

MAX PLANCK

Research

ECOLOGY

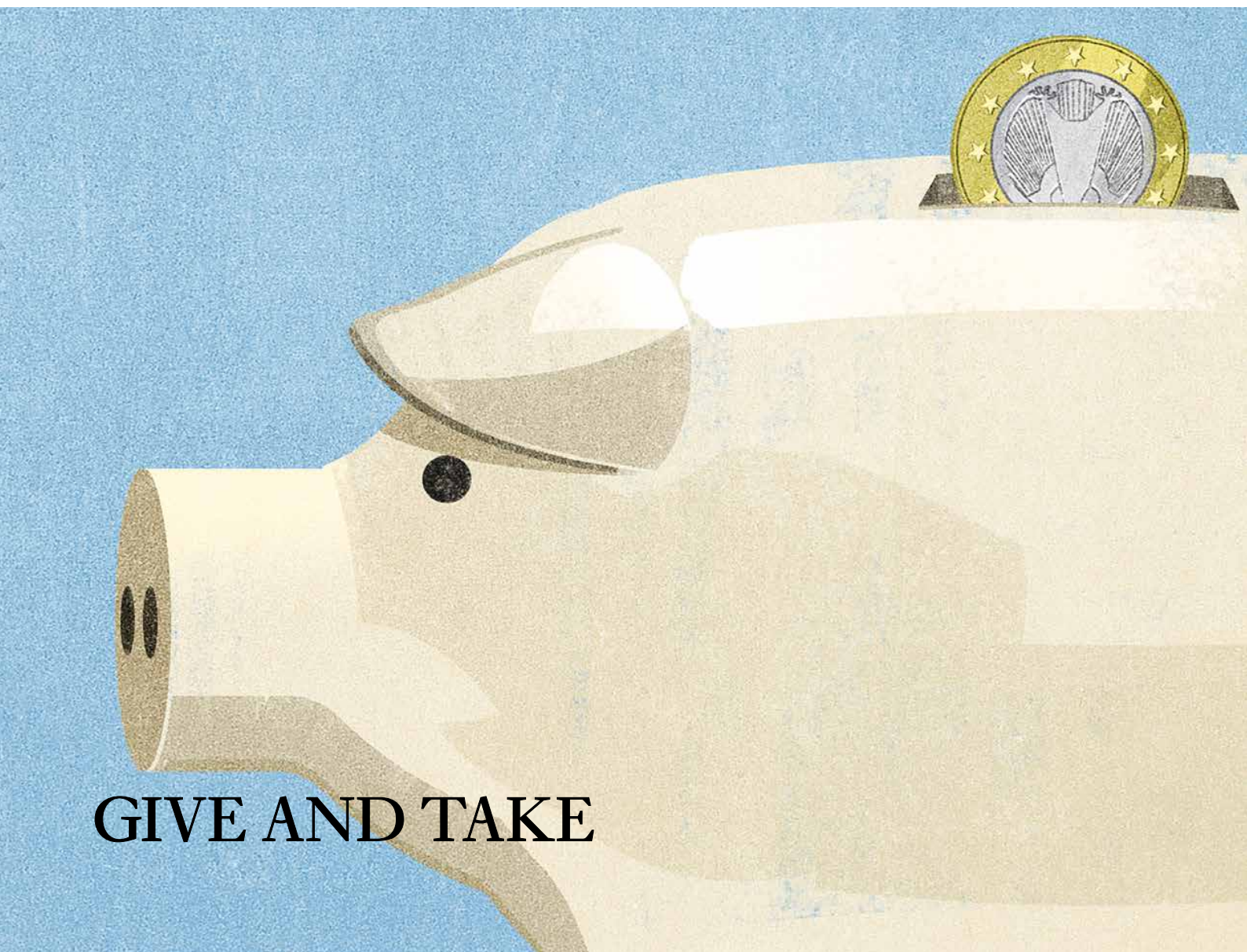
Using a tree's natural defenses

NANOCHEMISTRY

The light converters

CLIMATE RESEARCH

Risky cooling



GIVE AND TAKE



ILLUSTRATION: ALESSANDRO GOTTARDO

Save or spend?
In the corona crisis, politics in Germany have changed fundamentally, away from breaking even to taking on new debts so that money is available to support businesses and individuals who are suffering from the crisis. At the same time, the level of savings in private households has never been so high, with Germans setting aside EUR 150 billion in savings accounts. Researchers are following both developments with great interest.

EDITORIAL

Dear reader,

“To give is more blessed than to receive” – these words from the New Testament just about sum up the most important things that can be said on this subject. However, in a survey conducted by the Bertelsmann Stiftung in February of this year, 41 percent of respondents agreed with the statement “People do not care about their fellow human beings.” Then the coronavirus came along and changed everything. A wave of helpfulness has now swept the country. Neighbors have been helping neighbors, shopping services have been set up for elderly people, and regular customers have been collecting money for small stores and cafés that had to close during the lock-down. Another survey conducted in June showed that only 21 percent of respondents still believed that people do not care about their fellow human beings.

However, it is also clear that the coronavirus is deepening the social divide: people who were already disadvantaged have been hit particularly hard by the lock-down and its economic effects. This is intensifying the social inequality that had already been growing in our country for some time – a subject that we examine in greater depth in the “Focus” section of this magazine.

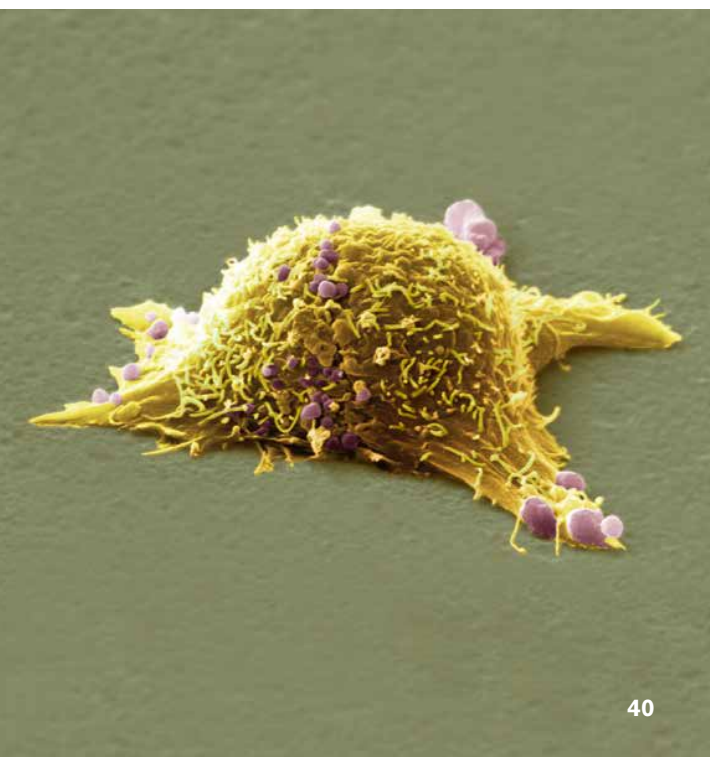
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The coronavirus crisis has also brought about astonishing changes in the relationship between the government and the economy. Over the last few decades, political leaders and their policies have disengaged from economic activities and public duties and services have been privatized. This trend now shows signs of reversing – and not only in the field of crisis management.

Covid-19 can affect anyone, but the course it takes varies widely. This has focused attention on our immune system. The immune system is also regulated by a certain give and take, a balance between the body’s ability to defend itself and the undesirable effect of the body attacking itself and developing autoimmune diseases.

On that note: stay healthy, and use your time for some exciting reading!

Your editorial team



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PHOTOS: SCIENCE PHOTO LIBRARY / STEVE GSCHMEISSNER (TOP LEFT); LARA WITTHAUT, FOTO-OSTERMANN.DE FOR MPG (TOP RIGHT); ANDREAS BÖCKLER / MPI FOR CHEMICAL ECOLOGY (BOTTOM LEFT); PICTURE ALLIANCE / ASSOCIATED PRESS | ICHIRO OHARA (BOTTOM RIGHT)

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A skin cancer cell like this one presents a challenge to the human immune system.

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Trees stand for strength and steadfastness. This is because trees can neither run nor hide from enemies. Nevertheless, trees are by no means defenseless.

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Five years ago, the arrival of thousands of refugees within a short period of time presented the administrative offices of the German municipal authorities with a huge challenge. How did they handle the situation?

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The sun sends more energy to Earth than humanity needs. Special materials are designed to put this supply to use for a whole host of purposes.

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Experts are discussing whether geo-engineering involving the targeted release of the gas could reduce global warming.

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6 **Q**uarks, leptons, photons, gluons – the world of physics features a bewildering diversity of particles – a veritable “particle zoo”. What’s more, some of these minuscule building blocks of matter occur in several different forms. One of the most abundant particles in the universe, the neutrino, exists in three types that are constantly transforming into one another in a phenomenon known as oscillation. This has wide-ranging consequences. For a long time, it was assumed that neutrinos had no mass – in other words, that they weighed nothing at all. But with absolutely no mass, oscillation between the three types of neutrino would quite simply be impossible.

Now, in order to measure the tiny mass of a neutrino, scientists have developed the most precise weighing scale in the world. Dubbed KATRIN, this scale is located at the Karlsruhe Institute of Technology (KIT) and consists of a high-precision spectrometer and an extremely strong tritium source. When this heavy variant of hydrogen undergoes radioactive decay, one electron and one neutrino are emitted. The energy released in this process is divided between the two particles – and the neutrino carries off at least as much energy as corresponds to its mass. Accordingly, the spectrometer data allows the scientists to draw conclusions about the “weight” of the neutrino.

The team led by Susanne Mertens from the Max Planck Institute for Physics is part of this international experiment. In 2019, the researchers calculated the mass of a neutrino for the very first time. The result: its mass is less than an electron volt. This is the world’s most accurate value so far, but the KATRIN scientists are certain that far greater precision can be achieved.

*THE MOST ACCURATE
WEIGHING SCALE IN THE
WORLD: THE KATRIN
EXPERIMENT IN KARLSRUHE.*



ON LOCATION



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PHOTO: MARKUS BREIG/KIT

**“It’s really amazing
how quickly
research into
CRISPR-Cas9
and its possible
applications
has developed in
recent years.”**



PHOTO: DEREK HENTHORN FOR MPG; ILLUSTRATION: HENNING BRUER



NOBEL PRIZE IN CHEMISTRY

EMMANUELLE
CHARPENTIER



CRISPR-Cas9 contains two molecules of RNA that can be combined into a single molecule. A recognition sequence matching a specific sequence on the DNA strand directs the enzyme Cas9 to the location where it should cut the strand.

With some discoveries, it seems like it will only be a matter of time before they are honored with the Nobel Prize, and the CRISPR-Cas9 gene-editing scissors were one such discovery. In early October, the time had finally come: the Royal Swedish Academy of Sciences awarded the Nobel Prize in Chemistry 2020 to Emmanuelle Charpentier for her work on CRISPR-Cas9. She shares the prize with Jennifer Doudna, a molecular biologist at the University of California, Berkeley. Charpentier is the Director of the Max Planck Unit for the Science of Pathogens in Berlin and is considered one of the world's leading experts on the infectivity and immunity of pathogenic bacteria. In the 2000s, researchers identified

CRISPR-Cas9 as an adaptive immune system that bacteria and archaea use to defend themselves from attacks by viruses. In 2011, Emmanuelle Charpentier and her research groups, who were conducting joint research at Umeå University and the University of Vienna at the time, described tracrRNA – an RNA molecule that activates the CRISPR-Cas9 system. A year later, Charpentier and Doudna published their findings describing exactly how CRISPR-Cas9 homes in on the correct location in the DNA strand and how the system can be used as a tool for modifying genetic material.

The key discoveries that paved the way for the award are therefore just nine years old. This unusually short time frame for the awarding of a Nobel Prize serves as a testament to the colossal importance of the research conducted by Emmanuelle Charpentier and Jennifer Doudna. In the ensuing period, researchers have refined CRISPR-Cas9 into a precise genetic tool that can correct defective DNA as easily as if it were a document in a word-processing program. This technique is therefore also referred to as genome editing and can be used to study a whole host of scientific questions. As the method is

also relatively straightforward in terms of its operation, it's hard to imagine laboratory work without it nowadays. However, CRISPR-Cas9 has not only revolutionized basic research, but has also become an indispensable tool in medicine, biotechnology, and agriculture. Indeed, physicians around the world are working flat out to convert the CRISPR-Cas9 technology into therapies for as-yet-untreatable diseases. Microorganisms with modified genetic material are intended to improve the efficiency of food and medicine production. And agricultural crops whose genetic material has been modified using CRISPR-Cas9 promise higher yields and greater resistance to diseases and environmental impacts.

But as with any new technology, the gene-editing scissors also involve some risks. So far, there has been barely any research into the environmental impacts of the release of genome-edited plants and animals. Moreover, the genetic modification of cells in the human germline (e.g. to create "designer babies") is highly controversial from an ethical perspective. It is up to society and political leaders to weigh up the pros and cons of genome editing and to establish a legal framework for its use.

**“The Nobel Prize
is a fitting honor
for the team
that has worked
incredibly hard
for 30 years
to make us better.”**

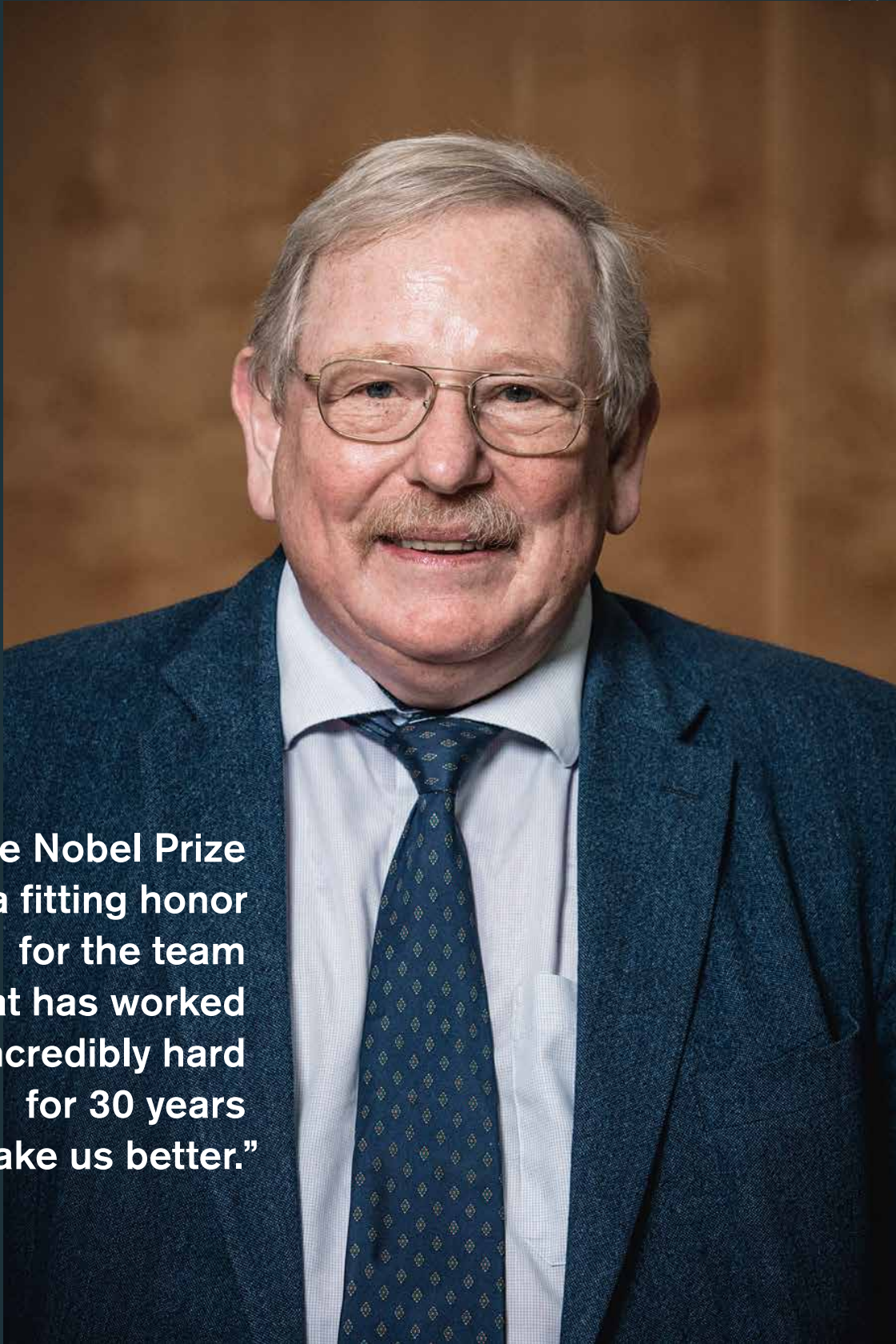


PHOTO: DEREK HENTHORN FOR MPG; ILLUSTRATION: HENNING BRUER

NOBEL PRIZE IN PHYSICS

REINHARD
GENZEL



Cosmic swarm: the black hole at the heart of the Milky Way reveals itself by the pull it exerts on nearby objects. This image shows the paths of stars as they orbit the gravitational monster at varying degrees of proximity. Reinhard Genzel and his team have worked relentlessly for many years to track the stars' movements, thereby gaining valuable astrophysical insights.

Deep in the heart of the Milky Way lurks a massive black hole. At a distance of 26,000 light-years from Earth, this behemoth is hidden behind dense curtains of gas and dust. Nevertheless, the phantom has been exposed by astronomers, chief among whom are Reinhard Genzel, Director at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, and the American researcher Andrea Ghez from the University of California. In recognition of their work, the two scientists are sharing one half of the 2020 Nobel Prize in Physics. The other half of the prize has been awarded to the British theorist Roger Penrose for his detailed mathematical description of black holes as a consequence of the general theory of relativity.

