roundabout way.

Just after Stefan Weber arrived at the Max Planck Institute for Polymer Research – he had just begun as a doctoral researcher in Berger's working group – he completed a research residency at Seoul National University in South Korea. While there, he was flicking through a journal and stumbled across an article on the measurement of light-induced current in organic solar cells – that is, cells that are made from a plastic film. The authors described how they used scanning probe microscopy to analyze the current at the nanoscale. Stefan Weber was fascinated: "For such a simple measurement, it delivers such an incredible amount of information." His immediate thought was "this is what I want to study for my doctorate." Rüdiger Berger was quickly convinced of the idea, and together they drew up a plan to conduct similar analyses of organic solar cells, which are also touted as a cost-effective and flexible alternative to silicon cells.

The two researchers not only wanted to use scanning probe microscopy to map the surfaces of the solar cells, but also to look inside them. Their plan was to examine the interactions between the various layers in cross section. Regardless of whether the cells are made of silicon, plastic or perovskite, there are at least three layers. The middle layer is the semiconductor material, which is made of plastic in the case of an organic solar cell. Above and below this material are two conducting layers that serve as electrodes and form the "+" and the "–" electrical poles. These poles collect the

GRAPHIC: MPI FOR POLYMER RESEARCH

The *Frankfurter Allgemeine Zeitung* described perovskite as the wonder material of photovoltaics. The Max Planck team in Mainz scanned a single crystal with a scanning force microscope and used their measurements to produce a color 3D image.

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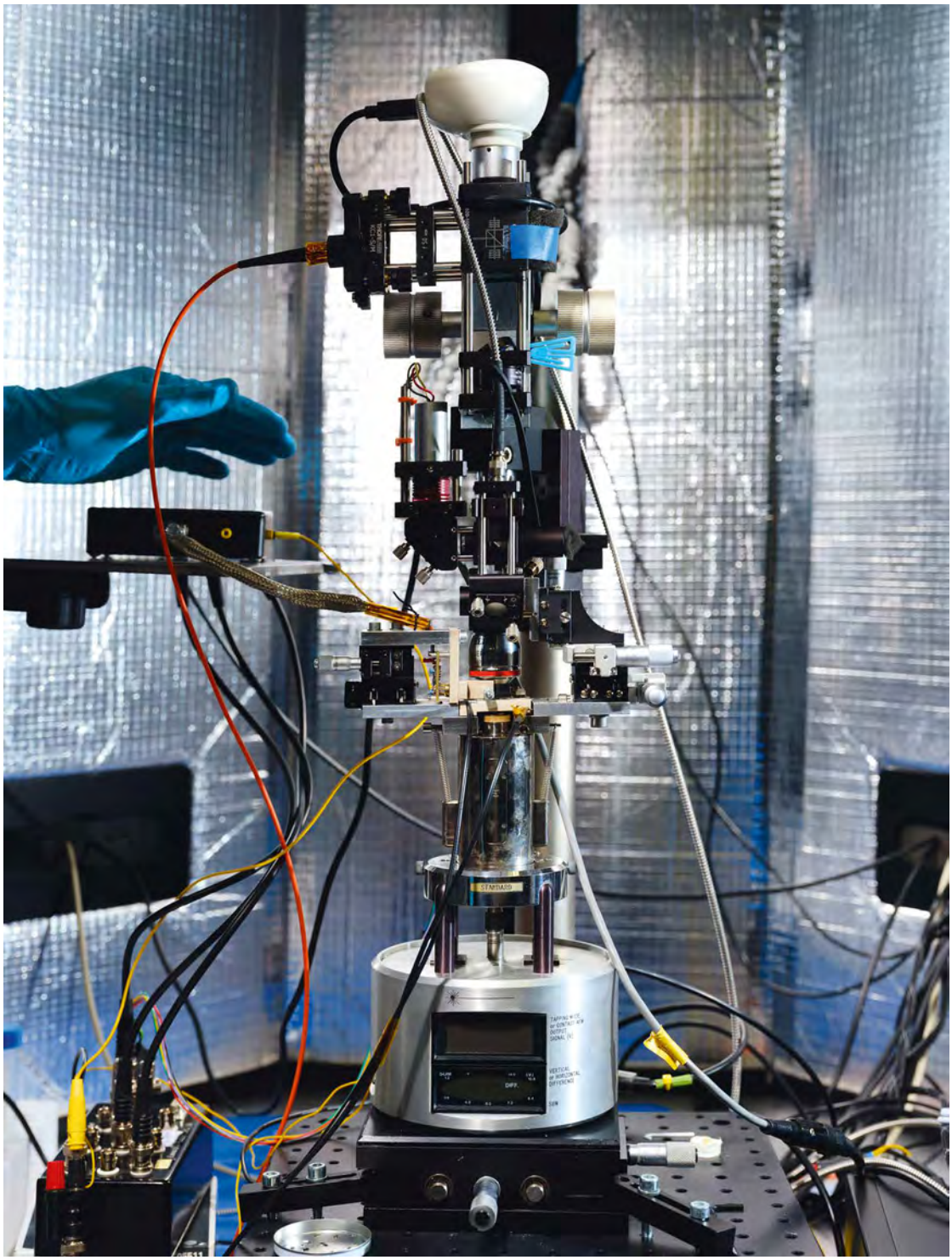

PHOTO: KATRIN BINNER FOR MPG

A versatile instrument: a scanning force microscope uses a fine probe to scan a sample, optionally providing either a surface profile or information about the electronic properties of the material.

charge carriers produced by the light in the semiconductor, which is essential in order for a solar cell to generate electrical power. One of the two conductive layers must also be transparent in order for light to reach the semiconductor. Additional layers are included in some solar cells to direct the charge transfer, for example, or to protect the semiconductor layer. Weber and Berger were particularly interested in the interfaces between the different layers, because if the layers are not perfectly coordinated with one another, the charge carriers experience a bottleneck at the transition points and the efficiency of the cell decreases.

To gain further insights into this material sandwich, the two researchers needed to cut a clean cross section through the organic solar cells. Despite numerous attempts, however, the individual layers would always detach from one another and fan out, preventing Berger's team from investigating the charge transportation process within the cells. It was once again a coincidence that alerted the team to a fresh line of inquiry in relation to these innovative solar cells in 2012. Shahzada Ahmad, a former colleague of Berger's, told him about her research into novel perovskite solar cells in Michael Grätzel's working group at the École Polytechnique Fédérale in Lausanne. Despite being in an early stage of development, the cells were already achieving astonishing levels of efficiency. The Swiss group also provided the team in Mainz with a perovskite solar cell for their research, and a graduate student went to Switzerland by train just to collect it. Unlike the organic cells, the sample could also be cut cleanly, which meant that the researchers