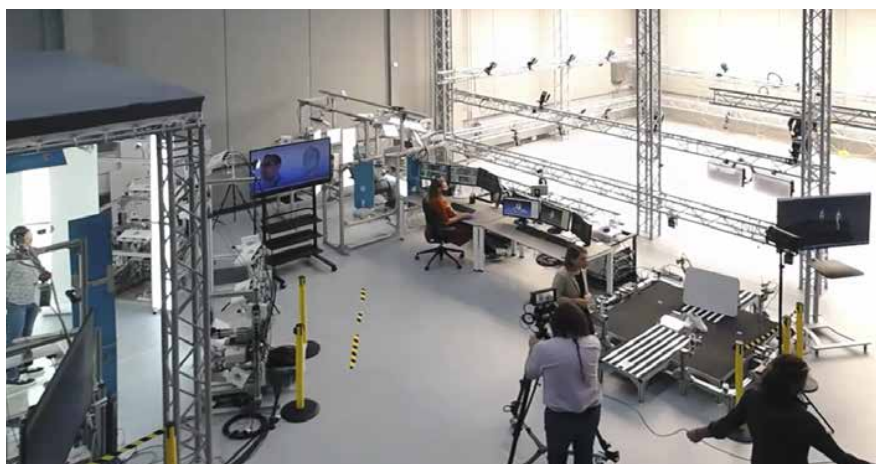
Reinhard Genzel and his group have achieved a number of groundbreaking results. For over three decades, the researchers have been using infrared instruments to study the center of our galaxy. There, they follow the movement of stars swirling around the invisible object like moths around a light. Based on these observations, the astronomers have determined the gravitational giant's mass – with a very high degree of accuracy – to be around 4.3 million solar masses. Because this mass is concentrated within a small space, the researchers believe that a black hole is the most plausible explanation.

Further studies by the team have revealed, for example, that stars in the center of the galaxy exhibit an unusual mass spectrum. Moreover, the scientists have discovered infrared flares that are thought to arise from gas close to the inner accretion disc of the black hole. Genzel's group has also found that gas is swirling around the black hole at a speed equal to 30 percent of the speed of light.

In 2018, the researchers succeeded in verifying the so-called “gravitational redshift” of a star for the first time. The light from S2, as the star is known, is stretched to

longer wavelengths by the very strong gravitational field of the black hole and therefore appears with a reddish color. This change in wavelength is exactly in line with the prediction made by Einstein's general theory of relativity. In the spring of this year, Reinhard Genzel and his colleagues published their results from another series of observations: the orbit of the star S2 does not remain stationary in space, but instead moves slowly forward – so that multiple orbits of S2 create the shape of a rosette. This is another effect that was predicted by Einstein's theory.

The astronomers made their observations using sensitive instruments such as Gravity, Sinfoni and Naco, all of which are operated at the Very Large Telescope (VLT) of the European Southern Observatory. The instruments were built under the direction of the Max Planck Institute for Extraterrestrial Physics and scan the sky in the infrared region. By combining the light from the four eight-meter mirrors within an underground laboratory, the researchers create what is known as an interferometer. This virtual telescope has a diameter of 130 meters, and its detail resolution is so precise that you could discern a one-euro coin on the moon.



THE CHANCELLOR'S VIRTUAL VISIT

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Angela Merkel wanted to form an impression of Cyber Valley, the artificial intelligence (AI) research consortium that is now Europe's largest facility in this field. The Max Planck Institute for Intelligent Systems' campuses in Tuebingen and Stuttgart play a key role in this venture. The Chancellor's visit, which she had originally intended to make in person, took the form of a one-hour video conference on October 21 and included a virtual tour, a brief overview of how Cyber Valley came into being, and information about its current research projects. The visit also included a project presentation by three of the start-ups

that have arisen from the initiative. The Chancellor appears to have been impressed. "Cyber Valley demonstrates the attractiveness of Germany as an AI location. Scientists and business leaders work hand in hand and show how excellent research can be successfully transferred to innovative applications and business models," said Merkel. Along with the Chancellor, the web conference was attended by Federal Research Minister Anja Karliczek, Baden-Wuerttemberg's Minister President Winfried Kretschmann, and Theresia Bauer, Science Minister in Kretschmann's cabinet.

Digital whistle-stop tour: Angela Merkel gained an insight into the workings of the Max Planck Institute for Intelligent Systems in Tuebingen by video.

30 YEARS OF JOINT RESEARCH

On October 3, 1990, the German Unification Treaty marked the end of the GDR and its assimilation into the Federal Republic of Germany. 30 years later, the extent to which science has benefited from this unification is readily apparent: the development of a research sphere has galvanized the scientific system throughout Germany. At the beginning of October, the Max Planck Society and eight other major scientific organizations celebrated the anniversary in a Twitter campaign with the hashtag #30Jahrevereinforschen. Video statements filmed by the founding Directors and Research Operations Coordinators hark back to turbulent times. The fall of the Berlin Wall was immediately followed by the establishment of a number of temporary research units, and the subsequent eight years saw 19 new Max Planck Institutes founded at breathtaking speed. The result was a dense network of exceptionally diverse research facilities that not only work in close cooperation with other institutions in Germany, but are also key players in international science.

AWARD-WINNING ★

SUSAN TRUMBORE

The Director of the Max Planck Institute for Biogeochemistry has been awarded the 2020 Balzan Prize for her work in the field of Earth system dynamics. The jury emphasized Trumbore's remarkable contribution to research into the carbon cycle and the critical role she played in introducing radiocarbon measurements to Earth system research. Susan Trumbore and her team have, for example, determined the great age and slow growth rates of certain tropical tree

species. They discovered that trees ensure their survival when carbon is in short supply by storing carbon for periods of up to ten years. Their research also proves that current global models are overestimating the rates at which carbon can be stored in soils. The Balzan Prize is awarded annually in alternation between the humanities and natural sciences. Half of the prize money of 750,000 Swiss francs will flow into research projects involving young scientists.



PHOTO: MPI FOR BIOGEOCHEMISTRY / ANNA SCHROLL

PHOTO: SOUTH AFRICAN RADIO ASTRONOMY OBSERVATORY (SARAO)



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Tuned in to space: the MeerKAT radio observatory currently consists of 64 telescopes, with 20 more to be added.

LISTENING TO CELESTIAL RADIO

It is the largest, most sensitive radio telescope in the southern hemisphere: 64 individual, dish-shaped antennas – each 13.5 meters in diameter – are tuned in to space from South Africa to allow researchers to investigate distant radiation outbursts with the same precision as pulsars or interstellar clouds in our own Milky Way. One of the important receiver systems for this gigantic “ear”, which goes by the name of MeerKAT, comes from

the Max Planck Institute for Radio Astronomy in Bonn. The Max Planck Society is providing a further EUR 20 million for the construction of 20 additional antennas. Max Planck President Martin Stratmann believes that the MeerKAT project is “a milestone in radio astronomy”. This branch of astronomical research uses radio waves emitted by objects in space as a means to explore the universe. Here the sensitivity of the tele-

scopes is a vital factor in the quality of the observations. Factors such as the accessibility of various celestial regions, time and frequency resolution, and the speed at which the firmament is mapped also play an important role. Thanks to its unique location in a semi-desert region of Karoo, the system is only slightly affected by terrestrial interference radiation, which means that its sensitivity can be fully utilized.

www.mpg.de/15382572

Under observation: a team in Bochum has investigated which words activate the language assistants in the networked loudspeakers produced by major manufacturers.



EAVESDROPPERS IN YOUR LIVING ROOM

It appears that networked loudspeakers with language assistants from Google, Amazon and Apple send snippets of conversation to the manufacturers more often than they should. A team from the Max Planck Institute for Cyber Security and Privacy Protection and the Ruhr-Universität Bochum has identified more than 1,000 English, German and Chinese words that unintentionally activate these language assistants and establish a connection with an Internet server. They are only supposed to react to “OK, Google”, “Alexa” and “Hey Siri”, but the networked loudspeakers were also activated by the words “OK, cool”, “on Sunday” and “daiquiri”. The systems are always listening, but only store the audio data locally for a brief time unless the applicable terms are used, prompting them to answer a question by accessing the Internet. If the systems mistakenly think they are being addressed, they transmit a brief sequence of what has been said to the respective manufacturer. The companies then search these audio segments for phonetic sequences that unintentionally start their systems – sometimes without the user’s knowledge – in order to make the speech recognition more reliable.

www.mpg.de/15183736

PHOTO: MAXIMILIAN GOLLA/MPI FOR CYBER SECURITY AND PRIVACY

A SPARKLING RING IN SPACE

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In the center of the giant galaxy Messier 87 lurks a gigantic black hole. The image of this mass monster, obtained using the Event Horizon Telescope (EHT) in 2017 and published last year, went around the world. The EHT team, which includes researchers from the Max Planck Institute for Radio Astronomy, has now analyzed a quantity of archive data, some of which have not yet been published. Observations dating from the years 2009 to 2017 show that the black hole in M 87 meets expectations: the shadow remains constant, and its diameter is consistent with the predictions set out in Einstein’s general theory of relativity for a black hole of 6.5 billion solar masses. Nevertheless, the data were hiding a surprise. This relates to a region farther away, where the shadow is surrounded by a disc of hot gas. In the EHT image, it appears as a bright ring – which over time seems to glitter. This appears to be caused by matter that falls onto the black hole, heats up to several billion degrees, and then becomes turbulent due to the presence of magnetic fields.

www.mpg.de/15424512

Snapshot images of the black hole in galaxy M 87 based on observations and geometric modeling. While all the rings are similar in diameter, the location of the most powerful radiation emission varies.

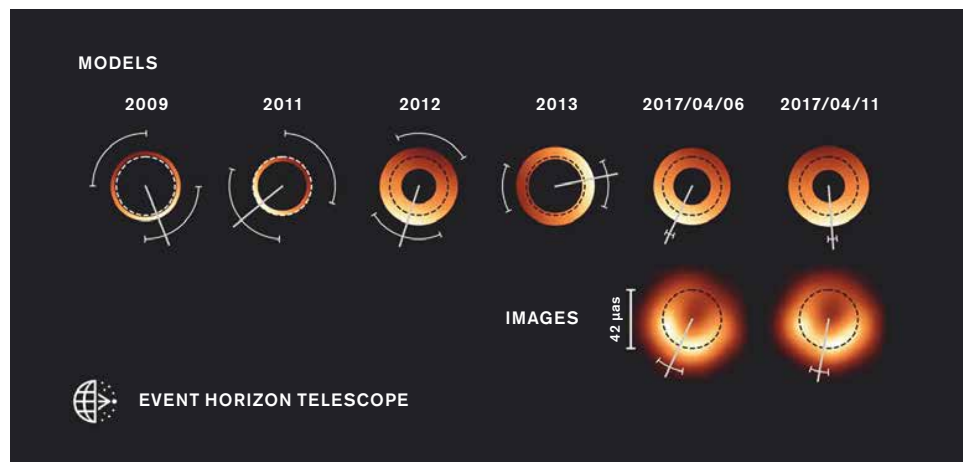


IMAGE: M. WIELGUS & EHT COLLABORATION

ANIMALS WITH A SIXTH SENSE

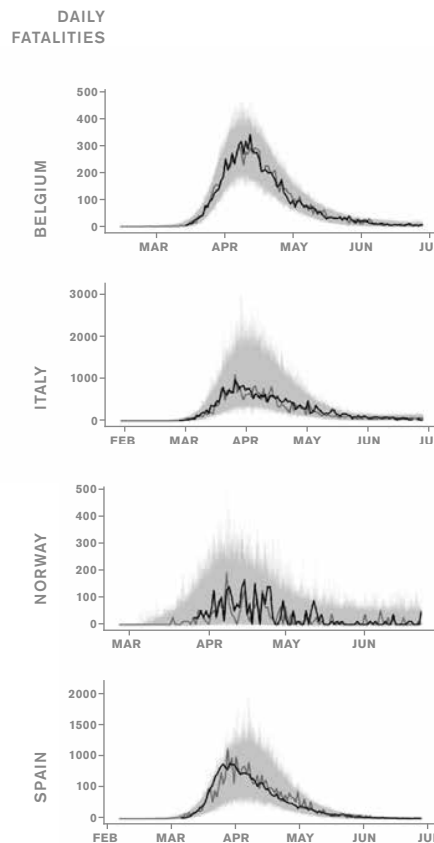
PHOTO: MPI OF ANIMAL BEHAVIOR / MACCINE / USCHI MUELLER

Throughout history, earthquakes have repeatedly wreaked havoc on humanity and wiped out entire civilizations. Even today, nobody can reliably predict when and where the next earthquake will occur. However, researchers from the Max Planck Institute of Animal Behavior and the University of Konstanz have now proved that domestic animals can detect even early signs of earthquakes. In an earthquake-prone region of Northern Italy, they fitted cattle, sheep and dogs with accelerometers and recorded their movements over several months. During this period, there were twelve earthquakes measuring four or higher on the Richter scale, as well as numerous small, barely perceptible quakes. In some cases, the researchers observed unusual behavioral patterns among the animals as early as 20 hours before a quake. Moreover, the closer the animals were to the epicenter of the impending quake, the earlier they changed their behavior. However, these behavioral changes were only statistically significant when the researchers evaluated all the animals collectively. In other words, their abilities are more easily recognized when studied collectively than when each animal is studied individually. It is still unclear how animals sense impending earthquakes. They may sense the ionization of the air caused by the intense rock pressure in earthquake zones through their fur. It is also conceivable that animals smell gases released from quartz crystals before a quake. A system that evaluates real-time data measured since December 2019 shows what an animal earthquake early warning system could look like. An alarm is triggered as soon as the sensors detect a marked increase in animal activity over periods of 45 minutes or more. This system has already issued one warning: a small quake shook the region three hours later.

www.mpg.de/15126191



A living early warning system: sensors on collars like that worn by the cow in front measure the motion profiles of farm animals and pets. Restlessness indicates that an earthquake is imminent.



Reality and simulation of the coronavirus pandemic: the black line shows the actual daily fatalities, while the dark gray line traces a single prediction. The predictions determined by the model are shown in light gray.

FLU INCREASES SUSCEPTIBILITY TO COVID-19

The flu epidemic this coming fall and winter will intensify the coronavirus pandemic. This conclusion was drawn by researchers at the Max Planck Institute for Infection Biology and the Institut Pasteur in Paris. They used a mathematical model to investigate the first months of the coronavirus pandemic in Europe and model its progression in Belgium, Norway, Italy and Spain – four European countries that experienced the pandemic with differing degrees of severity during the first half of the year. The simulations showed that the decrease in the number of Covid-19 cases in the spring was not only the result of countermeasures but also coincided with the end of the flu season. Influenza thus increased the coronavirus transmission rate by an average of 2.5 times. Based on these results, the team has concluded that flu vaccinations could reduce the risk both of influenza and of Covid-19 infection.

www.mpg.de/15373608

GRAPHICS: MPI FOR INFECTION BIOLOGY

LIVE LONGER IN SOUTHERN GERMANY

People in Baden-Wuerttemberg and southern Bavaria are most likely to live to a ripe old age. This has been shown in calculations made by Roland Rau and Carl Schmertmann from the Max Planck Institute for Demographic Research. Average life expectancy varies by more than five years in men and almost four years in women depending on the district in which they live. In the Salzland district of Saxony-Anhalt, for example, women only reach an average age of 81.8 years, while in the Starnberg region they live to be 85.7 years. There is also a marked north-south divide among the men: in Bremerhaven, they only live to be 75.8 years on average, while on the rural out-

skirts of Munich, they reach the age of 81.2 years. In all, most of the regions with lower life expectancies are located in eastern Germany. Yet even in western regions of Germany, particularly in the Ruhr district, there are areas where people are more likely to die at a younger age. According to the study, life expectancy in any given region is most affected by the unemployment rate and percentage of Hartz IV (unemployment benefit) recipients. In contrast, frequently debated factors such as average income, population density and the number of doctors per 100,000 inhabitants play a much less important role.

www.mpg.de/0320201en

COVID-19 RISK GENE COMES FROM NEAN- DERTHALS

One of the factors that influences the severity of a Covid-19 infection is the individual's genetic predisposition. Patients with a certain variant of a multi-gene cluster on chromosome 3, for example, are three times more likely to be treated in hospital and to require artificial respiration. Researchers from the Max Planck Institute for Evolutionary Anthropology in Leipzig have now discovered that the DNA sequence in these patients is similar to that in the Neanderthals. The scientists say that modern humans inherited the sequence from the Neanderthals when they interbred around 60,000 years ago. It is not yet clear why people with this gene variant are more severely affected by the disease. The risk variant is most widespread in South Asia, where around half of the population carry the Neanderthal variant in their DNA. In Europe, on the other hand, it is carried by only one in six people.

www.mpg.de/15451493

FERTILIZATION ACCELERATES CLIMATE CHANGE

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So far, too little attention has been paid to an important aspect of climate protection: agriculture also contributes significantly to the emission of greenhouse gases. The concentration of nitrous oxide (N₂O) in the atmosphere, for example, has risen at an ever-increasing rate in recent decades. According to an extensive study conducted by an international team including Sönke Zachle, Director of the Max Planck Institute for Biogeochemistry, it is now around 20 percent higher than pre-industrial levels. This is more than climate researchers had assumed in even their most pessimistic forecasts. One important factor in this increase is the growing use of nitrogen fertilizers worldwide. In Europe, however, nitrous oxide emissions from agriculture are declining because European farmers are using fertilizer more efficiently. The greenhouse effect of nitrous oxide is about 300 times stronger than that of carbon dioxide. This means that despite its relatively small proportion in the composition of the air, nitrous oxide currently contributes about seven percent to hu-

man-induced global warming. Current scenarios indicate that if the global community does not succeed in curbing the rise in nitrous oxide emissions, restrictions on emissions of other greenhouse gases will have to be tightened even more than currently planned if the agreed climate goals are to be achieved.

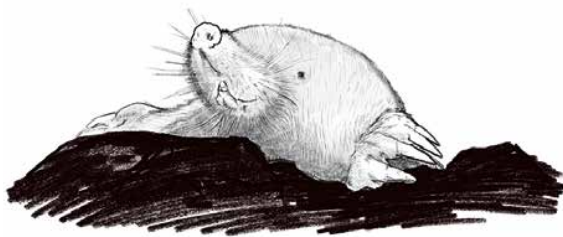
www.mpg.de/0320202en

Agriculture as a climate factor: nitrous gas emissions have risen worldwide in recent decades, primarily due to increased fertilization.



PHOTO: PICTURE ALLIANCE / DPA | ULI DECK

ILLUSTRATION: HENNING BRUER



The Iberian mole (*Talpa occidentalis*) is common in Spain and Portugal. Elevated levels of male sex hormones cause the females to develop powerful muscles and testicular tissue.

GENDER DEBATE AMONG MOLES

Moles may look cute, but they are true powerhouses and remarkably aggressive towards other members of their species. They also have an extra digit on each front paw that enables them to burrow more efficiently. Female moles have yet another anomaly: they are intersexual, i.e. they possess characteristics of both sexes, and have both ovarian and testicular tissue. The testicular tissue does not manufacture sperm, but produces almost as much testosterone as in the males. This natural “doping” helps the females burrow deep into the earth and fight for scant resources underground. Re-

searchers from the Max Planck Institute for Molecular Genetics in Berlin working with colleagues from the Charité and the Helmholtz Association have now identified the genetic sequences and mechanisms for the production of testicular tissue and male sex hormones in female Iberian moles. Regulatory sequences for the gene *CYP17A1*, which is responsible for hormone production, are for example present in triplicate. This enables the females to produce more testosterone. These findings testify to the wide spectrum of sexual phenotypes that occur in nature.

www.mpg.de/15476613

Unique diversity: the exhibit displays the skulls of various mammalian species that settled in southeast Asia 100,000 years ago as the tropical forests spread across the region.



PHOTO: JULIEN LOUYS

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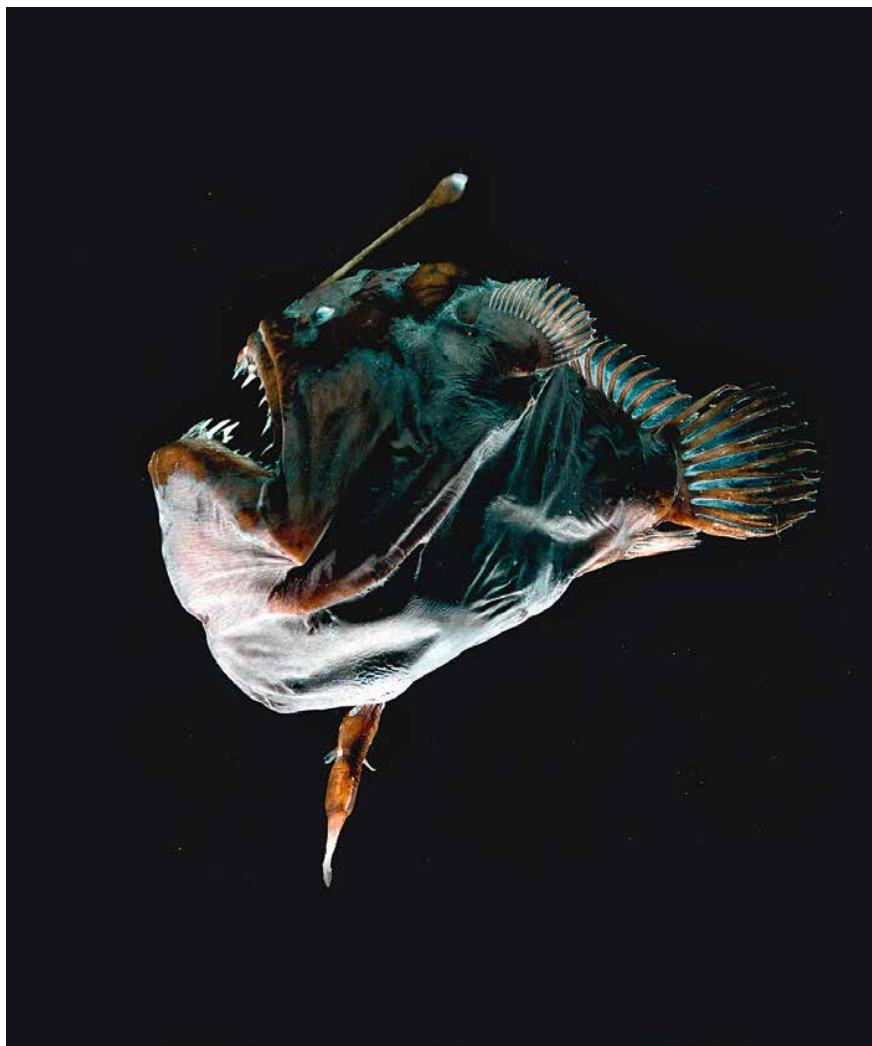
SAVANNAH INSTEAD OF TROPICAL FOREST

Southeast Asia, which is now known for its lush rainforests, was for some time covered by vast expanses of grassland. According to a study by the Max Planck Institute for the Science of Human History and the University of Griffith (Australia), during the early part of the Pleistocene era, rainforests dominated the area extending from modern-day Myanmar

to Indonesia but gradually began giving way to grassland some 1.25 million years ago. The grassland reached its maximum extent around one million years ago and became the habitat for numerous species of large grazing mammals, such as the elephant-like stegodon, which was hunted by hominins closely related to homo sapiens and thus played a significant

role in their survival. However, this change didn't last long. The rainforest began to return around 100,000 years ago, as numerous species of megafauna died out. Early humans such as *Homo erectus* were also unsuccessful in adapting to the tropical forest as a habitat.

www.mpg.de/15479583



A female specimen of the deep-sea anglerfish species *Melanocetus johnsonii* has a male fused to her belly. While the female is around eight centimeters in size, the male only grows to a length of two-and-a-half centimeters.

HOOKING UP WITH FOREIGN BODIES

Searching for the right partner is not always easy – especially if you live in the vast expanses of the deep ocean. Anglerfish have found a unique solution to this problem: once one of the tiny males has found a female, it permanently attaches itself to its much larger mate. The male's body taps into the female's bloodstream, which from then on supplies him with nutrients. Until now, it was not known how the male managed to circumvent the female's immune system, which ought to reject it as a foreign body. Researchers from the Max Planck Institute of Immunobiology and Epi-

genetics in Freiburg and the University of Washington in Seattle have now found out that the fish only use one of the two available immune defense mechanisms: they have no acquired immune response, instead protecting themselves against infection by means of enhanced innate defenses. In humans, loss of acquired immune response would lead to a fatal immunodeficiency. Knowledge of the immune system of anglerfish could help strengthen innate immunity in humans and thus help patients with immunodeficiency.

www.mpg.de/15121439

TURBO CHARGE FOR PHOTO-VOLTAICS

At present, the material of choice for solar cells is silicon, yet that could soon change. Researchers are working on replacing the element in photovoltaic components with perovskite compounds to make photovoltaic systems more efficient and cost-effective. An international team led by Stefan Weber from the Max Planck Institute for Polymer Research in Mainz has now observed that an electrical charge moves more than 50 percent faster when it is flowing parallel to the striated microstructures in perovskite crystals than when it is moving perpendicular to them. Purposeful alignment of these electron highways, known to specialists as ferroelastic twin domains, with the electrical contacts of perovskite solar cells could make the cells even more efficient. These cells are already generating energy more efficiently in the laboratory than conventional solar cells made of silicon. However, perovskite solar cells currently contain the toxic heavy metal lead, and are not yet sufficiently moisture-resistant for practical use. Scientists are attempting to remedy these defects as well.

www.mpg.de/15122989

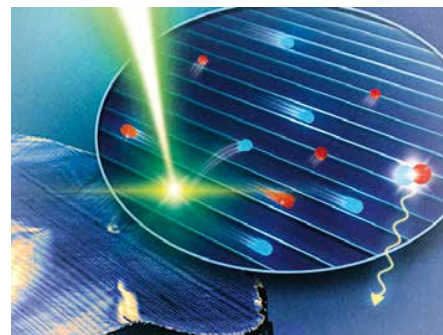


IMAGE: MPI FOR POLYMER RESEARCH

Charges generated by light are transported more quickly when they move parallel to striated microstructures in perovskite solar cells than when they are perpendicular to them.

CRYOVULCANISM ON CERES

Until around one million years ago, the dwarf planet Ceres – the largest body in the asteroid belt – was home to active ice volcanoes. Brine surged up from layers deep below the Occator Crater and erupted onto the surface. The water then evaporated and left behind bright, salty deposits. This process is probably still ongoing, albeit no longer in the form of violent eruptions. A team led by the Max Planck Institute for Solar System Research came to this conclusion after evaluating images from the American space probe Dawn. The surprising discovery thereby: the chunks in the asteroid belt are commonly believed to be simply structured, waterless, in-

active bodies, but Ceres, with a diameter of approximately 950 kilometers, turned out to be an exception. The findings indicate that remnants of a global, salty ocean are located around 40 kilometers below the Occator Crater. But why does the water rise to the surface in that area? This is probably due to the impact that once formed the crater. It caused a release of pressure, and the gases dissolved in the water and bubbled up in a manner similar to the opening of a champagne bottle. However, researchers are still puzzled as to why the water has remained liquid and relatively warm to this day.

www.mpg.de/15256170

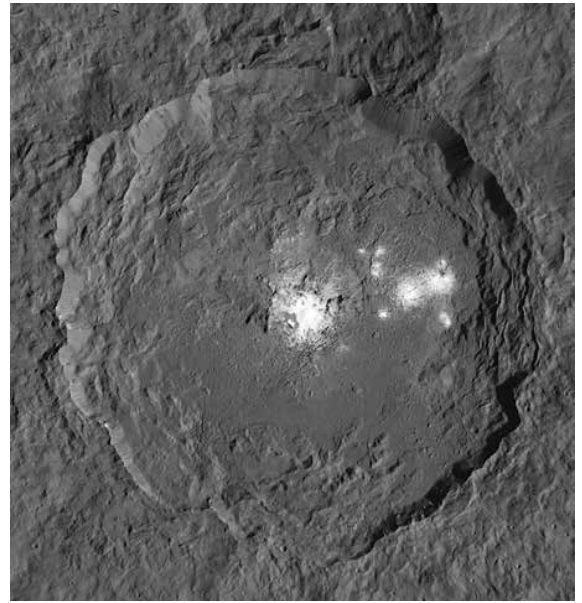
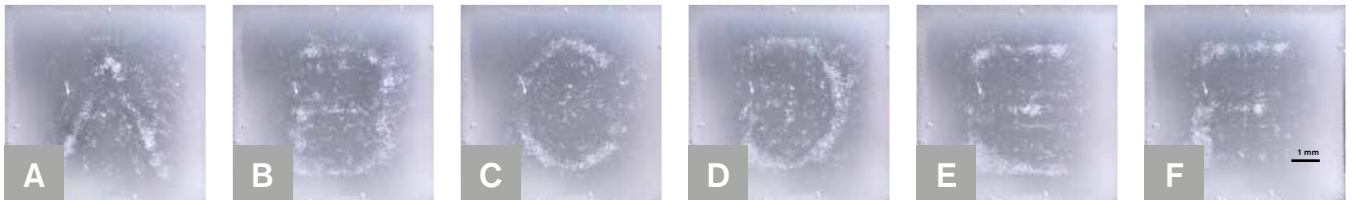


PHOTO: NASA / JPL-CALTECH / UCLA / MAX PLANCK INSTITUTE FOR SOLAR SYSTEM STUDIES / GERMAN AEROSPACE CENTER / IDA / PLANETARY SCIENCE INSTITUTE

A long history: brine erupting from deep within the dwarf planet Ceres over millions of years gave the Occator Crater its modern-day shape.



A slide show with ultrasound: researchers in Stuttgart are making ultrasound profiles visible by using sound pressure to capture microparticles. This enables them to write the alphabet using microparticles and sound, for example.

USING ULTRASOUND TO FIGHT TUMORS

Ultrasound is widely utilized as a diagnostic tool in medicine and can also be used to treat tumors. In doing so, the diseased tissue is specifically targeted and heated to destroy the cancer cells. The sound pressure profile has to be precisely shaped to avoid damaging healthy tissue. Researchers worldwide are using ultrasound to combat tumors and other pathological changes, for example in the brain. This is more difficult in the brain, since the cranium distorts the sound wave. A team from the Max Planck

Institute for Intelligent Systems and the University of Stuttgart has now developed a projector that can flexibly model three-dimensional ultrasonic fields with comparatively little technical effort, while forming more intensive sound pressure profiles with higher resolutions than is possible with the technology commonly used at present. For this purpose, the team has constructed a chip with 10,000 individually-controlled electrodes upon which they can electrolytically produce any desired pattern of hydro-

gen bubbles within a thin film of water. The gas bubbles block the ultrasonic waves, which means that the bubble pattern serves as a mask for the ultrasound. This means that when an ultrasonic wave passes through a chip that is partially covered with gas bubbles, a corresponding ultrasound profile is created. The bubbles can easily be removed and a new pattern generated. In the future, this could make it easier to tailor ultrasound profiles to individual patients.

www.mpg.de/15488241

GLOBAL MIGRATION AND THE “GREAT RESHAPING”

The future of societies worldwide is currently being reshaped at a fundamental level by concurrent crises: the coronavirus pandemic, the resulting economic recession and climate change. Steven Vertovec considers how these three crises are seriously affecting global migration. He describes the complex factors that relate to global migration and outlines the challenges that loom ahead.

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National politics, international institutions, legal parameters and economic structures and social practices are already undergoing a process of fundamental change today. Until now, migration has been an important driver of economic vitality, social transition and political changes all over the world. However, the pandemic has had a hugely negative impact on global migration. Now that borders are largely closed and economies are constrained, millions of migrants have been made destitute. As key workers, many migrants are disproportionately exposed to the risk of infection with Covid-19 in hospitals and care homes, food factories and agricultural businesses. Whether or not they are seen as being highly skilled or low skilled, currently migrants all over the world are also particularly affected by job losses.

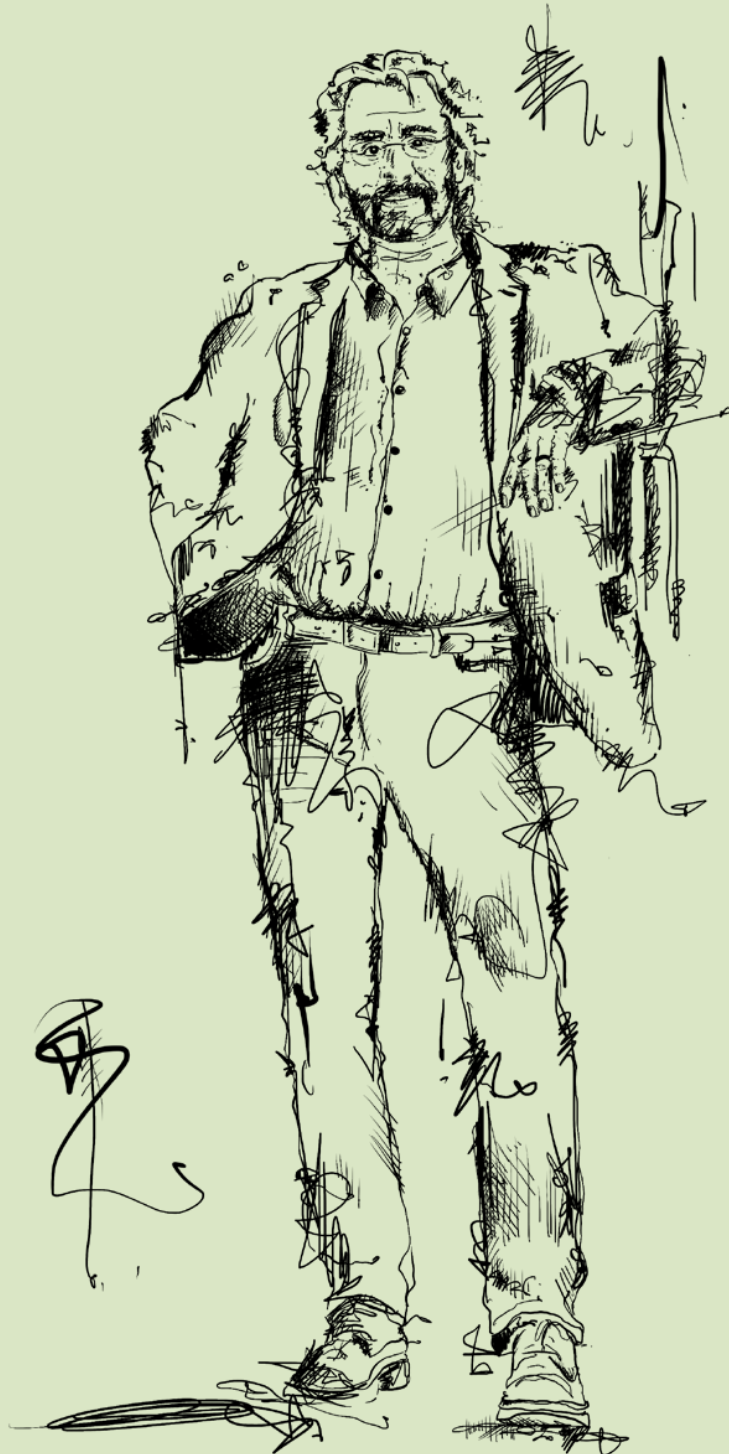
At the same time, national politics, international institutions, legal and economic structures and social practices are already undergoing a process of fundamental change. As a result of the pandemic, the International Monetary Fund, the World Bank and the European Union all forecast the worst economic breakdown since the Great Depression. In fact, this breakdown has already started. A reduction in demand for goods and services, the interruption of supply chains and the resulting bankruptcy among businesses are all leading to large scale unemployment. The recession is also taking its toll in the developing countries. Before the outbreak of Covid-19, the amount of money transferred by migrants to their home countries totaled more than USD 554 billion. That corresponds to triple the amount of money contributed

→

VIEW POINT

STEVEN VERTOVEC

ILLUSTRATION: SOPHIE KETTERER



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Steven Vertovec, who is from the U.S., studied anthropology and religious science. He gained his doctorate at the University of Oxford, where he eventually became Professor for Transnational Anthropology and the Director of the Centre for Migration, Policy and Society. In 2007, he was appointed Director at the Max Planck Institute for the Study of Religious and Ethnic Diversity in Goettingen. He has worked as an expert and an adviser on migration issues on behalf of various British ministries, the World Bank, the European Commission, the G8 and UNESCO. His core theories on migration are reflected in his concept of “superdiversity”, which describes the growing complexity of many societies around the world.

by the industrial nations as development aid. These transfers have already decreased by 20 percent, and further reductions will follow. For dozens of countries and countless households, this money is essential in order to survive. Now that these payments are being reduced, a large number of people will inevitably fall into extreme poverty

The climate crisis will have significantly worse and more far-reaching consequences on global migration than the pandemic and economic crisis. The Intergovernmental Panel for Climate Change assumes that by 2050, global warming will be at least 1.5 degrees above pre-industrial levels, and possibly even higher (particularly in certain regions). Both “rapid” changes are expected, such as extreme weather events and flooding, as well as “slow” changes through ongoing droughts, a rise in sea levels and a decrease in the supply of food and clean water. Estimates of how many “climate migrants” will be created as a result vary widely. The International Organization for Migration estimates that by 2050, between 200 million and one billion people will have to leave their homes due to the climate crisis.