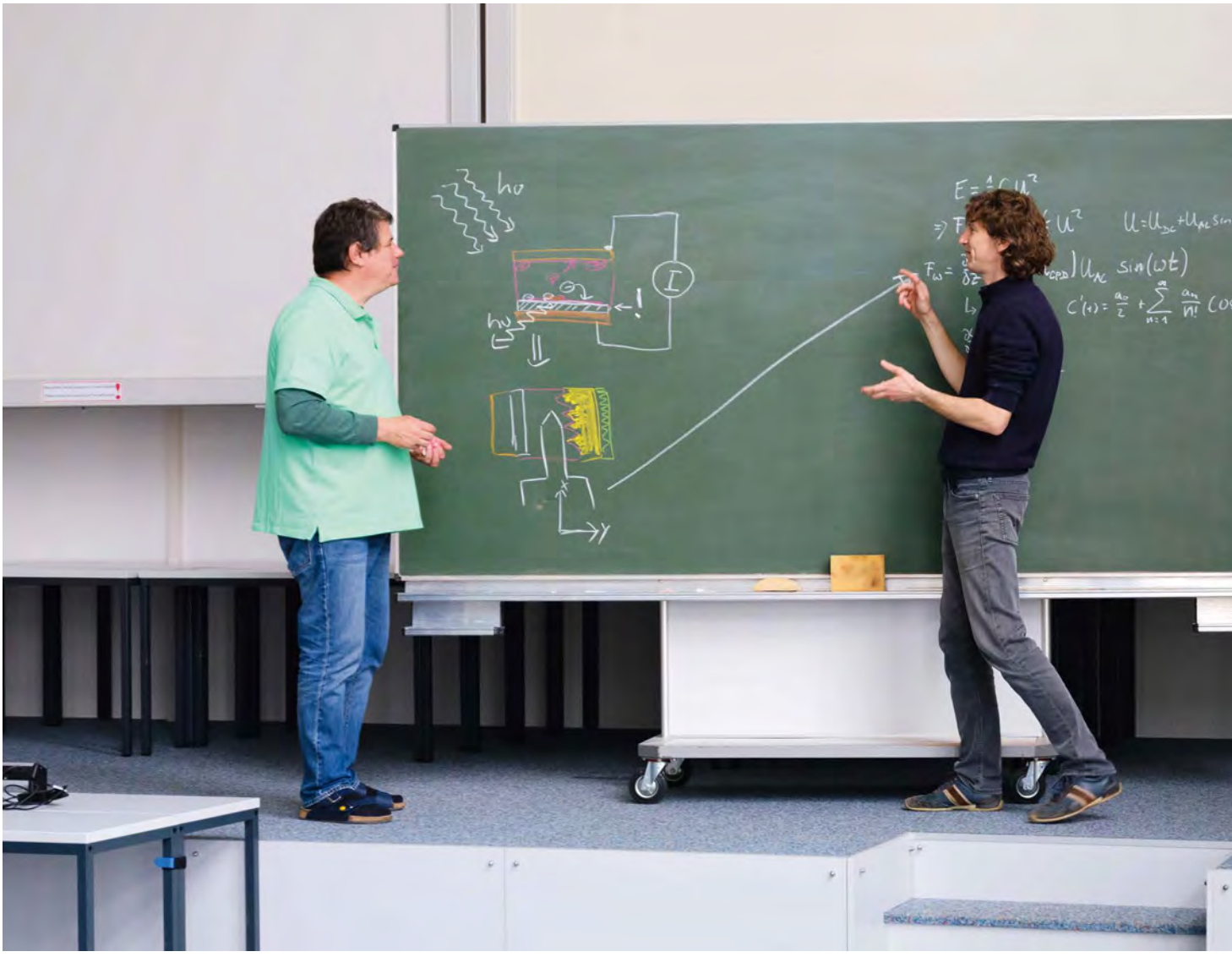

PHOTO: KATRIN BINNER FOR MPG

could finally measure electrical potentials along the cross section of a solar cell using scanning probe microscopy. This laid the foundations for further research into perovskite solar cells. The team in Mainz first wanted to understand what exactly was happening in perovskite cells when they generate electricity. "Unlike silicon, which is more like a stone and barely changes during electricity generation, perovskite is very dynamic," says Stefan Weber. This is because the perovskite and the adjoining layers form an electrochemical cell in which ions migrate just as they do in a battery.

For a long time, however, it was unclear what exactly was happening inside the layers. "By using scanning probe microscopy, we can gain insights into the material at the nanoscale."

To improve efficiency among other things, the Max Planck researchers attempted to solve riddles such as the hysteresis observed in perovskite solar cells. For a long time, it was unclear why it takes a moment for the cell to deliver power when it is exposed to light. Conversely, the power continues to flow for a brief moment after the light stops shining. This lag, known as hysteresis, does not occur in silicon solar cells. However, it must be taken into account in practice because it means that the measured efficiency of perovskite cells depends on how exactly the measurements are taken. "This inaccuracy is undesirable," explains Weber, "because the efficiency is the most important parameter when it comes to comparing different cells. The processes responsible for hysteresis also reduce the cells' lifespan." With the help of a scanning probe microscope, the team led by Weber and Berger was the first to

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Planning for new experiments: Rüdiger Berger (left) and Stefan Weber discuss the insights that their experiments could provide into perovskite solar cells.

SUMMARY

Solar cells made of or containing perovskite could be more powerful and cost-efficient than modules based purely on silicon.

Researchers from the Max Planck Institute for Polymer Research utilize scanning probe microscopy to investigate the processes taking place in perovskite cells with a view to enabling further improvements in terms of such things as efficiency.

Their analyses have clarified that hysteresis – the delay in current flow – in perovskite cells is caused by a build-up of charge carriers.

The researchers have also discovered a striped domain structure of different crystal orientations within the material. As electric charges flow up to 60 percent faster along the stripes than perpendicular to them, an appropriate design could help to make the solar cells more efficient.

work out why there is a lag in electricity generation. For a whole day, the instrument's nanotip scanned the cross section of a perovskite solar cell, which is only a few micrometers thick. Point by point, the team switched an artificial light source on and off and recorded the temporal variations in electric potential. They virtually recorded a video showing how the charge distribution varied along the different layers of the solar cell and eventually observed something that finally explained hysteresis: immediately after the light is switched on, positive charge carriers gather at the edge of the perovskite layer, shielding the electrical pole and therefore interrupting the flow of current. "These charges remain stable at the interfaces of the perovskite for about half a second after the light is switched off and sustain an electric field within the cell. Accordingly, they play a vital role in hysteresis," says Stefan Weber. "Conversely, that means it's possible to influence or completely suppress hysteresis by making targeted modifications at these interfaces."

However, the removal of charge carriers is not only influenced by the processes at the interfaces between the various layers, but also by the electrical properties of the perovskite layer itself. The faster the light-induced charge carriers reach the poles, the higher the electricity yield. With this in mind, the research team conducted a detailed analysis of the electrical properties of the perovskite material, which is not only a semiconductor but also has other properties, such as piezoelectricity, which are still poorly understood. Piezoelectric materials deform when exposed to an electric voltage. To investigate this property, Ilka Hermes from Stefan Weber's group scanned a sample using a microscope probe under an alternating voltage. The voltage caused periodic deformation in the perovskite and also moved the microscope probe. The scientists kept a precise record of the deflection and thereby obtained a high-resolution image of the piezoelectric nature of the perovskite. Following the initial measurement, a surprised Hermes told Weber that all she could see were stripes. But what initially appeared to be a useless measurement actually turned out to be a newly discovered property of the perovskite: the piezoelectric nature of the material barely changed along the stripes but differed significantly between light and dark stripes. This difference is due to the presence of two different orientations of perovskite crystals in neighboring stripes. "We then wondered whether the stripes had an influence on the operation of a perovskite solar cell," says Weber.

Freeways for electrons

Then, in 2020, Hermes and Weber managed to demonstrate that these microscopic structural differences play a part in charge transport. They did so by combining the images from piezo-response force microscopy with data obtained from a photoluminescence microscope. "Our photoluminescence detector works like a speed trap," Hermes explains. "We use it to measure the speed of electrons traveling in different directions at the microscopic level." By doing so, the researchers discovered that the electrons moved about 50 to 60 percent faster along the stripes than perpendicular to them. "The stripes are like tiny freeways for the electrons," says Weber. Accordingly, perovskite solar cells could be made significantly more efficient by ensuring that the stripes lead to the electrodes – for example, by targeted machining or suitable thermal treatment of the material.

Whether perovskite will ultimately become a material of choice for solar cells will depend on what further progress is made. At present, one major problem is the short lifespan of the material, as moisture and sunlight take their toll on the perovskite, leading to a gradual reduction in a solar module's performance. And although the cells are steadily becoming increasingly durable, they are yet to achieve the desired lifespan of 20 to 25 years. That is the aim of a new research project that Berger is launching in collaboration with Shahzada Ahmad.

Ahmad initiated the research into the innovative solar cells in 2012 and is now leading a working group at the Basque Center for Materials, Applications & Nanostructures near Bilbao. "We're going to incorporate a protective layer to prevent the diffusion of water and to make the cells more durable," Berger explains.

Another problem is that the most promising perovskite solar cells contain lead, a toxic component whose use is prohibited, at least in the EU. Considerable research is currently underway with a view to identifying a good substitute for lead or, alternatively, finding ways and means of making the lead in the solar cells safe. Oxford PV, the market leader in the area of perovskite solar cells, refuses to be deterred by these problems. The company has announced that it will commence production of a tandem cell made of silicon and perovskite in Brandenburg in 2022 at the latest, so it might not be too long before the first black solar cells begin appearing on our rooftops.

←

GLOSSARY

PEROVSKITES
are materials with a cubic crystal structure and include lead-containing ammonium halides that can be used as semiconductors in solar cells.

PIEZOELECTRIC MATERIALS
deform when a voltage is applied to them due to voltage-induced changes in their crystal structure.

SCANNING PROBE MICROSCOPY
This method, in which a sample is scanned with a fine probe, provides information about the surface structure or electrical properties of a sample, depending on the mode of operation.

Why so sloppy?