**MIGRATION IS
A HOUSEHOLD
STRATEGY:
ONE MEMBER
LEAVES HOME
IN ORDER TO
SUPPORT THE
OTHERS FROM
FAR AWAY**

Before the pandemic, there were around 272 million migrants worldwide (or 3.5 percent of the total global population). We know from research that migration is never a question of obvious push-and-pull factors or clear differentiations between voluntary and enforced migration. When viewed as a system, migration is so multi-faceted that it makes sense to apply complexity theories used in mathematics and physics. Important factors here are the growing number of migrants and their increasing differentiation with regard to age, gender, level of education, nationality and legal status. These features are increasingly interacting and mixing, creating emergent new systems. All this leads to unforeseeable processes and unpredictable chains of events.

The reasons why people are leaving their home countries also vary widely. Instead of the simple concept that persecution leads to “refugees” and poverty leads to “economic migrants”, we have to understand that migration always has several causes that are interwoven. Among others, these include political reasons, such as when a state riddled with corruption, suppression and violence, failing to provide for its people. Other causes are of a social nature, such as the desire for education, health and wellbeing, or the causes may also be economic and demographic, arising from increasing competition for resources due to a growth in the population, for example. Finally,

there are ecological reasons for migration, such as destruction of the environment and climate-related disasters. All of these causes are interdependent, continuously reinforcing and compounding each other.

Migration only rarely entails the movement of entire groups of people (for example due to wars or flooding). Instead, it is usually a strategy employed by an individual household, from which one or more members move away in order to gain access to resources with which they can support those who have stayed behind. For people in rural areas, the first step can be moving to a city, while migration to a neighboring country is often the next option; long-distance international migration is a more radical, though often

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necessary, option. In all cases, economic resources are an essential requirement for people who decide to migrate. For this reason, the people who migrate from a country are not usually the absolute poorest, unless they are forced to leave.

Among those who migrate to another country, the destination, mode of travel and the conditions under which they leave are determined by several factors. So-called regular channels involve numerous immigration regulations and visa programs that apply to the individual states, with complex preconditions that have to be met in each case. Programs for uniting families make it easier in different ways for relatives to follow on. By constantly experimenting with migration regulations, governments have attempted to meet the demands of employers and to control public opinion. Migration that occurs beyond the framework of immigration measures and employment migration measures is termed "irregular". The lack of opportunities for international migration via regular channels often leads to exploitation by people smugglers. Refugees are defined as people who are officially recognized as being persecuted and in need of protection. Generally, migration channels tend to correspond to specific combinations of nationality, ethnic origin, religion, age, gender, education and class. Over the past 30 years, the configurations of these characteristics

of migrating populations worldwide have changed considerably, creating a condition of "superdiversity" that is markedly more complex than social structures of the past.

After a migrant arrives in a destination country, what happens next depends on yet another series of influences. There is no uniform "integration" process. Rather, integration is a broad concept referring to an array of areas: the labor market, housing, language acquisition, education, legal administration, every-



day interactions, social services and healthcare. One's ability to participate in each of these areas often depends on factors including legal status, linguistic competence, age, gender, work skills, social networks, and education levels.

As part of the Max Planck Society research initiative on migration, integration and exclusion, we have learned that the “integration” of those migrants who came to Germany during the mass migration of 2015/16 was dependent on the interplay of elements, including asylum policies, adjustments in the law, municipal and civil reactions, discrete approaches of local authorities and migrants' own needs and resources. Minor contextual differences, such as administrative structure, type of accommodation, or even the specific town or city to where an asylum-seeker was sent, led to fundamental differences in the procedure, speed and success of a person's “integration”.

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WHEN WEALTHY
COUNTRIES
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AND THE LEVEL
OF HARDSHIP
GROWS

The fact that national policies, legal frameworks and economic structures are currently undergoing a process of fundamental change will influence all these elements and processes surrounding global migration, likely limiting opportunities for migrants. The pandemic has already led to numerous restrictions on international mobility. Covid-19 and the risk of future pandemics have led to specific measures designed to limit the risk of infection and restrict cross-border migration. The economic crisis will lead to high levels of unemployment, which in turn will decrease demands for imported labor, and possibly also reduce the level of public acceptance of economic migrants. In developing countries of the global South in particular, the climate crisis will lead to insufferable conditions, which will cause a further deterioration of the economic situation and further intensify the complex causes of migration. The decline of agriculture and fishing will lead to a wave of migration to cities, which will in turn create enormous social, economic and ecological strain. While some countries might promote migration as a kind of pressure valve, others, particularly those that are currently considered to be fragile, might collapse, triggering mass displacement.

Some international observers are calling for a special status for “climate refugees”. However, this looks highly unlikely. Since there is a wide range of reasons why people migrate due to climate change, it will be very difficult to develop a specific concept of refugee “protection”. Also, however the term “climate refugees” is defined, there will be far too many of them for the world

to be able to meet their needs. A vicious circle is looming: the more the wealthy countries try to limit global migration, the more money transfers to poor countries will decrease. This in turn will increase the level of hardship among the people in those countries in which ecological, economic, social and political conditions are steadily worsening. This will lead to the desperate need for even more migration. What can we do?

ONE ANSWER
COULD BE
TEMPORARY
CIRCULAR
MIGRATION
PROGRAMS

We need political decision-makers to start developing future-oriented ideas now. The standard approach of considering problems in isolation and then offering conventional, short-term solutions must be abandoned. Instead, systemic, complexity-oriented research, assessments and answers are needed. Despite a number of different ideas (including the “Global Compacts”), there is no international system for regulating migration. One possible coordinated, multi-faceted answer could be the establishment of new, large-scale, more comprehensive cooperation programs for temporary, circular migration between developing and wealthy countries. Such programs already exist, such as the Canadian program for seasonal agricultural workers. In the receiving countries, these programs offer important sectors (for instance, care work, agriculture and construction) the workers they will still significantly need

despite the great reshaping, as well as money transfers for the families of migrants and foreign capital for their countries of origin. Due to their temporary nature, programs such as these are often more acceptable to the members of the host country. An integrated set of new technologies could make it easier to administer, safeguard and “healthproof” such programs. These include technologies for data processing and screening for competence and disease, as well as for monitoring working conditions, facilitating return travel home and providing international money transfers and investments. If they are introduced on a large scale, bilaterally or even globally, these time-limited, circular migration programs could offer many advantages that might help alleviate some of the effects of the three crises – the pandemic, economic depression and climate change.

This “great reshaping” marks the beginning of a new age that presents us with urgent and momentous challenges. Global migration should not be regarded as part of the problem, but as an opportunity to take remedial action.



FOCUS

GIVE AND TAKE

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ILLUSTRATION: ALESSANDRO GOTTARDO FÜR MPG



UNDERESTIMATED INEQUALITY

TEXT: RALF GRÖTKER

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Despite the fact that social inequities are increasing, no broad alliance for a greater redistribution of income and wealth has emerged in democratic countries. Lisa Windsteiger, Andrea Martinangeli and Marco Serena are conducting research into the reasons for this at the Max Planck Institute for Tax Law and Public Finance. They are also studying the ways in which immigration and poverty influence people's attitudes towards state intervention.



Andrea Martinangeli, Lisa Windsteiger and Marco Serena (from left) are researching social inequality issues at the Max Planck Institute for Tax Law and Public Finance.

“The higher one’s personal income, the higher one presumes the average income to be.”

LISA WINDSTEIGER

The gap between rich and poor has been widening for a long time. The same trajectory was observable in all industrialized countries throughout the entire 20th century. Even before the First World War, the incomes of the richest – as well as their share of the total national income – had already reached peak values. The two world wars were followed by a phase of realignment and equalization, but the highest earnings soon began to rise again, more or less benefiting from the momentum of the downward trend, once again reverting to the conditions of the early 20th century. The richest ten percent of the German population currently owns 67 percent of the country’s assets, and more than half of these – i.e. 35 percent of the country’s total assets – are owned by just one percent of the population. In contrast, the poorer fifty percent of Germans have just 1.4 percent of their nation’s total assets at their disposal.

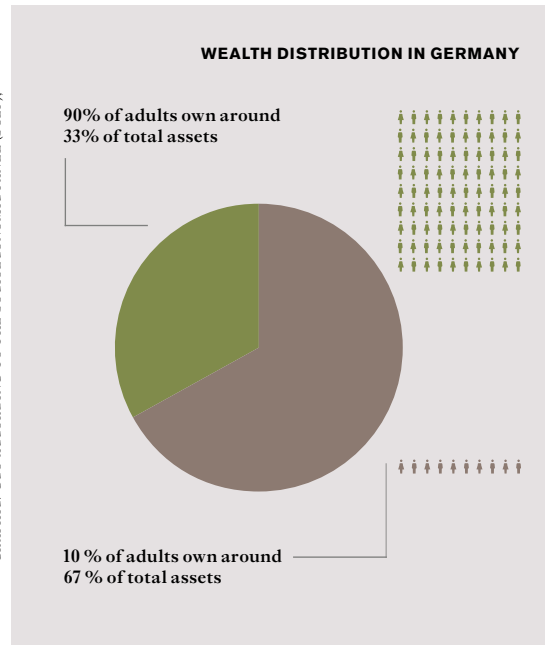
A majority opposes the inheritance tax

How are such conditions possible in a democracy? Should we not expect the less affluent majority to come together to demand higher taxes from the rich and to distribute a greater proportion of public funds to those on the losing side in terms of income and wealth distribution? Lisa Windsteiger, an economist at the Max Planck Institute for Tax Law and Public Finance, cites the “demand for redistribution” as one explanation for the fact that even a functioning democracy offers no guarantees against inequalities in income and wealth. Knowledge and the lack of it plays a role in this context. According to recent surveys, for example, around seventy percent of Germans generally consider the inheritance tax (which is rather low in this country) to be unfair. Yet, the fact is that, if one assumes two heirs per tax case, only one in thirteen inheritances is actually taxable, which means that the vast majority of Germans are not subject to the inheritance tax. And yet a political majority has not formed in favor of inheritance tax reform, which would require wealthy heirs in particular to pay a lot more.

However, Windsteiger finds how people react when confronted with certain issues more important than what people know or don’t know. “We generally assume that people’s preferences or value-based attitudes are essentially constant and don’t change in relation to the prevailing situation,” she says. “However, people do adapt their behavior under certain circumstances – when certain issues come to their attention, they suddenly agree with different statements about redistribution than before, while rejecting others. We refer to this as ‘demand for redistribution.’”

Windsteiger conducts survey-based experiments to research this demand for redistribution, often in colla-

boration with her colleague Andrea Martinangeli. “We present test subjects with very specific issues in these experiments,” she explains. “For example, we show them short teaser videos in which already known facts are presented about such things as immigration or poverty.” Their hypothesis is that the effect observed when already familiar topics are tested serves as an indicator of the effect a dominant media topic will have on the public over an extended period.



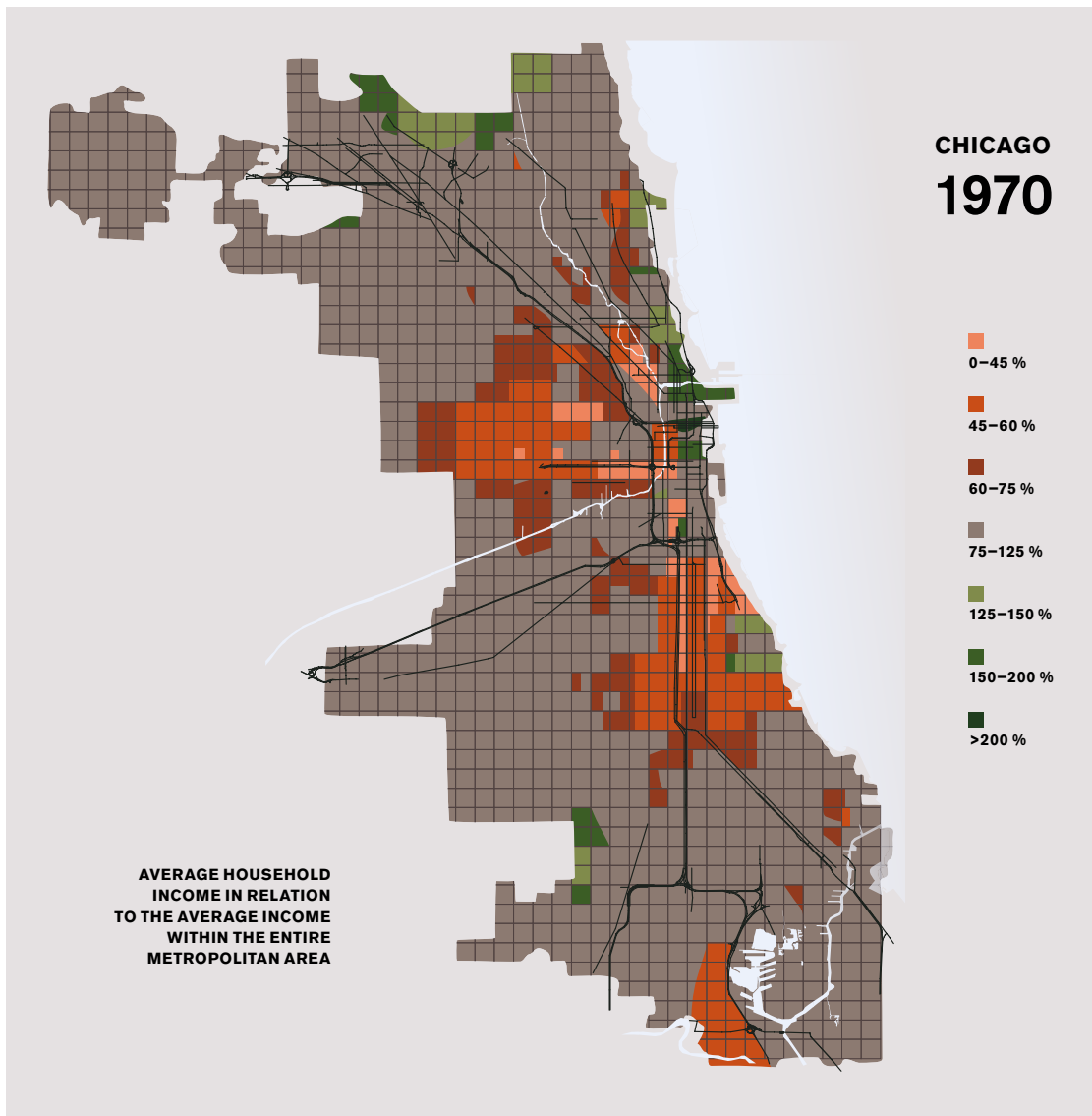
These experiments are conducted via an online platform. Between two and four thousand test subjects are invited to participate per experiment, and all have voluntarily registered with a commercial survey panel provider. Windsteiger explains: “Although we pay more than the statutory minimum wage for completing a survey that takes about a quarter of an hour, these clearly aren’t people who do this kind of thing full-time. I myself, for example, am registered with a survey panel provider and get inquiries every now and then. I not only do this because I’m interested in how others structure their surveys, but also because they often involve political issues on which I would like to voice an opinion.”

The influence of social isolation

Step by step, Windsteiger tests various hypotheses that are partly based upon one another, and for which she has usually already developed mathematical models. What influence does social isolation (i.e. when people interact exclusively with others of a similar social standing) have on opinions about redistribution? What effect does the degree of homogeneity have within



PHOTO: STEFANIE AUMILLER FÜR MPG



these isolated social pockets? How does thinking about such issues as immigration or poverty change the demand for redistribution? In addition to surveys, laboratory experiments are carried out at the Institute's premises in Munich involving a smaller number of participants (mostly students), who use computers to play through situations that primarily focus on interaction. As Windsteiger explains: "In this kind of setting one can, for example, closely study how a participant's expectations of another person can change in certain situations."