In advanced age, biochemical quality control in human cells becomes sloppy and this can lead to Alzheimer's disease – a dreaded diagnosis.

Franz-Ulrich Hartl and Ralf Jungmann want to gain a better understanding of the process leading to the emerging garbage dumps in cells.

We support their project at the Max Planck Institute of Biochemistry, because deeper knowledge can provide important clues to possible forms of therapy.

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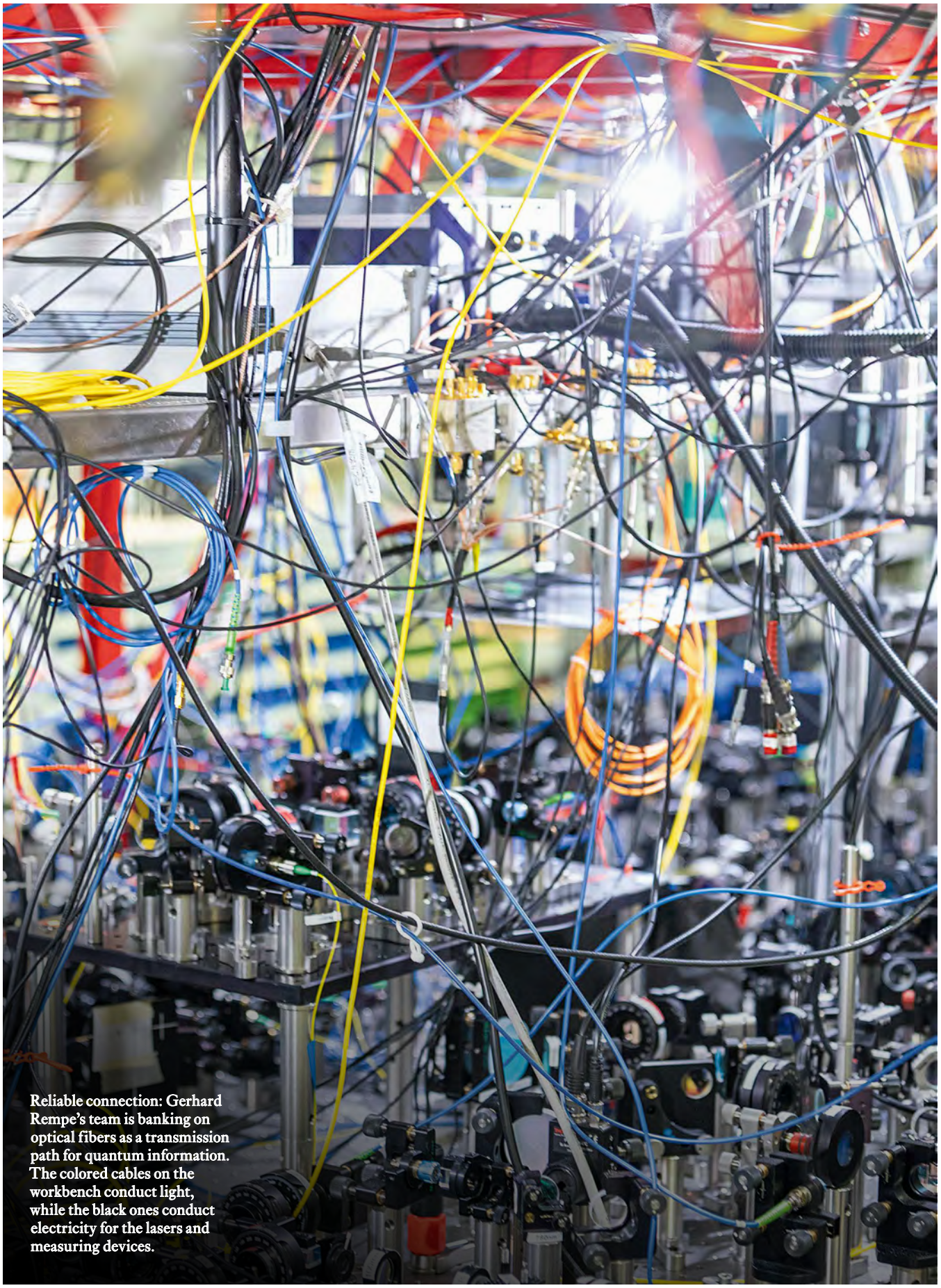

Reliable connection: Gerhard Rempe's team is banking on optical fibers as a transmission path for quantum information. The colored cables on the workbench conduct light, while the black ones conduct electricity for the lasers and measuring devices.

PHOTO: AXEL GRIESCH

THE ARCHITECTURE OF THE QUANTUM INTERNET

TEXT: ROLAND WENGENMAYR

Advances in technology are likely to make cyber-attacks ever more damaging. But at least the transmission of data could become more secure – through quantum communication. This has spurred researchers from around the world to work on its physical principles and technical components. Gerhard Rempe's team at the Max Planck Institute of Quantum Optics in Garching have set their vision even higher: to network quantum computers.

The two bright spots on the screen could represent the future of the quantum internet. "They're two glowing rubidium atoms, captured by a specialized high-resolution camera," explains Stephan Welte, a postdoctoral researcher in Gerhard Rempe's division at the Max Planck Institute of Quantum Optics in Garching. The atoms, just a few tenths of a nanometer (billionths of a meter) in diameter, were suspended in a vacuum in a cavity about half a millimeter wide when the image was taken. This "optical resonator" is formed by two almost perfect mirrors facing each other. Welte's colleague Emanuele Distante explains what this can be used for: "If you fire a photon, a quantum of light, at a minute atom, it is extremely unlikely that the two will ever interact with each other." But this is precisely what they have to do for quantum communication to work. Rempe's group aims to send quantum information by photon mail between senders and receivers composed of atoms or other particles that can store this information. The group hopes that Rempe's approach involving such mirror cabinets will eliminate the obstacle to communication. To achieve this, the two mirrors reflect the photon that is to be sent or received back and forth numerous times within the resonator, rather like a ping-pong ball – "in our case, about twenty thousand times," explains Welte: "This makes it highly likely that the photon will interact with the atom."

Over the course of two decades, Gerhard Rempe and his research team have perfected this mirror trick to the point where they are now using such resonators to develop components for quantum networks of the future. This field of research holds the promise of two advancements: enormously powerful quantum computers and guaranteed tap-proof communications. The latter would immediately be useful in everyday life for such things as online banking. In contrast, we are not likely to come into direct contact with quantum computers in our daily lives. Nevertheless, they would have a profound impact on the world in which we live. They could, for example, solve the "traveling salesman problem" of how to find the shortest route between a large number of different destinations. Such optimization problems that cannot be solved by conventional computers are common in science, engineering, business, and finance.

As quantum computers are costly to build, they are likely to be designed less like computing centers and more like world-wide quantum clouds. That is Gerhard Rempe's vision of the future and it would require a quantum internet. However, quantum computers could also crack the encryption we currently use to transmit data securely. Amazingly, quantum physics provides a solution to this

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problem in the form of quantum cryptography: eavesdroppers on the quantum channel used to distribute the secret key between sender and receiver would inevitably betray themselves.

This explains the huge interest in quantum information technologies in companies such as Google and IBM, which now have a substantial lead on the road to quantum computers. Beyond that, the competition is also on at the state level, above all between China, the U.S., and Europe. In 2018, the U.S. Congress passed the National Quantum Initiative Act, the purpose of which is to provide annually increasing funding to support and focus the wide range of research and development activities within the U.S. Nearly $ 800 million has been budgeted for 2021. The German government plans to provide EUR 2 billion to fund quantum technologies over the next few years, while the State of Bavaria is investing EUR 300 million to transform the Munich area into a "Munich Quantum Valley". The intention is to create new research opportunities and study programs, as well as to establish new start-ups within the Munich region.

Fierce international competition

When it comes to delivering strong media messages, China is currently ahead of the pack. Chinese physicists launched the first satellite to conduct experiments for interception-free quantum communications in space in 2017. On the ground as well, they have constructed the largest fiber optic network to date, spanning 4,600 kilometers, to accomplish this goal. Asked how he assesses the current international competition in physics, Gerhard Rempe points out the cultural context of the race. "The laws of physics are the same everywhere, but there is a strong spirit of pragmatism and creativity in places such as the U.S.," he says. He also considers Europe to be competitively positioned in terms of basic research, with different countries having different strengths. There are some excellent research teams in Germany, especially those that focus on quantum networks and quantum simulators. In fact, Germany is only falling behind when it comes to constructing a freely programmable, universal quantum computer, which is partially due to a lack of funding in the past. Rempe is impressed by the Chinese achievements in terms of management and technical implementation. "But," he says "their work is less exciting from a conceptual perspective." In his opinion, Chinese research is still slightly in copycat mode. On the subject of China's fiber-optic network, he says that: "the network subsystems are based on established off-the-shelf technology but the system as a whole is definitely playing in the first league."