Isolation, for example: increasing inequality is often accompanied by an equal increase in socio-economic isolation – "segregation" – which is particularly evident in relation to the gentrification of urban districts. A survey-based experiment was carried out to identify the causes and effects in this context. The basic hypotheses (which were set out in a mathematical model) were

that people misjudge their own position on the wealth and income scale and therefore hold a distorted view of the extent to which others have significantly more or fewer resources at their disposal, and that the prevailing level of homogeneity within such isolated social bubbles increases those distortions. What the survey experiment showed was that the higher one's own income is, the higher the average income of others is assumed to be. In relative terms, people earning a lower income underestimated the average national income to an even greater extent. As a result, their expectations of the additional income they could personally gain through social redistribution are probably lower than what could actually be achieved. The experiment also showed that the greater one's own social isolation, the more distorted one's perception of the income of others is (and thus of one's own position on the income scale). This effect also leads to division into rich and poor: the example of Chicago shows that people are increasingly

CHICAGO
2012

GRAPHIC: GCO ACCORDING TO DANIEL HERTZ

Division into rich and poor: the example of Chicago shows that people are increasingly congregating in certain residential districts according to their income levels, which promotes the formation of isolated social bubbles.

congregating in certain residential districts according to their income levels, which promotes the formation of isolated social bubbles. The conclusion that a consequence of isolated social bubbles is that people who earn less, in relative terms, underestimate the gap that separates them from the wealthy. As a result, their expectations of the additional income they could personally gain through social redistribution are probably lower than the actual reality.

Contrasting reactions to controversial topics

Immigration and poverty are another set of issues, in relation to which several different initial hypotheses were posited. One of them is that higher levels of ethnic diversity due to increased immigration causes non-im-

migrants to withdraw their support for redistribution and aid programs for the socially deprived. The reason: long-term residents suspect that the immigrants – with whom they themselves feel little social affinity – benefit most from the relevant services. Another hypothesis is that while immigrants are certainly viewed as competitors by population groups who themselves are in the low-wage sector, they nevertheless favor redistribution, as this competition may well put them in a situation in which they themselves might need social support. On the other hand, higher wage earners are more likely to withdraw support for such programs because, as net contributors to the social security system, they worry that their burden will increase.

The results of the survey experiments partially confirm these hypotheses. When confronted with the issue of immigration, lower wage earners actually respond by increasing their demands for (progressive) tax in-



“When the number of disadvantaged people becomes too great, the tendency is towards less redistribution.”

MARCO SERENA

increases, whereas middle-class income groups reduce their demands under the same conditions. High income earners – show no reaction. When confronted with the issue of poverty, none of the groups showed any change whatsoever in the demand for progressive taxation. On the whole, however, the issue of poverty has a positive effect on another factor – the demand for public expenditures on education. But a more detailed analysis shows that this effect is due solely to the behavior of the middle income groups. Low wage earners, on the other hand, withdraw their support for spending on public education when confronted with the issue of immigration.

A simulated Matthew effect

Deriving clear policy advice from these observations is difficult. Instead, the results reveal how complex the situation is. Should a party with a social redistribution agenda more openly broach the issues of poverty or immigration, or not? “What our results show,” says Windsteiger, “is that different voter groups often react very differently, even in opposite ways, to specific thematic messages.” But, she adds, this does not make strategic issue management impossible. “To be able to predict the impact that specific effects will have on the whole, it is necessary to understand them very precisely.” The behavioral experiments conducted at the Institute of Tax Law and Public Finance provide the foundation for this.

The economic causes of increasing inequality include globalization, technological change, and, above all, the Matthew effect of accumulated advantage, i.e., the concept that “the rich get richer”, rather like the Bible quotation: “Whosoever hath, to him shall be given.” The non-economic causes of increasing inequality include limited mobility within the labor market, self-isolating elites and, in terms of income, the self-reinforcing tendencies in remuneration practices, especially

within senior management circles. The role of politics in all of this is in dispute. Inequality increased in virtually all industrialized nations, not after, but before conservative governments had come to power and had begun to reduce redistribution. There is something else that suggests that the role of politics is rather less dominant: using game theory, Marco Serena – like Lisa Windsteiger a Research Fellow at the Max Planck Institute in Munich – conducted research into how inequality can influence elections. He reached the perhaps surprising conclusion that, rather than it being a larger percentage of financially disadvantaged citizens who vote in favor of greater redistribution, on the contrary, election results tend towards less redistribution when the group of disadvantaged people exceeds a certain size.

This effect can be best explained by using a highly simplified example. Peter, Marie and Sabine differ in terms of wealth. While Sabine has four gold pieces, Peter and Marie have just one each. An election is being held, in which a decision on redistribution of gold will be made. In the event of a tie, the decision will be made by flipping a coin. All three are now considering whether it is worth the effort to sacrifice their free time on a Sunday to go to the polling station, which results in a complex nexus of mutual expectations and possible outcomes. If all three go to the polls, Peter and Marie will gain the majority and will be able to enforce redistribution, as a result of which each of the three would have two gold pieces, i.e. Sabine would lose two gold pieces, whereas Peter and Marie would each gain one gold piece. Peter and Marie are thinking that, based on this probable outcome, Sabine may not even take part in the election, although she stands to lose more than either of them could win. In this case, however, it would be sufficient for only one of them, Peter or Marie, to cast a vote for both to receive one gold piece. However, the problem is that, if both think the same way and neither Peter nor Marie go to the polls, there will be no redistribution as Sabine may anticipate their strategic considerations and, therefore, be sure to go to the polls herself. Even this simple example involving only three people shows that accurately modeling possible scenarios – which in turn have an effect on mutual behavioral expectations and therefore on voter participation – is no trivial matter. It is now possible to use the model developed by Marco Serena to precisely track the effect that group size and wealth disparity have on an election’s outcome. “Mathematically, the most dif-

SUMMARY

The social exclusion of income groups in society means that people underestimate the real average income and therefore also the impact of redistribution.

Topics that are covered by the media, such as the immigration of refugees, leads to an increase in support for redistribution in poorer groups of the population, while decreasing among the middle classes.

A game-theoretic simulation shows for small groups that redistribution tends to be supported during elections when the number of poor does not exceed the number of rich to a very high degree.

ficult thing was to represent the asymmetrical benefit,” Serena explains. “This leads to several tipping points, at which the situation changes in favor of either the haves or the have-nots.”

Rule of thumb for small groups

Summing up his innovation, Serena explains that “This is in fact the first model capable of mathematically predicting the conditions under which those voters in an unequal group (who are among the have-nots but are in the majority) would have no incentive to vote.” In real terms, the model analyzes election processes based on the majority voting system in relatively small groups, such as a supervisory board. The reason: it is only in such smaller groups that voters can expect their votes to make a difference. “In municipal or national elections,” says Serena, “people tend to vote because they feel a moral obligation to do so or because they wish to express their political beliefs in some way.” In this context, specific expected benefits cannot be calculated, as

the probability that a single vote changes the election’s outcome is negligible.

However, a rule of thumb can be derived for smaller groups based on Serena’s model: redistribution would take place only if the number of have-nots were smaller than the number of rich people squared. So if there were ten rich people in a village and less than a hundred poor people, there would be a good chance that the mayor would be permitted to redistribute the tax revenues. But no redistribution would take place if there were exactly one hundred or more poor voters. Serena’s summary of this methodological approach is also applicable to the work of the other two researchers: “We are focusing on a single effect, which could plausibly play a role in the overall event. We are not claiming that there are no other effects. But if we had models for all of the effects that have a bearing on a situation, we’d be able to create an overall model that would make very far-reaching predictions.”

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ADVERT



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Die DUZ hat in den letzten Jahren einen bedeutenden Beitrag zur Professionalisierung des Hochschul- und Wissenschaftsmanagements

geleistet. Ihr gelingt es immer wieder, aktuelle Handlungsbedarfe zu identifizieren und praxistaugliche Lösungsansätze zu präsentieren. Das findet sich in dieser Form in keinem anderen mir bekannten Medium.

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Prof. Dr. Frank Ziegele
Geschäftsführer des CHE Centrum für Hochschulentwicklung und Professor für Hochschul- und Wissenschaftsmanagement an der Hochschule Osnabrück

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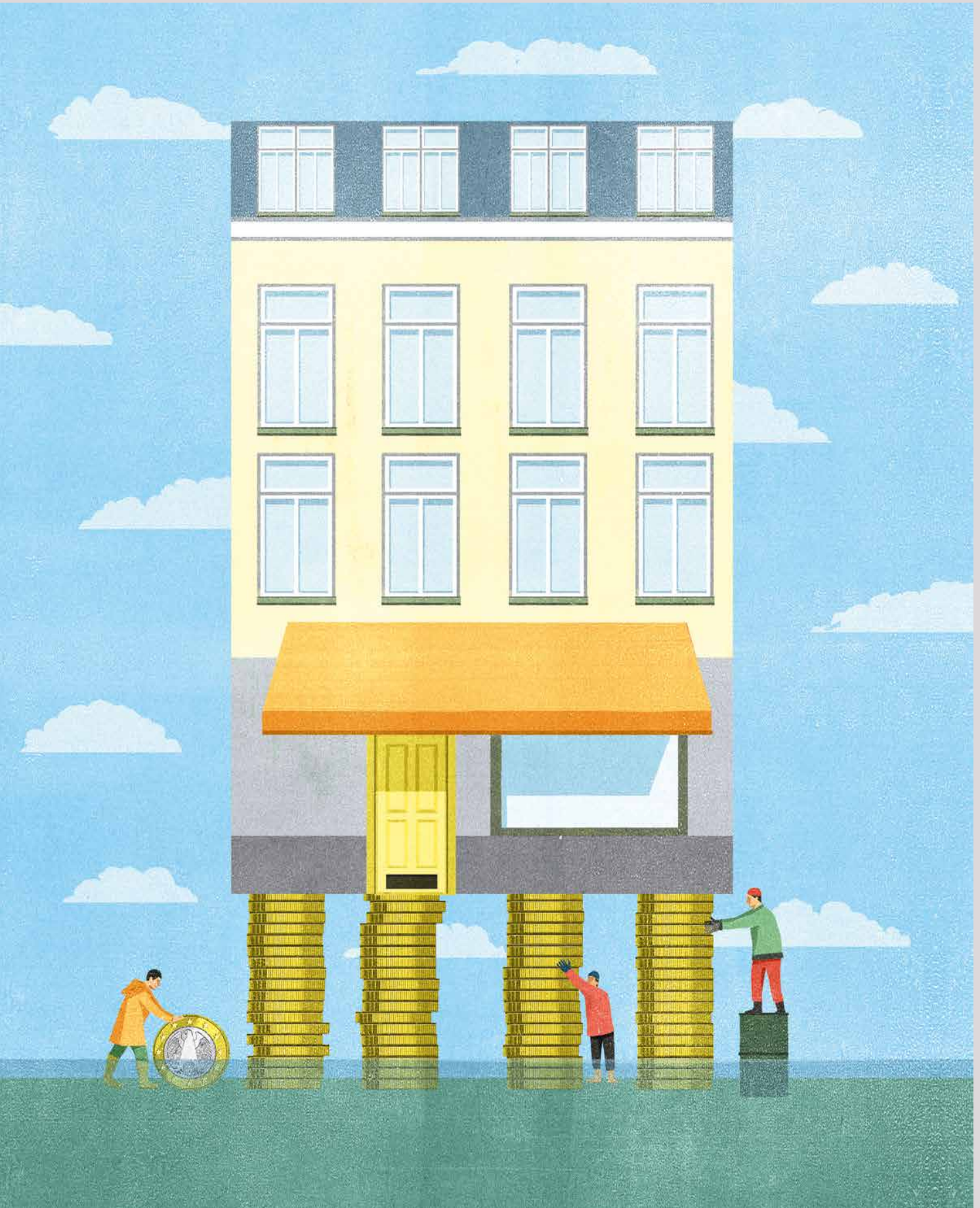
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NOT JUST IN TIMES OF CRISIS

TEXT:
WOLFGANG MULKE

Leon Wansleben, a sociologist at the Max Planck Institute for the Study of Societies in Cologne, takes an analytical look at the state's economic and financial activities. It appears that, rather than leaving everything to the market, the state has begun playing an active role in economic policy.



Certain dyed-in-the-wool market economists are currently rubbing their eyes in disbelief. The state is doing everything possible to counter the economic consequences of the Covid-19 crisis. Public authorities are even investing directly in private companies, something that was barely conceivable in recent decades.

“For many years,” as Leon Wansleben, a sociologist at the Max Planck Institute for the Study of Societies explains, “governments around the world have been vigorously supporting markets while cutting back on the public sector.” Now, he goes on, we are seeing the direct opposite – the state has become very active in fiscal matters. For example, it is counteracting the current crisis by taking on a heavy national debt load. “This process is particularly evident in relation to the Covid-19 crisis,” says Wansleben. The 38-year-old researcher has been head of the “Sociology of Public Finances and Debt” research group at the Max Planck Institute in Cologne since 2019. There are still many unanswered questions in this field: what influences state economic policy, and who are the ones taking action? Which rationale are they following, and which interests and concepts are playing a role in the background?

The merging of markets and the state

Among other things, the research group is devoted to examining economic sociology and, according to the group’s thesis, the traditional, ideal-typical notions about the market and the state are no longer applicable. Many economists treat them as two separately operating, homogeneous units, yet the market and the state overlap in many areas, such as the energy markets, where municipalities often have to compete with private suppliers. Wansleben wants to ascertain the actual structure of these markets and what role the public sector plays in them. The relevant projects are part of an extensive study into the role of the state as an economic stakeholder. The state’s economic interventions take many different forms, ranging from direct investment in private companies that have encountered difficulties as a result of various crises (e.g. Lufthansa and the Commerzbank) to investment funds, or from Germany’s state-owned development bank KfW to municipal companies.

Wansleben is looking into why, since the 1980s, parliaments and governments have gradually withdrawn from economic governance and ceded control to the

central banks. “The dominance of central banks is characterized by their robust independence, increasing media attention, and the leading role they play in countering financial and economic crises,” Wansleben explains. These are indicators of their increasing power over recent decades. The central banks ensure that inflation remains low; they stabilize the economy and help floundering states to stay afloat. There is hardly a newscast in which the name of a central bank is not mentioned.

Central banks as crisis managers

In the past, central banks, such as the German Bundesbank, controlled inflation via the amount of money in circulation. Whenever they raised interest rates, consumers and companies would reduce their spending, preferring instead to invest their money, as a result of which pricing pressures decreased. Reducing interest rates produced the opposite effect. Today, rather than stabilizing economies through the money supply, central banks adjust their interest rate policy to align with price developments within the goods and services markets. However, there is a problem with this approach, as it does not take asset markets, e.g. those for equities and real estate, into account. When they burst, price bubbles in these markets can rapidly lead to economic crises. The 2007 to 2009 financial crisis showed just how quickly this can happen.

While the increasing influence of the Bundesbank, the U.S. Federal Reserve (aka the Fed), and other central banks was initially based on different approaches to the threat of inflation, the inflation problem increasingly receded into the background to be replaced by concerns about weak growth, falling real interest rates and the expansion of the financial sector. The world’s cen-

“Covid-19 has wiped the market-dogma off the table.”

LEON WANSLEBEN

Dizzying: the European Central Bank (ECB) headquarters building in Frankfurt am Main is one of the tallest buildings in Germany. However, many observers consider the ECB's balance sheet total (which currently accounts for 50 percent of the economic output within the euro zone) to also be extraordinarily high.

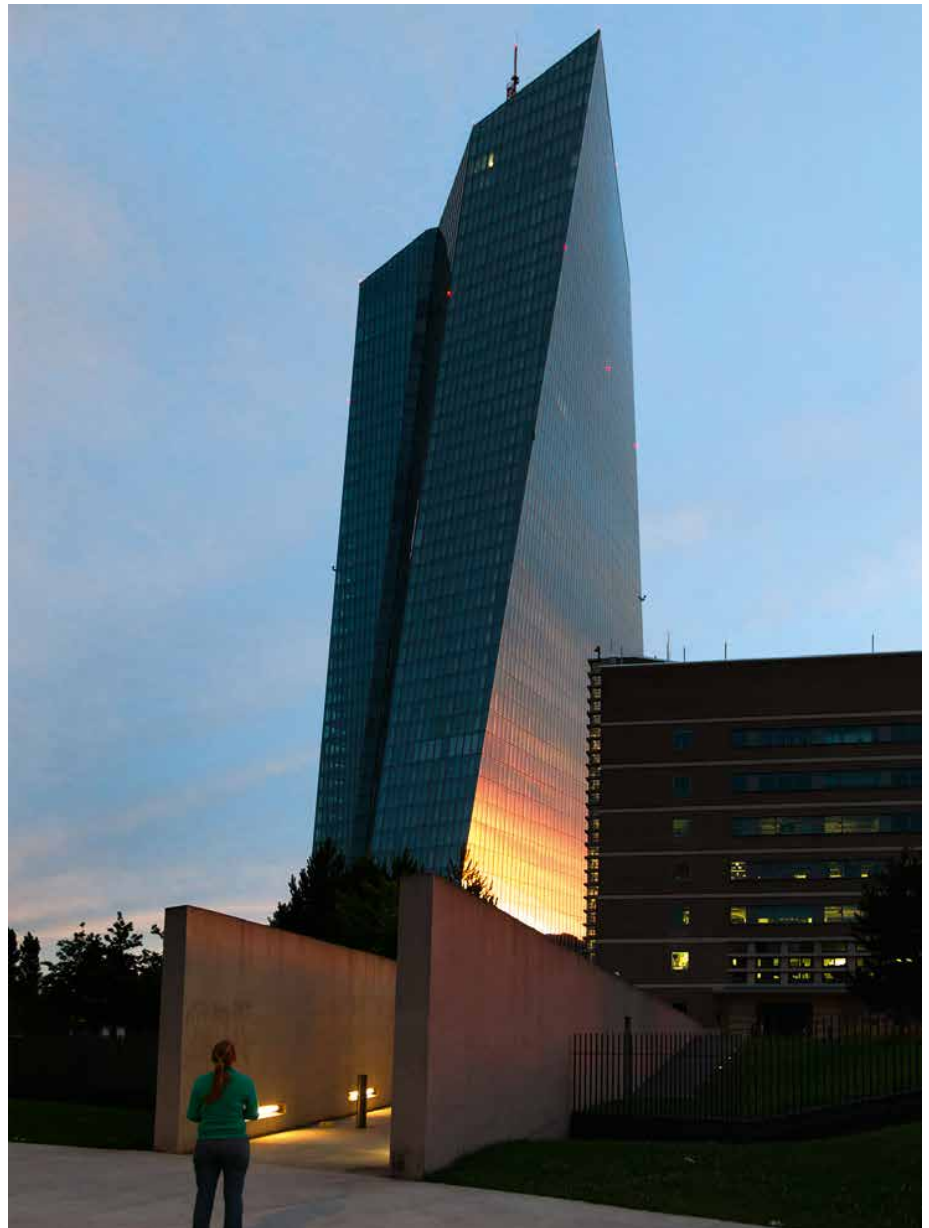


PHOTO: CARO / BASTIAN / FOTOFINDER

tral banks became the most important crisis managers when, for example, the dotcom bubble burst at the turn of the millennium or after the terrorist attack on the World Trade Center in 2001.