For Rempe, the term "quantum internet" refers to something much more radical than the simple point-to-point connections currently being implemented. According to him, such a network would eliminate human actors communicating via quantum channels of longer or shorter distances. Humans belong to the macroscopic world, which is subject to the

Tracking of quantum post: the Max Planck physicists trap an atom in two crossed resonators, each formed by two optical fibers. This allows them to verify the existence of a photonic qubit without destroying the quantum information.

SUMMARY

Even if quantum computers end up breaking the encryption codes we currently use, the quantum internet could protect data transmission against eavesdropping. It could also connect remote quantum computers to form more powerful units.

The U.S., China, Germany and the EU, are all in a race to develop quantum communication. China, for example, has already constructed a 4,600-kilometer fiber-optic network to this end, which however, still uses nodes based on everyday physics which leaves them vulnerable to attack.

Gerhard Rempe's team aims to transmit information over long distances purely on the basis of quantum physics. The researchers rely on photons as mobile carriers of quantum information and on individual atoms in resonators as stationary elements that act as senders or receivers. Among other advances, they have been developing a quantum repeater.

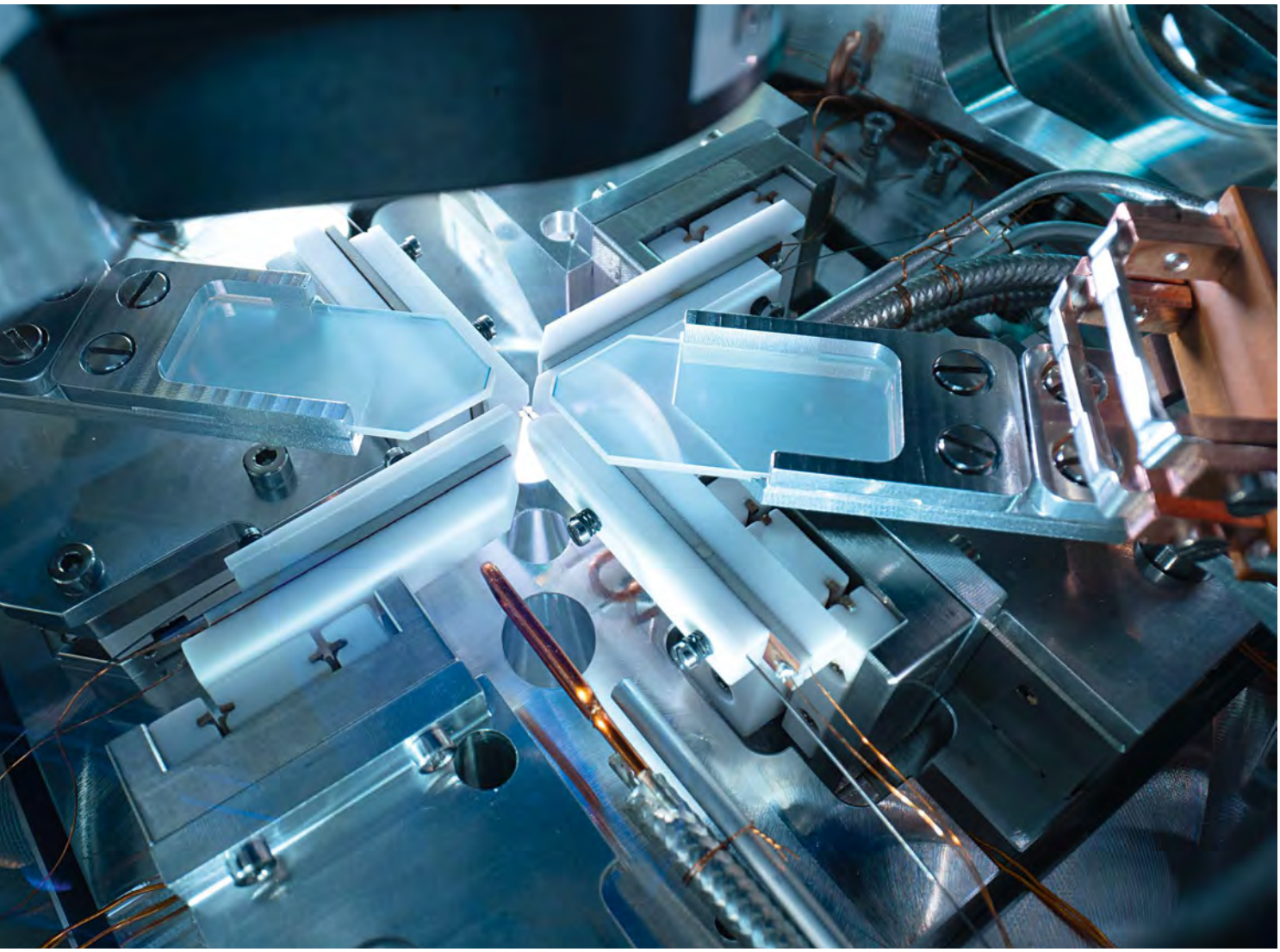

PHOTO: CHRISTOPH HOHMANN (MCQST / LMU MÜNCHEN)

rules of everyday physics, in which no sensitive quantum information can survive. Rempe envisions a future in which true quantum systems, and one day even quantum computers, will be able to communicate with each other over larger distances in a quantum cloud. "That would be Champions League level," he says. He has already taken the initial steps in his laboratories in Garching, and all the involved modules rely on the mirror cabinets.

But, for a layperson to understand what it is all about, one needs to briefly dive into the world of quantum physics – and that is a very strange place. Quantum information is always linked to its physical carrier, such as a quantum of light or photon. Photons transport quantum bits, or qubits for short, as quantum long-distance mail – whether through the atmosphere up into space to a satellite or through an optical fiber to a receiver. The information encoded in the photon can be envisaged as a small pointer extending from the center of a sphere to its surface. The north and south poles of this sphere correspond to the bits used in traditional computers, which can represent either a 0 or a 1. All other points on the sphere represent a superposition of these two states – an increase in possibilities that underlies the computational and storage potential of quantum information. Another crucial factor is that any time the photon is measured, the original superposition of all permissible states collapses to either 0 or 1 in accordance with the probabilistic rules of quantum mechanics. So, any attempt by an eavesdropper to surreptitiously read the quantum information encoded in a passing photon will inevitably be exposed, because the attempt to read the information constitutes a measurement that collapses the superposition which constitutes the actual content of the message. An eavesdropper cannot simply copy the quantum information to a second photon to read it there without being noticed, because,

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by its very nature, quantum information cannot be copied – a fact referred to as the no-cloning theorem. The information can only be transferred, for example from the photon to an atom as a storage medium. The communication deployed in the individual sections of the Chinese network is based on this no-cloning theorem. The problem is that as the length of the fiber increases, so does the number of photons that are lost, which means that trusted nodes need to be interposed within the network – 32 of them in the Chinese implementation. Currently, these nodes that link individual quantum subsections are still subject to everyday physics. "That's not immune against eavesdropping in the sense of quantum physics," as Rempe explains, "because an eavesdropper could discover what was happening at the nodes."

The physicists are hoping to make progress here based on another property of quantum systems, namely entanglement, which allows distant quantum systems to be fused into a single quantum object. To get a feel for entanglement, let us imagine that "Alice" in Munich and "Bob" in Toronto have a pair of quantum dices. Both are tasked with rolling their individual dice a thousand times and writing down the sequence of numbers obtained. In isolation, this sequence will seem completely random for both. However, as soon as they compare their lists, for example via a video call, they start to notice something strange: every time Alice rolled a six, Bob rolled a one – and vice versa. And if the result was not one and six then it was two and five or three and four. The reason is that the two dices were entangled with each other over thousands of kilometers.