When describing his research project, Wansleben explains, “What I’m trying to figure out is why central banks were able to be so successful in spite of the financial crisis brewing in the background, and which institutional conditions fostered their increase in power.” He had already been exploring this subject prior to relocating to Cologne, when he was still teaching at the London School of Economics and Political Science. One of his findings is that the central bankers are, so to speak, the stabilizing force in an economy dominated

by the financial markets. They curb uncertainties within the markets, particularly through a predictable interest rate policy, as well as by converting private loans into sovereign payment instruments – by purchasing bonds, for example. The extent of these stabilization efforts can be seen in the central banks’ balance sheet totals. The ECB’s balance sheet total already accounts for half of the eurozone’s economic output, and that of the Fed accounts for about 30 %. This is where the sociological research approach comes into play. Why is it, Wansleben asks, that national parliaments and governments have for so long neglected to exercise not only their authority, but also their decision-making powers and responsibilities regarding economic policy?



This voluntary self-disempowerment is evident in tax policy, which has been used less and less for redistribution purposes in recent decades. Nor, to a large extent, have these powers been used to address political challenges such as climate change. Wansleben, however, foresees the next change on the horizon. He says, “There are many signs that central banks are currently reaching the limits of legitimacy and effectiveness with their concepts for economic governance, as well as their specific interventions.”

A lack of transparency in municipal enterprises

Central bank policies have long been seen as controversial. They spend vast amounts of money on buying up government and corporate bonds to revive the economy and want to increase lending to the economy through a zero-interest policy. However, neither of these measures is having the desired effect. Critics in Europe, for example, fear that the ECB is indirectly communitizing the national debt of southern European states by buying more and more of their state bonds. Achieving the inflation target of two percent is also a long way off. Wansleben asserts that democratic institutions now need to develop new approaches and instruments of economic governance.

His other two projects at the Max Planck Institute in Cologne are still in the early stages, yet hopes for exciting results are high. One of Wansleben’s research projects concerns the state’s municipal institutions. Using Cologne as an example, he is investigating the economic activities of the public authorities, whereby the focus is on public services – a term which, as he notes, is not precisely defined but “formulated in a deliberately vague manner.” The state may take action if there is a public interest in doing so, a precondition, which the city of Cologne interprets rather loosely. It acts, for example, as a telecommunications network operator through the municipal company Netcologne, and has acquired a shipping company that is active throughout Europe. According to Wansleben, the question of what the state is permitted to do and what it is economically sensible to do is “really fascinating.”

But a glance into the engine room of the state ought to also reveal who is influencing the actions of its institutions. In this context, Wansleben has identified a lack of transparency in the decision-making process, especially in municipal enterprises. Therefore, politicians are loathe to engage in democratic discourse about the

business orientation of municipal companies, apparently due to exaggerated concerns about scandals that could arise from their decisions. Instead, the public debate over municipal policies tends to focus on marginal issues.

In another project, Wansleben and his research group are also investigating the public sector investments being made by municipal authorities in Germany. In general, cities and municipalities reduced their investment budgets at the start of this century. “That was followed by a process of divergence,” says the sociologist. The communities’ development went in different directions. Some communities, particularly in the wealthy southern German states, started reinvesting more in their infrastructure, while treasurers in other regions continued to cut costs. The consequences quickly became evident to local residents. The infrastructure deteriorated, many schools became dilapidated and were insufficiently maintained, or the construction of new housing was neglected. Wansleben suspects that, “Faced with cost-cutting pressures following the reunification of Germany, the federal system began exerting fiscal pressure on the municipalities.” High fixed expenditures for such things as social services have deprived poorer cities and municipalities of the funds needed for investments. Their income from trade taxes is also very low.

“This whole subject has a certain explosiveness these days,” as the researcher knows. Population growth in the cities has been greater than expected. They simply must develop their infrastructures. Then there are also the investments necessary for climate protection, such as improvements in public transport services. The Covid-19 crisis is currently providing clear evidence of the more active role the state is again playing. The federal government is providing the municipalities with substantial financial support; after all, the most important tasks in the practical management of the pandemic must be undertaken by the cities and municipalities. One recent example of this is the announcement by the federal government that it is expanding the public health authorities. The federal and state governments want to create 5000 new jobs, as well as implement a digital upgrade within the departments.

SUMMARY

Many years after the state had withdrawn from its economic activities and control of economic policies, the trend is now reversing.

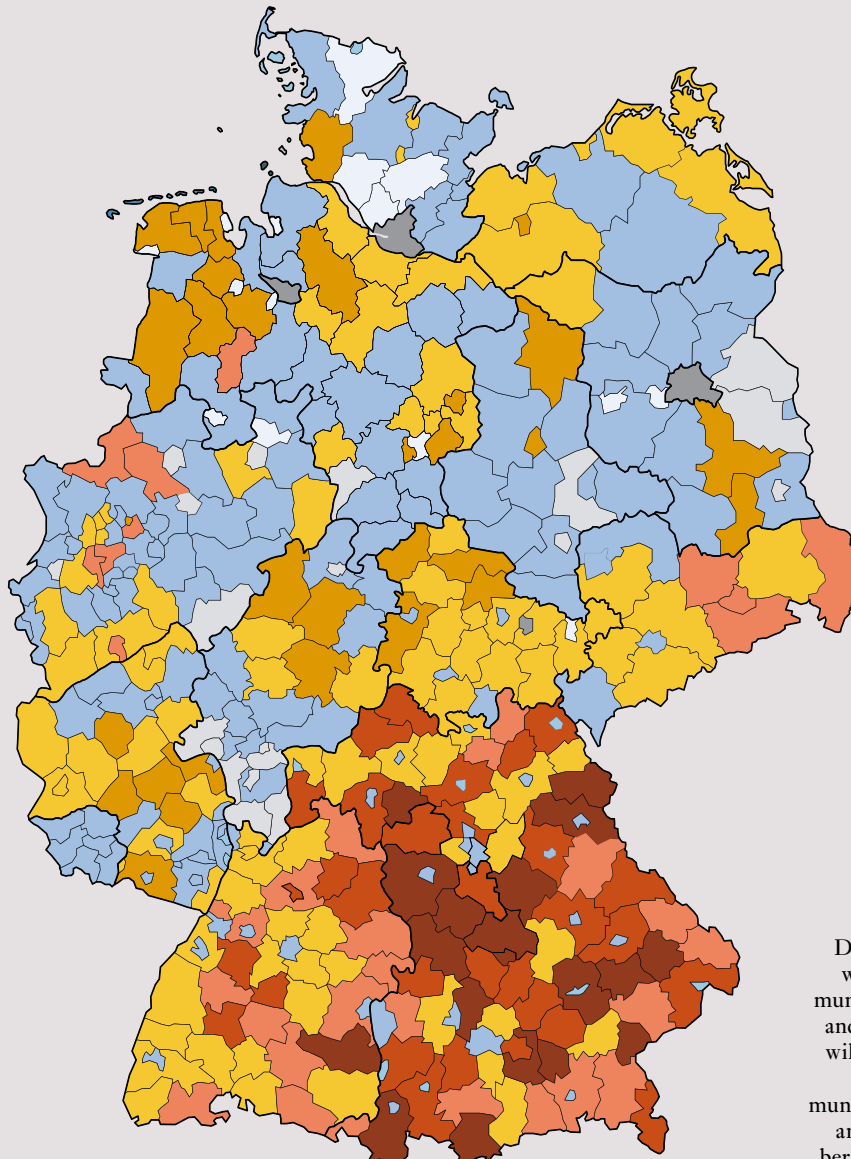
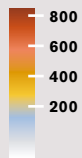
The central banks’ ability to avert economic crises is in doubt and a greater political commitment is required.

Municipal enterprises play an important role in the provision of public services.

More state investment in infrastructure is also required.

INVESTMENTS PER CAPITA

in 2018 (in EUR)



Dissimilar conditions: while many cities and municipalities in central and northern Germany will have to continue to save money, most municipalities in Bavaria and Baden-Wuerttemberg can afford to invest generously.

However, Wansleben identifies a requirement for action on one central issue. He is calling for at least partial debt relief for over-indebted municipalities, because without it they will be unable to solve their structural problems. He asserts that debt repayments and restrictions on municipal supervision have left no room for investment, which in turn has a negative impact on the development of these municipalities. In other words, over-indebtedness triggers a downward spiral. Although acting Finance Minister Olaf Scholz came up with a debt relief plan, it was not accepted by the governing coalition due to long-standing reservations. According to its critics, the plan would reward poorly managed cities and communities. Conversely, the researcher's evaluation of the state's response to the pan-

demic is positive. "The market dogma has been wiped off the table," Wansleben says and sees the aid packages as a reasonable mix between economic stimulus and investment. "This has now revealed a major disadvantage of the U.S. system," he concludes. There, the federal government is refusing to provide financial support to the individual states. This means, Wansleben explains, that the U.S. states are having to bear the costs of the Covid-19 crisis, while losing revenue at the same time. The German model, in contrast, is based on cooperative federalism in which the federal, state and local governments redistribute funds among themselves and between levels, i.e. they act in solidarity, especially in times of crisis.

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





ILLUSTRATION: ALESSANDRO GOTTARDO FOR MPG

IMMUNITY – A BALANCE BETWEEN ATTACK AND DEFENSE

TEXT:
CATARINA PIETSCHMANN

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Everything has its price – especially health, of course. At the Max Planck Institute for Evolutionary Biology in Ploen, Tobias Lenz and his team are researching what the evolutionary costs of perfect immunity might be and why we are not immune to all pathogens.

We've rarely been so keen to discuss pathogens and immunity as we are right now. The corona pandemic has highlighted the importance of having a robust immune system. But why do viruses, bacteria, and other microbes overcome our body's defenses time and time again? Isn't all-inclusive protection possible, and how much would it cost? Tobias Lenz and his team are analyzing the battle between defenders and attackers. They use computer-based approaches to investigate how the immune system reacts to pathogens, such as leprosy bacteria and HI viruses. Their research focus is on "MHC" genes.

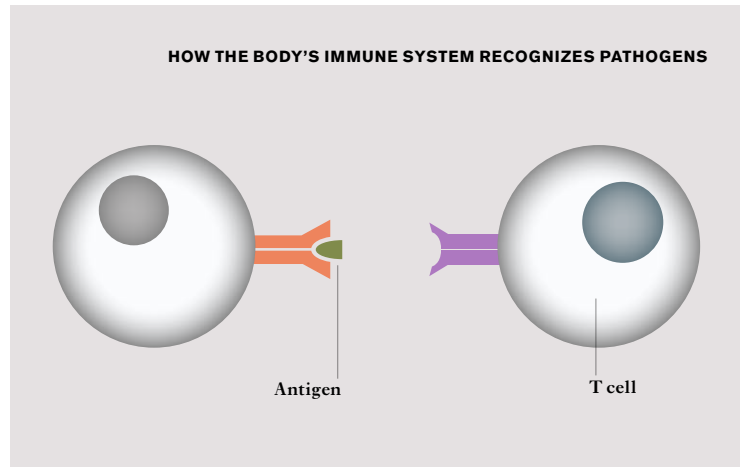
MHC stands for "major histocompatibility complex" and refers to a group of genes possessed by all vertebrates. Humans possess six such genes, here named "human leukocyte antigen" (HLA). They encode proteins that are responsible for the immune system's ability to recognize invaders. These proteins bind molecular fragments that are left behind by pathogens that have penetrated cells and that are displayed, like in a shop window, on the cell surface. Patrolling immune cells recognize them as foreign molecules and put the immune system on alert.

"It might well be that we possess too many HLA genes for the modern day life we live today."

TOBIAS LENZ

However, given the sheer immeasurable multitude of viruses, bacteria, fungi, and other parasites, how do such a small number of genes succeed in ensuring that barely any invaders avoid detection? The key lies in these genes' extremely high variability. They are the most variable genes in the entire genome. "The HLA-B gene, one of the human MHC genes, for instance, has more than 4000 known variants," says Tobias Lenz.

The MHC genes encode the information for the production of proteins on the surface (orange) of an immune cell. These can bind to molecular fragments from a virus, referred to as antigens, from the interior of a cell and present them to a T cell of the immune system (right). The T-cell can then trigger a defensive response.



GRAPHIC: GCO FROM TOBIAS LENZ / MPI OF EVOLUTIONARY BIOLOGY

The great variability in MHC genes ensures that a matching MHC protein exists for almost every intruder. Hence, if a specific pathogen is circulating in a population, those individuals with the matching MHC variant will be at an evolutionary advantage. Their carriers will become only mildly ill or perhaps not at all. And consequently, the frequency of this variant will increase within the population. To remain successful in the future, the pathogen needs to mutate and evolve in such a way that MHC variants cannot continue to provide protection. The mutated pathogen then needs to be matched by another MHC gene variant, and the evolutionary race enters the next round. The process can always result in evolution taking a different direction. Advantages can be rendered useless from one day to the next. However, not only do attackers quickly mutate from one generation to the next, they occasionally only appear in certain places and times. "In the long term, this means that no single variant will dominate the population, but that instead different ones will coexist," explains Tobias Lenz. This is what evolutionary biologists refer to as a "balanced polymorphism."

Lenz and his colleagues simulate the interplay between MHC genes and pathogens on the computer. With the help of specialized programs, they can observe the co-evolution of the adversaries in time-lapse. The researchers can also compare present-day genetic information with that of the past and, thus, learn how the MHC variants have changed over time. For example from skeletons from a medieval graveyard in Denmark. Here, the dead were from a leper colony. Such colonies were frequent in the past and up to the modern era, in order to prevent the spread of this often fatal disease. Thanks to antibiotics, most cases of leprosy are now curable.

→



Tobias Lenz in his Institute's aquaria room. In addition to his work on human MHC genes, Lenz also investigates those of sticklebacks, whose immune system is similar to that of humans. The great diversity of MHC variants in the fish also plays an important role in their defense against parasites.

To this day, leprosy still occurs sporadically in Southeast Asia. Some people there have an HLA variant that increases their susceptibility to the disease. Is it possible that most of the people in Europe who contracted leprosy possessed this variant? “In collaboration with researchers from the University of Kiel, we have indeed discovered that the HLA variant that makes people more susceptible to leprosy is found at a higher frequency in these bones from the Middle Ages,” says Lenz.

A variant with advantages and disadvantages

But why has this gene variant persisted over the centuries and not been eliminated by natural selection? “We now know that this variant isn’t solely disadvantageous. Yes, it provides poor protection against leprosy, but it also helps protect those who carry it from hereditary type 1 diabetes,” explains Tobias Lenz. Hence, the negative selective pressure due to leprosy is counterbalanced by the positive selective pressure of better protection against diabetes. That might explain why this HLA variant still exists in the population.

44 HIV is another example for a balanced polymorphism: some HLA variants in the immune system are better at keeping HIV in check than others. “We’ve demon-

strated that some variants are able to present a particularly large number of different HIV antigens. This makes HIV more visible for the immune system, so it can be fought more efficiently.” In contrast, the less effective variants may confer resistance to another pathogen. HLA variants may also be involved in the fact that SARS-CoV-2 causes severe symptoms in only a small percentage of those infected. As coronaviruses have circulated among humans for many years, most of us possess gene variants that can recognize the viruses. “We’re susceptible to SARS-CoV-2, because it’s relatively new, but thanks to thousands of years of natural selection, most people’s immune systems can limit its effects,” says Tobias Lenz. Along with colleagues from around the world, he is currently investigating the extent to which HLA genes may be involved. Although thousands of different HLA variants exist in humans, each one of us has only a handful of them. High variability, it turns out, also has a drawback: autoimmunity.

MHC proteins are adapted to bind molecules from bacteria, viruses, and other parasites and present them on the cell surface. There, these foreign molecules are recognized by a particular type of immune cell known as T cells. A selection process for T cells occurs in the embryo: those that recognize foreign molecules are retained, while those that recognize the body’s own molecules are removed. However, this process isn’t perfect, and so T cells that recognize the body’s own molecules keep emerging. The more HLA variants a person

Degenerated pigment cells from the skin. An immune system with a large variety of HLA types is better able to recognize and fight such cancer cells. As a consequence, immunotherapy is more effective in skin cancer patients with a high variability of these genes, but in such patients, treatment can also frequently trigger inflammatory reactions.

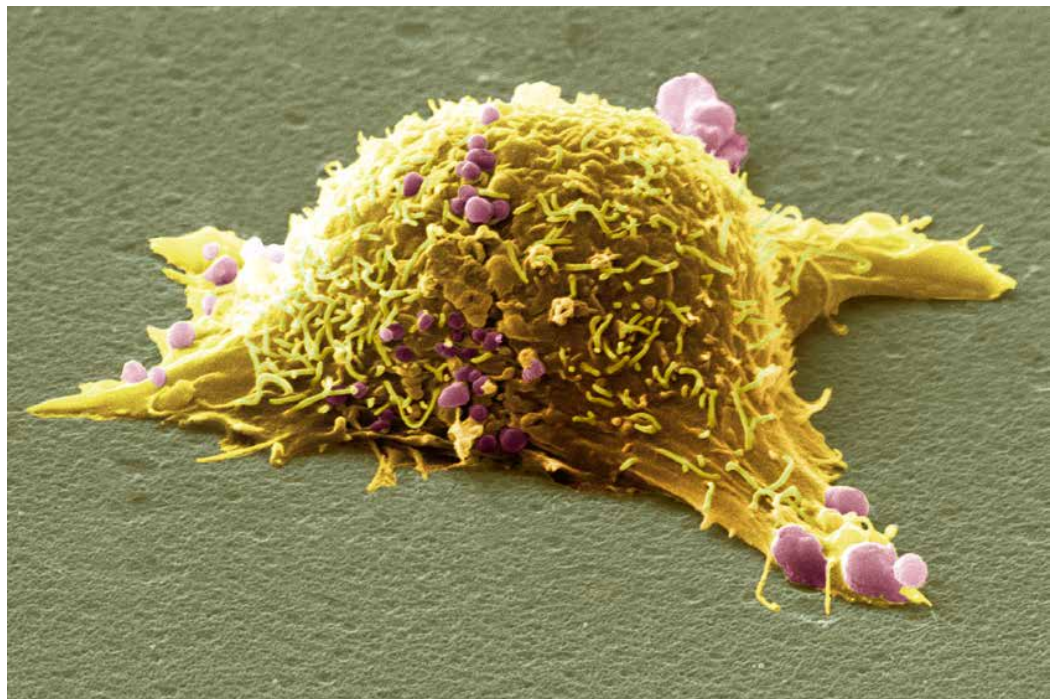
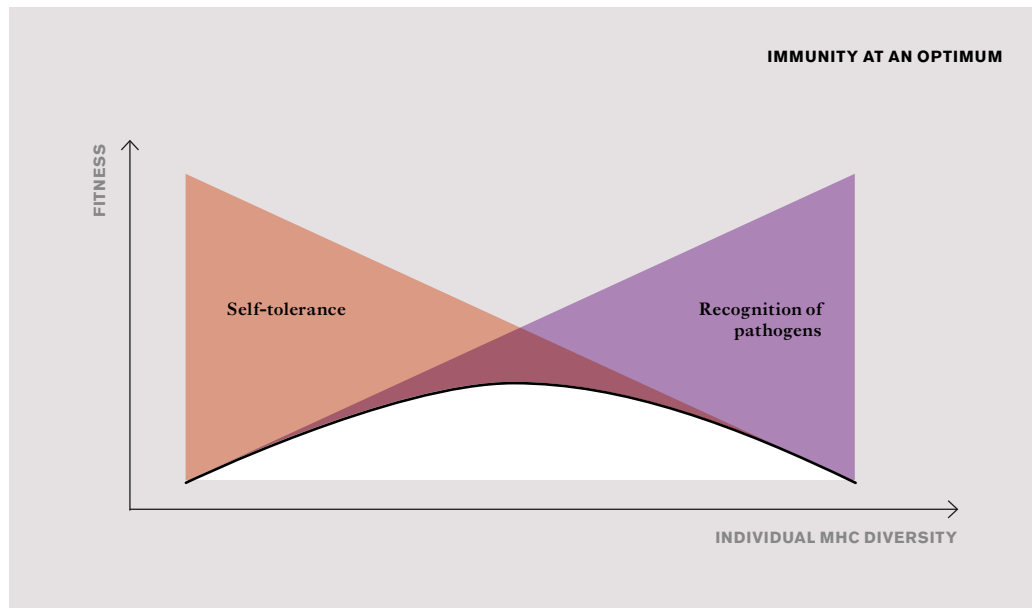


PHOTO: SCIENCE PHOTO LIBRARY / STEVE GSCHMEISSNER



The relationship between MHC diversity and an individual's fitness (black curve). The greater the diversity of MHC variants, the better the body is protected against pathogens and parasites. At the same time, however, the immune system's tolerance towards the body itself decreases. The body's optimal MHC diversity is located at the apex of the curve.

SUMMARY

MHC genes produce an abundance of differing proteins that help the immune system to recognize intruders.

Some MHC variants provide protection against specific pathogens but can also trigger autoimmune diseases.

The more of these variants a person possesses, the better they are equipped to fight pathogens. The price, however, is a higher risk of developing autoimmune diseases.

possesses, the more foreign molecules they can present – in the case of pathogens that can mutate as rapidly as HIV, that's a huge advantage! Unfortunately, however, this will also lead to more of the body's own molecules being presented. This can cause the immune system to turn against itself, resulting in autoimmune diseases. Multiple sclerosis, type 1 diabetes, celiac disease, psoriasis, ankylosing spondylitis, and many more – all are associated with certain HLA variants. Throughout evolution, the diversity of HLA genes seems to have settled at an optimal level. "This means we're well protected against pathogens, while at the same time the risk of autoimmune diseases is minimized," says

Tobias Lenz. But is this still the case in our hygiene-oriented society? Autoimmune diseases are on the rise in many countries. Does this suggest that the balance between infection defense and autoimmune disease has shifted in favor of the latter? "It's possible that we possess too many HLA genes for the age we live in." Hence, the diversity of immune genes influences our susceptibility to both infectious and autoimmune diseases. The immune system and the HLA genes may also play a role in cancer, as immune cells can recognize and eliminate cells that are dividing uncontrollably. This helps to destroy some tumors at an early stage. Also, a tumor, even one at an advanced stage, can occasionally shrink in a seeming miracle.

This can occur when one of the mutations frequently manifesting in tumors causes the immune system to suddenly recognize the tumor cells as foreign and attack them.

More effective treatment

Together with oncologists from the Memorial Sloan Kettering Cancer Center in New York, Tobias Lenz and his team have investigated the influence a cancer patient's own contingent of HLA genes has on the success of immunotherapy. Such a treatment with "checkpoint inhibitors" aims to induce immune cells to act against the body's own cells that are multiplying uncontrollably. "Our results have shown that immunotherapy is more effective in patients with metastatic skin cancer if they possess a broad diversity of HLA variants," says Lenz. However, HLA genes are also associated with common side effects of immunotherapy, such as skin rashes or liver and intestinal inflammation. In cancer as well, the immune system has to maintain a balance between combating tumor cells on the one hand and avoiding autoimmune diseases on the other. The price for possessing a perfect defense against pathogens would be that such a system could turn against one's own body – too high a cost to bear. Thus, the legions of pathogens will keep discovering ways to outsmart our immune system.

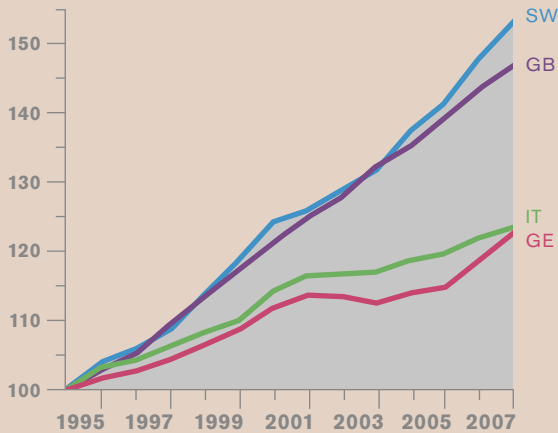
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HOW THE ECONOMY GROWS

GROWTH IN GDP

(represented with an initial value of 100 for 1994)

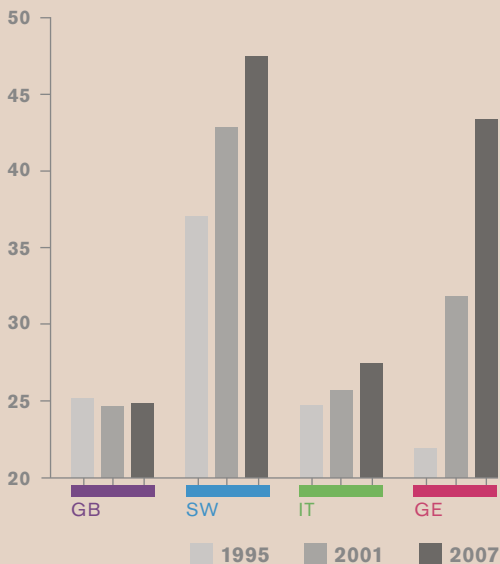


The years between 1994 and 2007 saw the longest period of sustained growth in the OECD since the beginning of the oil crisis in 1974/75.

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EXPORT SHARE OF GDP

(in percentage of GDP)



Exports are price-sensitive, particularly when industrial products are involved. This means that an export-oriented economy profits from low wages.

CONSUMPTION ORIENTATION

GREAT BRITAIN

Consumption-oriented growth model

- High current account deficit: imports exceed exports
- High consumer spending
- High demand for services, also from moderately skilled and low skilled providers



Important economic factors

- Financial services
- Oil industry / petrochemicals
- Gas turbines

ITALY

Growth model neither consumption-oriented nor export-oriented

- Small export sector, specialization in labor-intensive goods
- Real Euro exchange rate too high in relation to economic performance
- Low consumption



Important economic factors

- Tourism
- Footwear and fashion
- Wine
- Furniture

Until about 30 years ago, growth in Europe was fueled by rising wages and growing consumption. However, national and international developments started undermining this model in the 1990s. Since then, Germany has strengthened its reliance on exports, while Britain, Sweden and Italy have branched out onto other paths. Lucio Baccaro from the Max Planck Institute for the Study of Societies in Cologne has been analyzing the various possibilities.

SWEDEN

Consumption-oriented and export-oriented growth model

- Simultaneous growth in export and consumption
- Price-insensitive exports: particularly IT services
- Wage growth in industry and the service sector

Important economic factors

- Research and development services
- Flat steel
- Refined copper
- Timber

GERMANY

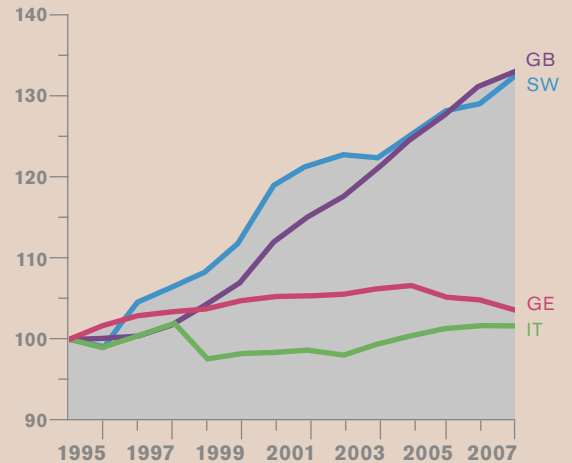
Export-based growth model

- Sustained current account surpluses: exports exceed imports
- Real Euro exchange rate too low in relation to economic performance
- Growing inequality due to low wages in the service sector

Important economic factors

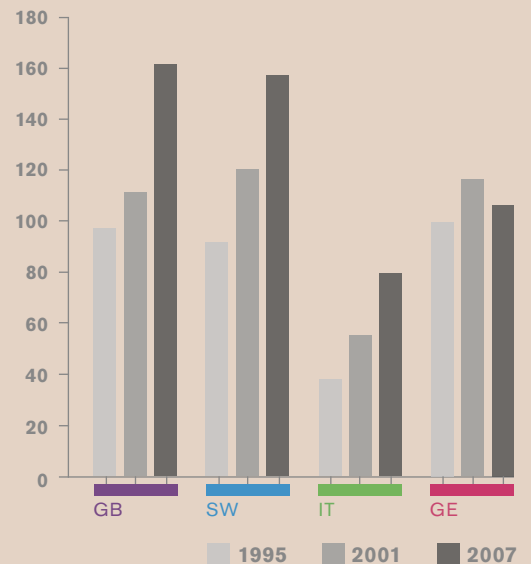
- Aircraft construction
- Machine construction
- Automobile construction

GROWTH IN REAL WAGES
(represented with an initial value of 100 for 1994)



The majority of economic performance still depends on private household consumption and consequently on disposable income.

PRIVATE HOUSEHOLD DEBT
(as percentage of available net income)



Borrowing boosts spending and consequently economic growth. However, this type of “growth on credit” is also viewed critically.

EXPORT ORIENTATION

HUNTING FOR SPIES IN COMPUTER CHIPS

Becoming a Max Planck Director via “second-chance” education is probably something of an exception. But that is precisely what happened in the case of Christof Paar, one of the founders of the Max Planck Institute for Security and Privacy in Bochum, where his work now includes tracking down hardware Trojans on computer chips.

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TEXT: KLAUS JACOB

Christof Paar has fond memories of the construction of the Colonius telecommunications tower in Cologne. In 1980, the soaring stairwell that provides access for the fire service had to be fitted with loudspeakers: four of them at every ten meters of height. This laborious task fell to an apprentice in his first year – namely, to Christof Paar. Since then, the former telecommunications technician has climbed to the upper echelons of science to become one of the founding Directors of the Max Planck Institute for Security and Privacy in Bochum. His research work at the Institute is also of great political relevance – and he’s a good contact when it comes to Huawei and 5G networks or the protection of companies against hackers.

When you look at the individual milestones on Christof Paar’s résumé, it is clear that his journey to becoming a Max Planck Director is something of a rags-to-riches story. In the beginning, things didn’t look all that promising. While attending an academic-track high school, Paar struggled with languages and therefore switched to an intermediate secondary school, where he obtained his “Mittlere Reife” diploma. He then went on to complete

an apprenticeship, but it doesn’t sound as if he regrets going into a skilled trade – indeed, he says that, even as a young boy, he enjoyed tinkering with things and was fascinated by technology. His parents were actually quite accepting of his decision to learn a trade, even though his father was an academic. Having qualified as a tradesman, Paar then took something of a roundabout route into the world of science. After all, switching from a skilled trade to an academic career was harder in those days – almost 40 years ago – than it is today. Paar first attended a specialized upper secondary school. He graduated after one year and then spent half a year working as a journeyman at a small three-man firm. “I used to ride my motorbike to the building sites.” He then pondered “for weeks”, whether to become a master craftsman or switch to studying for a degree. His boss urged him to stay, taking the view that a career as a master craftsman offered much more security than becoming an engineer. In the end, Paar opted for the academic route and signed up to study telecommunications at Cologne University of Applied Sciences. “It was a rational decision,” he says, adding that the higher earning potential was the decisive factor.

On his detour through so-called “second-chance education”, Paar managed to fulfill many of the expectations one has of a Director of a Max Planck Institute: his excellent academic performance was impressive, not least because he was – and still is – enthusiastic about his subject. His eyes light up when he talks about fast microprocessors or the fight against hackers. The 57-year-old Director is talkative, easy to get along with and full of laughter, and takes a relaxed approach to team meetings. Although most of his team members are young researchers, Paar treats them as equals; he is open to criticism, and is on familiar terms with everyone.

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VISIT TO

CHRISTOF
PAAR



PHOTO: LARA WITTHAUT, FOTO-OSTERMANN.DE FOR MPG

A passion for technology: Christof Paar hunts for security flaws in computer hardware.



PHOTO: LARA WITTHAUT, FOTO-OSTERMANN.DE FOR MPG

50 Youthful and fit: it's no surprise that Christof Paar is in such good shape, especially thanks to his tri-weekly karate training sessions.

Meetings with Paar have a relaxed, collegiate atmosphere – with pizza and coffee at the ready. Indeed, Paar looks much younger than his years, partly thanks to his lean physique. Thrice-weekly karate sessions help him to keep fit.

Paar graduated from Cologne University of Applied Sciences at the top of his class – and was one of only a handful of graduates to complete the degree within the prescribed period of study. He met a group of fellow students who spurred each other on to high achievements. “The A-Team,” he says with a smile. It was in those early days, while working as a teaching assistant for math, that he discovered his passion and talent for teaching. For his dissertation, he developed an electronic control system for flip-disk displays such as those on buses, where the names of the respective stops are displayed by an array of tiny disks that flip to show either their black or white side. To this day, a large display of the same type notifies traders of current prices at the Frankfurt Stock Exchange. The technology, which was very advanced in those days, is

known as an “embedded system” – in other words, a combination of a computer and a physical device. This is the area of research that Paar still works on today – and even then, at the age of 24, he knew exactly what he wanted his future career to look like. “I wanted to become a professor, without a shadow of a doubt.” Indeed, his main motivation in those days was teaching.

Of course, this meant that he would first have to do a doctorate, which wasn't possible at a university of applied sciences in those days. So with that, together with the A-Team, he switched to the University of Siegen, where he was largely spared the need to complete the basic course of studies. However, as an acknowledged conscientious objector, he first had to complete his civil service as substitute for the compulsory military service – and he was in luck: the audiologist Hasso von Wedel, who had made a name for himself as a tinnitus researcher, was offering two research-related positions for conscientious objectors at the University Hospital of Cologne. Paar secured one of the posi-

tions and was responsible for the technology used in the experiments. As a result, he actually managed to turn this forced career break to his advantage. During his civil service, he attended lectures in physics and mathematics at the University of Cologne, and toward the end he began his studies at the University of Siegen.

From Siegen, he moved to the U.S. to write his second thesis – at Michigan Technological University. But why would someone who had to switch schools because he struggled with foreign languages move to the U.S.? “Of course, my thirst for adventure was a key factor,” says Paar. Moreover, he had already hitchhiked across the U.S. twice during his time at Cologne University of Applied Sciences, and had found it much easier to learn the language by conversing with Americans than he did in

cated mechanisms that operate in the background to ensure that even scratched CDs can be played without errors. The technology even makes it possible to drill a hole with a diameter of up to three millimeters into the disk without affecting playback. Paar simplified the algorithms for real-time error correction, which are implemented directly in the form of special hardware circuits, in order to make them significantly smaller, faster and more energy-efficient – a method that was later put to commercial use.