Albert Einstein viewed this "spooky action at a distance" as evidence that quantum theory is incomplete. But he was mistaken, because nature operates precisely like this, and entanglement has now been successfully demonstrated in experiments spanning many kilometers. It is this entanglement that nascent quantum information technologies are exploiting as a key resource. In its advanced form, the distribution of quantum keys – quantum cryptography – depends on the extreme sensitivity of entanglement to any external influences. The moment eavesdroppers try to snoop on the quantum channel, they betray themselves due to the immediate collapse of the entangled state. In a future quantum internet, as envisioned by Gerhard Rempe, quantum modules will be capable of entangling with each other via traveling qubits. The modules – which could even be full quantum computers in the future – will serve as intermediate storage devices for quantum information. For Rempe's team, these memory modules are made of the atoms in the mirror cabinets.

Quantum repeaters for long distances

In the view of the Max Planck Director, any future quantum internet will inevitably be based on a fiber-optic network. Satellite transmission becomes problematic as soon as larger amounts of data are involved, because the atmosphere is no exception to the rule that precious photons sometimes disappear, or because a satellite sinks below the horizon. Compensating for the losses in optical fibers requires a larger quantum network to incorporate some form of repeater, analogous to the repeaters in conventional optical fiber networks. As yet, however, no such quantum repeaters have been developed, although several groups around the world have been researching them for the past 20 years.

The difficulty is due to the fact that a quantum repeater cannot function as an amplifier. In principle, a conventional repeater collects attenuated laser light and transfers the signal received onto a stronger laser beam for reemission. In quantum physics, this would constitute the prohibited process of copying, i.e., the quantum message would have been opened prematurely, rendering it worthless. So, a quantum repeater must be capable of passing on Alice's highly sensitive entangled message to Bob at a distance, without reading it. More precisely, a quantum state is sent from Alice through to Bob via an entanglement. This process is known as quantum teleportation, although the term, inspired by Star Trek, is frequently misunderstood. Unlike in the science fiction show, it does not mean that matter, including a full-sized Mr. Spock, can be beamed from place to place. It only works for non-material quantum states, in other words, quantum information.

In fact, Gerhard Rempe's team recently conducted the world's most successful laboratory experiment on quantum repeaters. A mirror module housing two atoms served as the repeater. This ensemble is placed in the fiber optic path between Alice as the sender and Bob as the receiver. It involves one of the two atoms in the mirror module repeatedly sending an individual photon entangled with the atom to Alice, until one eventually arrives successfully. At the same time and independently, the other atom establishes a connection with Bob. As soon as this is established, both atoms in the mirror module are subjected to what Rempe refers to as a "magical measurement." This causes the entanglements of the two partial sections to be "glued together" to form an entanglement between Alice and Bob.

Since the two sections have been processed in parallel before this last step, the transmission rate is higher than that of the simple connection without a repeater as soon as a specific section length is exceeded. The experimental setup has not yet achieved this distance: the longest connection path achieved in the laboratory to date was equivalent to a two-kilometer fiber-optic path. The measured results already show that beyond a distance of seven kilometers, the Garching quantum repeater would result in bet-

ter transmission of photons than a link without a repeater. However, the path to this achievement is still long and hard. Simply extending the distance will not work, as Rempe explains. Prior to that, the researchers will have to solve a number of problems, in particular they will have to reduce losses caused by the magic measurement. Any quantum fiber optic network would then have to include a quantum repeater every few kilometers.

Another crucial tool developed by the team performs the task of a herald. In a network with quantum repeaters, this herald issues a success signal as soon as each section of the link has established entanglement that is subsequently switched through by means of the final magic measurement. The challenge is that the herald is not permitted to carry out a full measurement itself. Metaphorically, its job is to discover if someone is in a room solely by listening, without opening the door. To implement such a herald, Rempe's team has devised a clever arrangement of two crossed resonators. The main resonator, which is aligned in the same direction as the actual communication link, serves as a network node with a memory function. The secondary resonator, which is aligned perpendicular to it, checks as a herald carefully whether the atom in the resonator has stored the incoming qubit.

Network of quantum processors

Rempe and his team can also use their herald method to check whether a photon has arrived at the crossed resonators in an optical fiber. This is essential, in order to establish as quickly as possible whether the quantum mail has been lost in transit. In this context too, the trick is to "sense" the photon, without measuring it directly. Any measurement would destroy the information stored in the photon. Such heralds are part of the toolbox with the aid of which multiple quantum computers could be linked via a quantum network. This is because multiple heralds distributed over the quantum network would enable the rapid detection of whether a photon is still present or has already been lost so that a new transmission attempt could be made if required.

Gerhard Rempe's team has recently taken an important step towards a quantum network with an experiment in which Alice and Bob were already represented by two quantum processors. This experiment consisted of two modules 60 meters apart, comprising atoms in mirror resonators,

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Philip Thomas, Olivier Morin, Gerhard Rempe and Leonardo Ruscio (from left) gather around the table on which the vacuum chamber used in experiments involving individual atoms sits. The lasers needed for this are mounted on the table on the left.

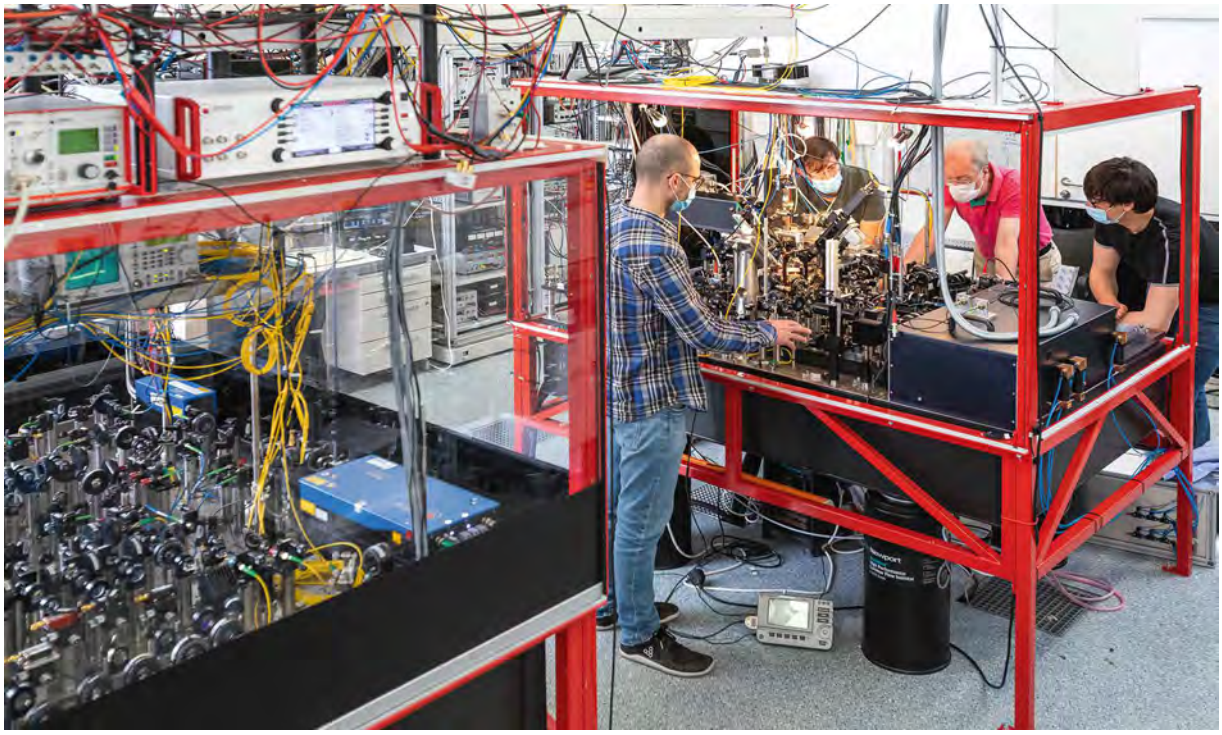
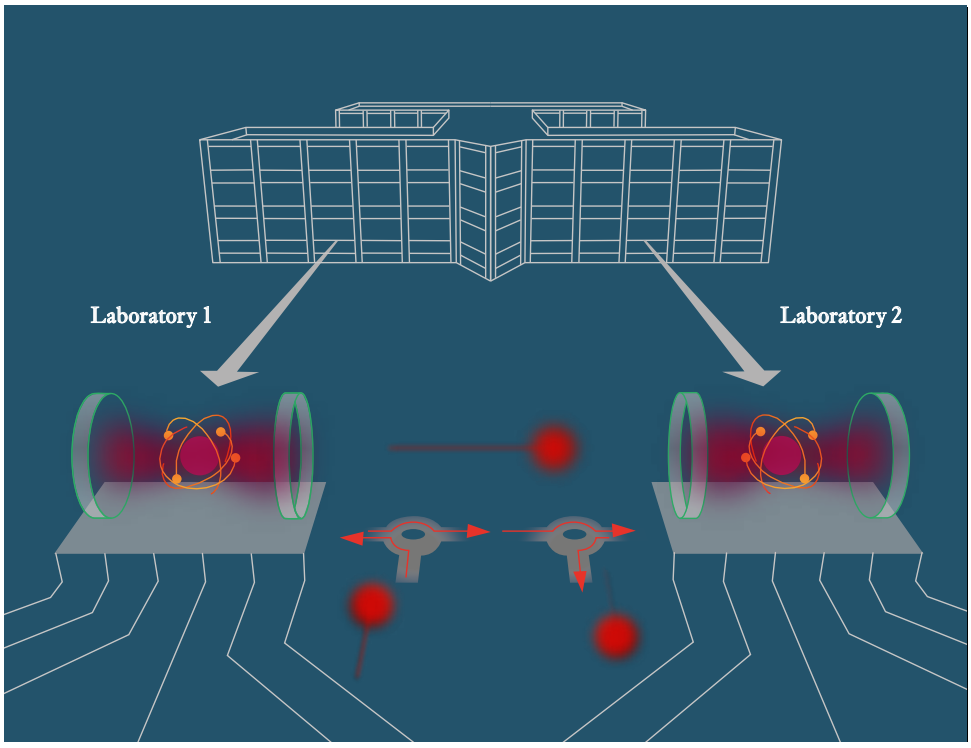


PHOTO: AXEL GRIESCH



GRAPHIC: GCO BASED ON A DESIGN BY THE MPI OF QUANTUM OPTICS

Distributed computing: two atoms between pairs of mirrors located in different laboratories perform a joint quantum calculation. This is mediated by photons rather than the electrical signals used in conventional computers.

connected via an optical fiber. The researchers succeeded in coupling the two atoms in the modules to form a quantum logic gate with a herald via a single photon transmitted through the fiber. The quantum gate can be envisioned as an analog of the logic gates used in conventional electronics, but with optical fibers for photons rather than electronic conductors. Such distributed quantum processors could overcome a key problem of quantum computers: qubits are located in close proximity to each other and can therefore interfere with each other in undesirable ways. This problem could be prevented by a quantum network comprised of distributed processors. Establishing local quantum networks with this kind of function within individual premises is also a much easier initial step than, say, creating a global quantum internet. Such local quantum networks could represent an initial use case.

Recently, Rempe and his team also succeeded in creating the first "random-access memory" for quantum information in the form of two atoms in the mirror cabinet. This type of memory permits unrestricted access to each memory cell, and in the configuration devised by Rempe's team, these cells are represented by each of the two atoms.

In this way, the researchers are progressively developing quantum communication modules. Rempe's confidence comes as no surprise. He firmly believes that we will witness the establishment of a true quantum technology long before the end of this century. Among other things, his optimism is based on the history of scientific progress: major discoveries in physics, for instance in optics and mechanics, thermodynamics, electrodynamics, and quantum physics, have always proved to be the economic engines of the following century. They are at the root of countless technical and societal breakthroughs, from trade to mass production and automation.

"Quantum physics has brought us a multitude of major breakthroughs in the form of transistors and lasers, and I believe that the 21st century will be the century of quantum information."

GLOSSARY

QUBITS
The smallest unit of quantum information is known as a qubit. Qubits can not only encode a 0 or a 1, but also states in between. This is expected to make quantum computers much more powerful than conventional computers. The laws of quantum physics also prohibit the copying of quantum information, thus enabling tap-proof communications.

QUANTUM REPEATERS
are designed to enable fragile quantum information to be transmitted over long distances by using quantum entanglement.

ENTANGLEMENT
transforms multiple quantum systems, even spatially separated ones such as photons and atoms in resonators, into a single extended quantum system.

Sie müssen auf Englisch schreiben oder vortragen? Sie fragen sich, wie deutsche Wendungen, z.B. *„aus Platzgründen muss ... ausgeklammert werden"* oder *„... sei zunächst angemerkt, dass ...“* korrekt und geschliffen ins Englische übertragen werden? Oder Sie suchen nach Formulierungsalternativen?
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Dirk Siepmann ist Professor für Fachdidaktik des Englischen an der Universität Osnabrück. Er verfügt über eine jahrzehntelange Erfahrung in Fremdsprachendidaktik, Übersetzungswissenschaft und Lexikographie.

DEUTSCHER HOCHSCHUL VERBAND

From the street into the courtrooms: as was the case in Hamburg, young people around the world demonstrated in 2019 for fast and effective climate protection measures. Now they are also taking legal action against the government.

PHOTO: PICTURE ALLIANCE / XIM.GS

CLIMATE-PROTECTING COURTS

TEXT: MICHAELA HUTTERER

Thus far, most industrialized countries have taken only half-hearted measures to limit their CO_2 emissions, and the effects of global warming are becoming increasingly apparent. At the same time, the pressure on governments is growing as climate activists are increasingly taking the matter to court. Researchers at the Max Planck Institute Luxembourg for International, European and Regulatory Procedural Law and the Max Planck Institute for Comparative Public Law and International Law are looking into how jurisprudence and legislation could help to counter climate change.

Hannes Schwerdtner from Uckermark is furious. Furious because the meadows which once fed 400 head of cattle, are being turned into sandy deserts because of violent storm gusts. Furious about the German government's unambitious climate policies and its emergency water laws which prohibit him from drilling new wells. As the farmer testifies at the International Court of Justice in Berlin, he has only been left with 30 cows after having been forced to slaughter the rest. The court has been temporarily relocated because of local flooding.

Though all too believable, what you have just read is (still) a fictional tale taken from "Ecocide", a TV film shown on the German ARD channel last November. In summary, the plot is that 31 southern hemisphere states sued the Federal Republic of Germany in 2034 for damages resulting from insufficient climate protection, whether due to the late phase-out of coal power, the grant of loans worldwide by the state business development KFW bank for the construction of coal-fired power plants, or the support for the domestic car industry through half-hearted measures for CO_2 reduction.

Total science fiction? Not at all. The dystopia presented by author and Director Andres Veiel is based on the latest findings of climate research and legal science. Experts from the Max Planck Institute for Comparative Public Law and International Law in Heidelberg provided the legal background for the script. Scientific facts for a very real future scenario; a script for the time when the Earth's atmosphere will have heated up even more and untold numbers of people will be suffering the effects. In fact at this point, the scenario is not so far from reality. Whether in Australia, the United States, France, the United Kingdom, Switzerland or Germany, more and more climate protesters are taking their cases to court "We are seeing a dynamic development of climate-related court cases all around the world, with the number of pending cases exploding," reports Tom Sparks, a senior research fellow at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg. "While no case has yet been brought to the International Court of Justice, it would be possible," explains the expert on international climate and procedural law, who also advised the ARD filmmakers.

The majority of cases are currently presented in national courts. #climatejustice is the buzzword for the legal fight for more climate protection and a fairer distribution of the burdens resulting from global warming and is the legal extension of the Fridays for Future movement, which represents a continuation of protest marches into courtrooms around the world. Cli-

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mate scientists, activists, and lawyers are pooling their knowledge in a global network: whether it is "Lawyers for Future" or environmental lawyers in academia, they rely on the publicity that court cases create, collecting and analyzing legal documents and rulings worldwide. Ecolex is just one of several databases documenting the global battle for climate in the courts.

Climate targets are not directly enforceable

The main argument of activists, victims, and environmental associations who take legal action against the state is that climatic change violates human rights. It threatens the ecological subsistence level of human beings, which is derived from the right to life, to family, but also to housing, and is incorporated in national (constitutional) law, or is at least accepted as a standard, in almost every country.

"This path is very promising, but there are limits," legal scholar Sparks observes. Following the adoption of the Paris Agreement in 2015, the 191 signatory states, which include all EU member states and the U.S., are obliged to set and meet certain climate objectives that they set for themselves. "However," as Sparks explains, "these targets themselves are not directly enforceable." He goes on to say that it was particularly important for the industrialized nations, as greenhouse gas emitters, not to create any new ground for legal suits under the agreement.

And, as a cursory glance at the database of court verdicts shows, this is precisely why many court cases collapse: at the end of March, the European Court of Justice (ECJ) in Luxembourg rejected the "People's Climate Case", a lawsuit filed by ten families from the EU, Kenya and Fiji for stricter climate targets on formal grounds alone. All of the plaintiffs, such as the German Recktenwald family from Langeoog, all work in tourism or agriculture. They had filed a complaint against the European Parliament and the EU Council because of insufficient climate protection standards. The ECJ did not allow the case to proceed to judgment on the basis that, as in the previous instance, the applicants lacked any basis for the lawsuit. As the judges ruled, climate targets do not create individual rights even if the consequences of climate change – such as droughts or floods – are already having an effect on individual persons or groups. More demanding climate targets such as the reduction of greenhouse gases by 50 to 60 percent compared to 1990 levels by 2030 (rather than the 40 percent currently envisioned) – cannot be established by taking legal action before the ECJ.

The European Court of Human Rights, however, was less restrictive and decided to hear the case put forward by a group of Portuguese young people in a special procedure. The plaintiffs, children and young adults between the ages of nine and 22, are demanding stronger climate protection measures from the 33 states that have signed the Convention for the Protection of Human Rights and Fundamental Freedoms, which includes Germany. Their case is based on the devastating forest fires in the Pedrógão Grande region in 2017, which claimed more than 100 lives. The plaintiffs invoke Articles 2 and 8 of the Convention, which protect the right to life and the right to respect for private and family life. Their accusation is that the inaction of the EU states, but also of Russia and Great Britain, against climate change is partly responsible for the extent of the repeated fires.

The fact that the judges allowed the lawsuit to proceed to judgment is a novelty for legal experts: plaintiffs usually have to go through national courts before they are allowed to bring a claim before the European Court of Human Rights. The Strasbourg judges made an exception in this case. What's more, they bundled the lawsuits against the 33 governments into a single procedure and emphasized the importance, urgency and priority of

Fictional trial: in the TV film "Ecocide", the International Court of Justice hears a case brought by countries in the Global South against Germany in the year 2034. The states are claiming damages because the German government has done too little to combat climate change.

SUMMARY

Lawsuits for more climate protection have been successfully filed in national courts. The judges based their decisions on fundamental and human rights.

In March, the European Court of Human Rights allowed a climate lawsuit against 33 European states.

An obligation to protect the climate can also be derived from international law: the no-harm rule prohibits a country from taking any actions that harm another country.

PHOTO: 2020 MATTHIAS FLEISCHER / ZERO ONE FILM

the process. The respondents now have a rather short deadline until mid-July 2021 to respond. If the Strasbourg judges were to rule in favor of the young people, it would be an important victory in the fight for climate protection by court order.

Climate plaintiffs are mainly drawing support, above all, from the Netherlands and the breakthrough decision from December 2019 – called "Urgenda". "It is the blueprint for many lawsuits around the world," as Alessandra Donati, a senior research fellow at the Max Planck Institute for International, European and Regulatory Procedural Law in Luxembourg explains.

The Dutch Urgenda foundation (from Urgent Agenda) had already sued the Dutch government in 2013 for stronger climate protection on behalf of 900 Dutch citizens. The foundation invoked international, EU and national law and called for the government to do significantly more by the end of 2020 in order to keep to the Paris climate objectives. The government thought it was in line with the rules offering a reduction of greenhouse gas emissions by 20 percent below 1990 levels. Too little, the District Court of The Hague decided, and ordered the government to limit emissions to at least 25 per cent by 2020. The High Council, the highest court in the Netherlands, upheld that decision. The judges also referred to the European Convention on Human Rights: by setting insufficient climate protection standards, the state violated its duty to protect citizens from the dangers of climate change, which follows from Articles 2 and 8 of the ECHR.

The decision is something of a sensation for legal experts. "For the first time, a court has established a duty of action on the part of the state to comply with climate objectives and condemned it for inadequate implementation," as environmental law expert Donati explains. "States have a duty of care to their citizens to provide a healthy environment and protect them from harm." Whether this danger affects individuals or the entire population is just as irrelevant as the question as to how immanent the danger already has to be. As Donati, a former solicitor, explains: "Urgenda" establishes the state's liability for any foreseeable danger to its citizens.

Judges in France came to a similar ruling in February in the case "L'affaire du siècle". In its ruling, the Paris Administrative Court found ecological damage in connection with climate change and held the French state liable. The case was brought by environmental and social associations, which are now preparing a lawsuit for damages. In Germany, too, pressure on the legislator is mounting. In an unexpected but impressive verdict this April, the Federal Constitutional Court (Bundesverfassungsgericht)

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ruled in favor of 44 complainants led by Fridays for Future activist Lisa Neubauer, declaring that the provisions of the Federal Climate Change Act of 2019 (Bundes-Klimaschutzgesetz – KSG) governing national climate targets and the annual emission amounts allowed until 2030 are incompatible with fundamental rights insofar as they lack sufficient specifications for further emission reductions from 2031 onwards. The law stipulates that Germany should become climate-neutral by 2050, in line with the Paris Agreement, and sets specific reduction targets until 2030 yet fails to make any specifications for the period between 2031 and 2050. For the judges, this is an inadmissible interference with the civil rights of young people and future generations. If CO_2 emissions do not decrease by a considerable degree by 2030, the relevant restrictions will have to be tightened if the climate targets are still to be achieved. Because almost all areas of human life are still linked to the emission of greenhouse gases, the court reasons that many freedoms will have to be restricted from 2031 onwards.

The judges are demanding a real, long-term climate strategy for future generations as set out in Article 20a of the German Basic Law (Grundgesetz) which states that: "Pursuant to its responsibility to future generations, the state shall protect the natural foundations of life and animals." It remains to be seen whether the new climate protection legislation that the federal government enacted rather swiftly following the court ruling in mid-May will meet the judges' demands. It envisages a 65% reduction in greenhouse gas emissions by 2030 (rather than 55% in relation to 1990) and aims for climate neutrality by 2045 (rather than 2050). The Netherlands, France, Germany – what good is a patchwork of national decisions? Does global warming not require global action and global legislation? "I see two ways to mitigate the effects of global warming," says Alessandra Donati: "Legislation and litigation. Climate related lawsuits are only one part of it. More important are meaningful climate laws themselves." In the course of a research project, she is looking into how the proposals outlined in the EU's Green Deal, the purpose of which is to mandate tougher targets for the EU, could be implemented to tackle environmental, economic, and legal climate risks in accordance with EU law.

For the right to a climate that benefits all humans: Mariana (9), Cláudia (22), Martim (18), and Catarina (20), together with two other Portuguese youths, successfully filed a complaint with the European Court of Human Rights.

PHOTO: GLAN

Experts are waiting with bated breath to see what legal imperatives will be brought to bear in the struggle against global warming in the future. What is required is a global will to act, which is predicated on a shared set of goals within the global community. "Since Paris," Sparks observes, "the process of agreeing on more profound measures has stalled – often due to the resistance of the emitting countries." He and Donati are cautiously optimistic about the outcome from the virtual Earth Day Summit in April, at which the U.S., the host country, in particular, forged ahead under its new administration.

No country should harm another

Whether or not the international community truly takes climate protection seriously will be seen later this year. More aggressive climate protection targets could be established at the climate summit in Glasgow. But what happens if they are not set? Can one argue the case for a duty to take action? Tom Sparks is looking into this question and is considering the extent to which countries may even be obliged to take action based on international law. An obligation to reach agreement may even be derivable from international law, for example through the no-harm rule, which prohibits a country from taking measures whose effects are to the disadvantage of another country. An international duty to protect the climate would appear to be the solution in view of rising sea levels, fire and storm damage, and increasing droughts.

In the meantime, the only hope is for climate protection to be fast-tracked by a court ruling. Above all, hopes are resting on the International Court of Justice in The Hague (ICJ), which can tackle all the relevant legal issues as long as the parties accept its jurisdiction. "Inter-state claims can have a far greater effect on solving the climate problem because, unlike proceedings based primarily on human rights violations, they usually have more than just a national impact," says Sparks.

PHOTO: PATRICIA DE MELO MOREIRA/AFP VIA GETTY IMAGES

Deadly fire: in 2017, forest fires claimed the lives of more than 100 people in the Pedrógão Grande region of Portugal. It was this disaster that caused young Portuguese to file a lawsuit in favor of climate protection.

Unlike in the TV movie, it is not clear whether any of the countries in the southern hemisphere are currently preparing a lawsuit against Germany or other industrialized nations. One can also set about finding out what the supreme judges of the world think about the objectives and climate efforts of the global community in a different way. "It would be possible to raise a request in the UN General Assembly next year to oblige judges to provide a legal opinion on some of the specific legal questions," says Sparks. "An advisory opinion from the International Court of Justice has enormous significance as it provides an authoritative statement on the rights and obligations of states." National courts would benefit from this in their decision-making. So, the ICJ judges could become the supreme climate defenders. ←

PHOTO: VIRAJ TADWALKAR

Danger from the well: in some areas of India, groundwater is naturally contaminated with arsenic. An information campaign is intended to educate villagers about the risks. This includes asking about the health of all family members.

Max Planck researchers cooperate with partners in more than 120 countries. Here they write about their personal experiences and impressions. Shambhavi Priyam of the Max Planck Institute for Research on Collective Goods is coordinating an information campaign in northeast India in order to protect people from arsenic-contaminated well water. She reports on culinary delights, the slow wheels of the Indian bureaucracy, and celebrating her birthday in the midst of a pandemic.

For many of use, the word 'arsenic' conjures up images of old murder mysteries. But hardly anyone in Germany knows that millions of people in India and Bangladesh suffer from chronic arsenic poisoning – and that tens of thousands of people die from it every year. Highly toxic arsenic compounds occur naturally in the groundwater in some areas of northeast India. Many wells are contaminated with it. The problem is that you can't see, taste, or smell the arsenic in the water. And because it doesn't make you sick right away, many people don't even realize that they are damaging their health every day. They use the well water for drinking, cooking, and irrigation. In the process, they suffer from chronic poisoning over the years. Typical symptoms are painful, itchy calluses on the palms of the hands and soles of the feet as well as dark spots on the skin. It sometimes takes years – or even decades – for nervous diseases or cancer to develop.

We want to figure out the best way to make people aware of the invisible danger and persuade them to change their habits. The study involves 150 villages from the Bihar region in northeastern India. The people here either farm or earn their living as migrant workers. Many cannot read or write and have limited access to medical care. In order to educate them about the arsenic problem, we have made a film in cooperation with the local government. Film work was completely new territory for me. But it was a lot of fun.

The footage provides information about the invisible danger and shows the inhabitants of the region how to obtain safe water. One method is to boil water collected from ponds and rivers. But there is an even easier way: well water is left to stand overnight so that the arsenic can settle to the bottom. The water at the top of the vessel can safely be used. A small change in behavior can thus have a huge effect – I want to spread this message to as many people as possible! To do this, I work together with local helpers. They go to the villages, measure the arsenic levels in the wells, interview people about their habits and health status, and show them the film. In order to reach people, it is important that all contributors speak the local language and know the local conditions. I was born in Patna, the capital of Bihar, and spent the first 10 years of my life here. An interim assessment

POST FROM

INDIA

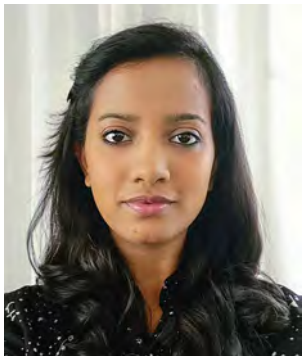

PHOTO: VIRAJ TADWALKAR

Shambhavi Priyam

27, studied economics at St. Xavier's College in Mumbai. Since 2017, she has been working on her PhD at the Max Planck Institute for Research on Collective Goods in Bonn. In the "Experimental Economics" Department of Director Matthias Sutter, she is investigating how social norms affect health behavior. As an award-winning "science slammer", she enjoys sharing her research with others.

of a subsample of our households has shown encouraging effects with respect to improvement of water quality. In the longer run, however, we want to elicit answers to questions such as: do they remember the content of the film and behave differently now? Do they share the information with others? How are they doing healthwise? The campaign got off to a promising start, and people are open to the topic. However, because of the coronavirus pandemic, the project has been considerably delayed.

I currently spend most of my time in a small apartment in Patna working on my computer. I would like to meet with my relatives, many of whom live around here. But unfortunately, that's not possible at the moment. I recently celebrated my birthday in a quiet manner in line with COVID-19 regulations. My cousins surprised me with a homemade cake. And later, there was a party with friends – via video chat. It is great to have a support system in India during the COVID-19 catastrophe which can make it difficult to work alone in the field. When I am in India, I especially enjoy the delicious food with all its wonderful spices. German cuisine doesn't quite have enough spice for my taste. So I often have to give it a bit of help. But every now and then, I enjoy eating plain cheese spaetzle. What I like about India is how easy it is to strike up a conversation with people on the street and find out something new. But sometimes I miss Germany – especially when I have to deal with the authorities. The wheels of Indian bureaucracy move incredibly slowly. What I like about the Germans is that they are straightforward and say what they think. This is different in India. Here, you rarely hear a clear "yes" or "no".

I love to travel and have lived in the U.S. and France for a while. But I feel at home where I am at the moment. I would like to continue to work in Germany as a scientist because it is the ideal research environment for me.

FIVE QUESTIONS

ON GLYPHOSATE

FOR MARTIN KALTENPOTH

Mr Kaltenpoth, in your study, you showed that glyphosate causes harm to saw-toothed grain beetles. Another study showed that the substance had an adverse effect on honeybees. What other insects might be affected?

MARTIN KALTENPOTH We are still not exactly sure. But glyphosate could be harmful to many insects that rely on symbiotic bacteria. These include species that feed on plant saps, such as aphids, cicadas or heteropterans. However, many beetle, bee, and ant species also host symbionts and could be affected by glyphosate.

Glyphosate was thought to be nothing more than a herbicide. Why does it also affect insects?

It inhibits the shikimate pathway, which plants use to produce aromatic amino acids, among other things. But, in addition to plants, certain bacteria and fungi also use this metabolic pathway. Insects that cannot meet their demand for aromatic amino acids, such as tyrosine, from their food host bacteria in special organs for amino acid production. They live in symbiosis with these bacteria. Glyphosate acts on these microbes like an antibiotic: once the insects have absorbed the toxin through their food, it spreads throughout their bodies and kills the bacteria living in the cells of the symbiotic organs. Without their partners, the insects lack the tyrosine they need to form their exoskeleton, which causes them to dry out faster and makes them more vulnerable to predation. In the case of bees, the toxin damages bacteria in the intestinal flora rather than in symbiotic organs, which renders them more susceptible to pathogens.

Glyphosate has been on the market for decades: what should one be on the lookout for in the future during the approval process for pesticides to identify adverse effects on other organisms at an early stage?

We should test the effect of future pesticides on a larger number of different species. Not all insects are the same – and what one species tolerates can be harmful to another. We now know that focusing on the median lethal dose – the concentration at which half of the test organisms die – is not sufficient. Pesticide manufacturers need to take greater account of effects that do not directly cause death. Fortunately, this realization is playing an increasing role in risk assessment.

Microorganisms are also vitally important for us humans. What consequences could residues of the pesticide have for our intestinal flora?

Some bacteria in the human intestine also use shikimate metabolism, and so they could certainly be harmed by glyphosate. Studies have shown that the product can affect the intestinal flora of mice and rats at concentrations that are assumed to be acceptable for humans. It remains unclear whether a glyphosate-induced change in intestinal flora could also potentially affect humans – and, if so, how.

Until now, it has been assumed that glyphosate had, at most, an indirect effect on insects – for example, by destroying the plants they feed on. In light of the new findings, could the product be partly responsible for the widespread decline in insect populations?

There are undoubtedly various causes for the decline in insect populations. What is clear, however, is that many insects need symbiotic bacteria to survive. I therefore fear that glyphosate could be contributing to the decline in insect numbers, and so I believe its continued use is cause for concern. However, if we want to reduce the use of pesticides, then we need to discuss alternatives such as the use of genetically modified plants. Unfortunately, rational discussions on the alternatives are currently rare.

Interview: Harald Rösch

Professor Martin Kaltenpoth is Director at the Max Planck Institute for Chemical Ecology.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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Content Authority
Dr. Christina Beck (-1276)

Editors-in-Chief
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Conceptual Advice
Sandra Teschow and Thomas Susanka
www.teschowundsusanka.de

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

Layout
GCO Medienagentur
Schaezlerstraße 17
86150 Augsburg
www.gco-agentur.de

Printing & Distribution
Vogel Druck & Medienservice GmbH
Leibnizstraße 5
97204 Höchberg

Advertising
Beatrice Rieck
Vogel Druck & Medienservice GmbH
Leibnizstraße 5
97204 Höchberg
Tel: +49 931 4600-2721
e-mail: beatrice.rieck@vogel-druck.de

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