After completing his doctorate, Paar planned to embark on an academic career in the U.S. so that he could be with his girlfriend, whom he had met two years earlier and later married. “Two years of long-distance relationship were enough.” In 1995, he was offered a position as assistant professor at

Paar works on the implementation of new encryption methods in hardware and software. He is one of the experts who established this area of research.

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school. He even went on to marry an American woman. “My English teacher would be pretty amazed,” he laughs.

Paar spent a long, cold winter in Michigan working on his Master’s thesis. Once again, he chose a topic that was at the cutting edge of technical development: active noise cancellation, a technology that is intended for use in cars, for example; it cancels out undesired noise using what is colloquially known as “anti-noise.” Paar has a habit of combining different fields within his projects: physics with computer technology, engineering with mathematics, classical hardware with software. His doctoral thesis at the University of Essen is another example. This time, his focus was on error correction in digital technology – a technology that is used in data transmission from satellites to Earth or in CD players, for example. Very few people who listen to a CD are aware of the sophisti-

Worcester Polytechnic Institute in Massachusetts, a private university that is funded by tuition fees and therefore places a lot of value on high-quality teaching. As part of the application process, Paar was required to deliver not only a research lecture, but a teaching lecture as well – and with that he outdid his competitors. The freedom he now enjoyed as a professor allowed him to introduce a new subject at the university: cryptography.

The word cryptography conjures up images of the secret codes that children find so fascinating, or of the Enigma, the Nazi encryption device whose code was cracked by the Allies. As a research discipline, however, cryptography still led a marginal existence in the 1990s. There was only a single textbook, which was brand new at the time – and the subject was only offered at a few universities. Paar had backed the right horse. “Luck was also on my side,” he says. Back then, the rapid expansion

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of the dot-com bubble was making cryptography and data security increasingly important. Their importance has also been bolstered by cases such as that of the whistleblower Edward Snowden, who revealed just how brazenly intelligent agencies intercept data and how important it is to protect them. Another of the countless examples is the scandal surrounding Crypto AG, a Swiss company that manufactured encryption devices during the Cold War. It later emerged that the company had been selling manipulated devices on behalf of the CIA and the German Federal Intelligence Service (BND), allowing the secret services to conduct espionage in over 100 countries.

However, Paar's work doesn't focus primarily on the development of new encryption methods, but rather on their implementation in hardware and software. Indeed, he is one of the experts who established this area of research within the scientific community.

he returned to Germany – partly to be closer to his elderly parents, but also for the opportunity to help establish the Horst Görtz Institute for IT Security at the Ruhr University in Bochum. The initiative for founding the Institute came from Horst Görtz, the owner of a medium-sized business who made his fortune in IT security during the dot-com boom. It was born of his desire to use his foundation to launch an influential research institute in Germany. Paar's two older children, Noah and Maja, found the move to Germany easy – they had been raised bilingually and entered elementary school here, while his younger daughter, Flora, was born in Germany. For Paar's wife, the transition was more challenging from a career perspective. In the U.S., she had taught at a community college – a type of higher education that doesn't exist in Germany. She now works as a lecturer in biology at the Ruhr University in Bochum. “The job brings her a lot of satisfaction,” says Christof Paar.

Subtly manipulating just a few transistors is often enough to deactivate vital safety functions.

Together with his colleague Çetin Koç, he launched the Conference on Cryptographic Hardware and Embedded Systems (CHES) in 1999. Although the conference was actually intended to be a relatively small workshop, the first CHES was attended by over 150 international specialists from academia and industry and was even covered in the New York Times. Today, CHES has evolved into one of the most important international conferences in the field of cryptography.

But let's turn our attention back to Christof Paar's journey from a mere apprentice to becoming a Max Planck Director. Paar stayed in the U.S. for seven years, during which he rejected a number of offers to join start-ups – because he enjoyed university life and the combination of research and teaching that it offered him. He was also worried that getting involved in a start-up would mean he would no longer have enough time for his wife and children. In 2001,

In any case, things are going well for him: not least thanks to the Horst Görtz Institute, Bochum is now one of the world's leading locations for IT security and is home to 1,000 students in the field. However, the Institute has caused a stir not only within the scientific community – in 2008, Paar and his colleagues succeeded in cracking the security system used in an electronic door opener that controls millions of car and garage doors. To do this, the researchers first had to analyze the electronics using a very laborious process known as reverse engineering. The resulting insights allowed them to produce a sort of master key that could open garage doors and the doors of some cars. This was a major story for the media. “We were overrun by journalists for weeks,” says Paar.

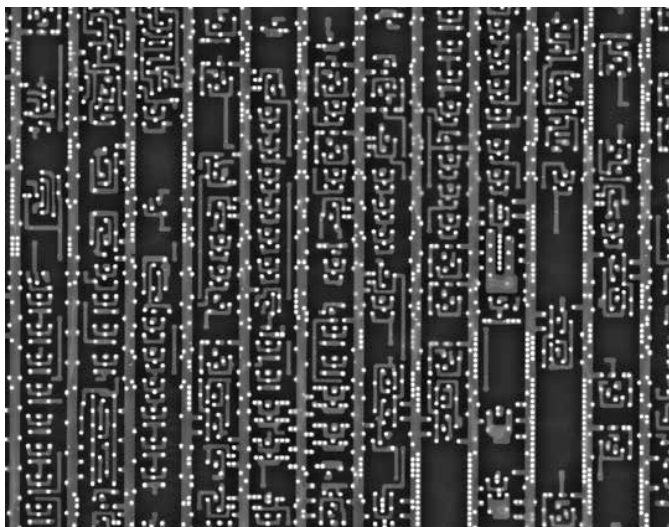
Such “vulnerability research” projects like these are part of Paar's everyday work – after all, those who seek to improve security need to be aware of a

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PHOTO: LARA WITTHAUT, FOTO-OSTERMANN.DE FOR MPG

Secure monitoring: Christof Paar's team is developing technology that can be used to check whether nuclear warheads are stored securely. The monitoring cannot be circumvented, because the warheads record an electromagnetic signature that is specific to the storage site. It is this connection to physical characteristics that links the project to research into computer hardware.



Scanning components: this image from a scanning tunneling microscope reveals details in the chip structure that help the researchers in Bochum to search for hardware Trojans.

system's weaknesses. But Paar goes one step further: he also wants to know what makes hackers tick, what their thought processes are, and where their mental restrictions lie. This has led him to develop a new area of research in collaboration with Nikol Rumel, a cognitive psychologist at Ruhr University Bochum. The two researchers were confronted with a problem: professional hackers are reticent. They keep their cards close to their chest, even when working for companies that have hired them to seek out vulnerabilities in their products. Paar and Rumel had to make do with students from Ruhr University who volunteered to participate. Through this research, they discovered that the speed at which a hacker makes progress is correlated with the hacker's working memory. From cognitive psychology, we know that most people can process a maximum of seven units of information at the same time. One approach to preventing hacking attacks is therefore to design hardware and software so that attackers have to grapple with significantly more information. Christof Paar and the French researcher Gilles Barthe became the founding Directors of the new Max Planck Institute in Bochum in 2019. Now, Paar can spend more of his time on research – for which he also works with the Federal Criminal Police Office, or BKA, and companies such as Google. That being said, he doesn't want to give up on teaching altogether. "The difference is that, now, I can cherry-pick the most interesting topics," he says. A highlight is Paar's introductory lecture on cryptography that he successfully introduced in the U.S., albeit in an updated form.

The current wrangling over Huawei highlights the importance of Paar's research area. The U.S. and Britain suspect the company of spying for the Chinese

state and are excluding it from the rollout of 5G technology. Paar is all too aware that manipulations of this kind are possible. After all, he also studies hardware Trojans – and he has received an ERC Advanced Grant on this very topic, one of Europe's most prestigious research awards. Hardware Trojans – in other words, circuit manipulation within a computer chip – can be used for espionage and could even allow attackers to shut down entire industrial systems.

Non specialists could be forgiven for thinking that manipulation of this kind can't be too hard to find – but they would be mistaken. Chips such as those inside smartphones or in 5G-connected computers contain many millions of transistors that measure just a few nanometers across and whose schematics are a carefully guarded secret. Christof Paar and his team have found that subtly manipulating just a few of these transistors is often enough to deactivate vital safety functions. To understand circuits of this kind, the researchers must laboriously analyze the chips layer by layer, with the help of ablation techniques. Meanwhile, they have developed an automated method for analyzing the high-level structure of the computer chip. For example, this allows them to identify the sub-modules of the chip in which encryption takes place – sections that are especially suited for introducing Trojans. Until now, these analysis techniques were only available to powerful intelligence agencies and a small number of specialized firms. However, Paar's research will help the entire international research community gain a better understanding of hardware manipulation, so that new safeguards can be developed.

Exactly how attacks by governmental or semi-governmental organizations can be foiled is the subject of research at the Cluster of Excellence "Cyber Security in the Age of Large-Scale Adversaries" (CASA), of which Christof Paar is one of the speakers. "As we know from Edward Snowden's revelations, intelligence services sometimes go to absurd lengths to circumvent security solutions," says Paar. It seems unlikely that he will run out of work anytime soon.





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USING A TREE'S NATURAL DEFENSES

TEXT: CATARINA PIETSCHMANN

56 Trees stand for strength and steadfastness. However, the latter can also be a handicap. This is because trees can neither run nor hide from enemies. Nevertheless, trees are by no means defenseless. Sybille Unsicker from the Max Planck Institute for Chemical Ecology in Jena is investigating how black poplars defend themselves against voracious insects.

Not only the ravages of time but also a multitude of large and small herbivores, bacteria, fungi, and viruses eat away at a tree throughout its life. Which pests infest which parts of a tree depends, among other things, on its age (and that of its leaves), the season, and the weather. Different conditions also prevail within the tree crown. Leaves can have different micro-climates, depending on how high they are off the ground, the direction they face, and their position on the tree. “You have to think of a tree as more like a meadow in which there are various ecological niches,” explains Unsicker. The tree as an ecosystem, so to speak.

Predators also have to cope with these constantly changing and locally varying conditions. In the plant kingdom, a common way to spoil the appetite of attackers is to produce very indigestible or even toxic substances. However, there are hardly any toxins that keep all predators equally at bay. What is toxic to one species may be attractive to another. For example, the nicotine in tobacco plants, the caffeine in coffee plants, or the piperine in pepper plants are produced to make the leaves or fruits of their respective plants inedible. And this works against most insects. But for humans, these substances are popular stimulants. True to the motto: “The enemy of my enemy is my friend,” other plants get external help for defense. And Unsicker aims to find out exactly how these alliances work.

For her diploma thesis, she examined tree crowns on the Ivory Coast. She is currently conducting research in a riparian forest on Küstrin-Kietz, an island in the Oder River, which is a nature reserve directly on the German–Polish border. The more than 300 black poplars (*Populus nigra*) growing along the banks of the Oder are among the last naturally occurring black poplars in Germany. While elsewhere more competitive species make life difficult for them, the battles at the end of the Second World War destroyed almost all the vegetation here. This was a stroke of luck for these trees because they are weak competitors. As seedlings, they can rarely prevail against other plants.

“I was eager to study a native tree species that occurs in an ecosystem with great

PHOTO: ANDREAS BÜCKLER / MPI FOR CHEMICAL ECOLOGY



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Using professional climbing equipment, Sybille Unsicker can examine the treetops even at these heights.

Maybe not pure herbivores after all? In addition to leaves, the caterpillars of the gypsy moth (*Lymantria dispar*) like to eat fungi. The orange-colored spore deposits of poplar leaf rust alter the mixture of odorous substances that the poplars release from their leaves.



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biodiversity. Riparian forests are hot spots of biodiversity. The fact that black poplars have become rare in Europe has given me additional motivation. Our results might even contribute to the preservation of these trees,” says Unsicker. Since 2009, she and her team have been studying how poplars react to insect attack – both in the field and in the laboratory. For this purpose, Unsicker has equipped several trees in the riparian forest with ropes. Researchers can use these to climb into the tree crowns and take leaf samples from different heights. They regularly encounter caterpillars of the gypsy moth, a moth that is about three centimeters in size. The investigations have shown that the insects prefer to feed on older, already hardened leaves.

To avoid having to climb into the tree-tops every time they want to observe the interplay between caterpillars and poplars, Unsicker and her team have planted poplar cuttings from the floodplain forest in their greenhouse in Jena. For their analyses, the researchers wrapped the branches in fine nets and placed gypsy moth caterpillars inside. “You can easily smell that the insects change the smell of the leaves,” says Unsicker. Once the caterpillars have begun to destroy the leaves, the researchers replace the nets with gas-impermeable bags. These collect the volatile substances of the trees that are being attacked. The researchers then capture the volatiles with a filter. The filter content is rinsed with solvent and analyzed using gas chromatography and mass spectrometry.

The difference between the damaged and the undamaged leaves is enormous. “Infested leaves produce large quantities of volatile compounds, which give crushed leaves their characteristic odor. We can also detect sesqui- and monoterpenes, aromatic hydrocarbons, and nitrogen-containing volatiles, including benzyl cyanide,” says Unsicker.

Is this the “cry for help” we are looking for – the message to the enemy of the enemy? The team had colleagues from Austria send one of the caterpillars’ most formidable enemies: parasitoid (i.e., Braconid) wasps. These insects deposit several eggs inside the body of the caterpillars. The hatched braconid wasp larvae feed on the tissue of their hosts but spare the vital organs. The caterpillar thus continues to live until the wasp larvae bore

through its skin to the outside and pupate. At this stage, the caterpillar behaves as if it were under the control of an external force and even defends its deadly tenants against attackers. Its strength is eventually exhausted, and it dies. The volatile analysis shows that the parasitoid wasps can detect the odorant molecules from the injured leaves extremely well. Faced with the choice between the odor of intact or damaged leaves, they clearly prefer the damaged leaves. Only a few odorant molecules are required for the highly sensitive antennae of the parasitoid wasps to locate their prey. But is this also the situation in the wild, where – in addition to poplars – other plants also release their volatiles and the wind swirls all the scents together? To find out, the researchers placed the presumed attractants on glue traps in the riparian forest. “Af-



PHOTO: FRANZISKA EBEL

ter only a short time, we had braconid wasps and other parasitic insects such as ichneumonid wasps in the traps,” says Unsicker.

Examinations of the cuttings in the greenhouse confirmed the findings. As soon as the researchers removed the caterpillars from the leaves, the concentration of the nitrogen-containing volatiles dropped to zero. Because the wasps are attracted to these very odors, it was clear: “We had found the distress call molecules produced by the trees,” says Unsicker. Poplars produce volatiles mainly during the day when they also carry out photosynthesis. At night, however, they largely stop production. The kinds of volatiles released by the leaves depend on the type of injury they sustain. If they are cut with scissors, for example, they release diffe-

rent substances than when they are infested by caterpillars. But how does a leaf know what is causing it harm? “Leaves can recognize insects by their saliva, which penetrates the leaf tissue. They also perceive the way an animal eats and how much leaf area is lost in the process,” explains Unsicker. “Sucking aphids trigger a different reaction than caterpillars that feed on large areas, or leaf beetles that punch small holes in the leaves.”

The trees can thus not only call for outside help but also warn parts of the crown that may not have been infested yet. After all, branches of large trees are often many meters apart. “Communication within the tree crowns via volatiles would thus be comparatively quick. It would take much longer to send information through the tree’s supply lines, from the leaf to the branch to the trunk, and from there back to another branch and so on,” says Unsicker. In the coming years, Unsicker hopes to find out exactly how one leaf perceives the odor of another as well as which receptors and transport molecules carry the volatiles through the cell membranes.

Caterpillar toxins in the leaves

But why don’t the attacked poplar leaves produce toxins that would repel the caterpillars like tobacco, coffee, and pepper plants do? “The leaves of the black poplars also contain substances that are toxic in high concentrations. For example, salicinoids can be toxic, especially for generalists (i.e. caterpillars that feed on various tree species) like gypsy moth caterpillars. But there is a considerable danger that such a toxin would also affect all the many beneficial insects that live on and in a tree.” Unsicker suspects that the arsenal of defense molecules that

can be found in plants is highly complex and used in a variety of ways. Only in this way is it possible to conceive that a poplar tree – which reaches sexual maturity no earlier than the age of 10 years and then lives on for another 90 years – can survive the attacks of its extremely diverse predators.

This is supported by the fact that the volatiles that summon the parasitoid wasps can be produced very easily. The starting point is the amino acid phenylalanine, which is converted into benzyl cyanide in only two steps. The intermediate stage, phenylacetal oxime, can accumulate in the leaf and is toxic. The higher the concentration

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SUMMARY

Black poplars emit odorous substances from their leaves; these attract parasitoid wasps. The insects parasitize caterpillars and thus help the trees keep the voracious larvae at bay.

Odorless substances are also suitable media for transporting information from tree to tree as well as within the tree crown. They reach their destination relatively quickly and are easy to produce.

Leaves infested with fungi also release characteristic volatiles. Their smell attracts butterfly caterpillars, which apparently do not live a purely vegetarian life but also eat the fungi as a source of nitrogen.

of this substance in the leaves eaten by gypsy moth caterpillars, the higher the mortality of the caterpillars. “The production of these toxic substances thus serves not only the indirect but also the direct defense. The tree essentially has a double defense strategy,” explains Unsicker.

The poplars communicate not only with the parasitoid wasps but also exchange information with each other – a phenomenon that has been communicated to the public as well, thanks in part to the books by Peter Wohlleben. It has been known since the 1980s that trees can pass on information about pests with the help of volatiles. Trees are also connected to each other via fungal networks at the roots, the mycorrhizae. However, critics accuse Wohlleben of humanizing trees. “Even for my taste, he sometimes embellishes the facts too much. But I

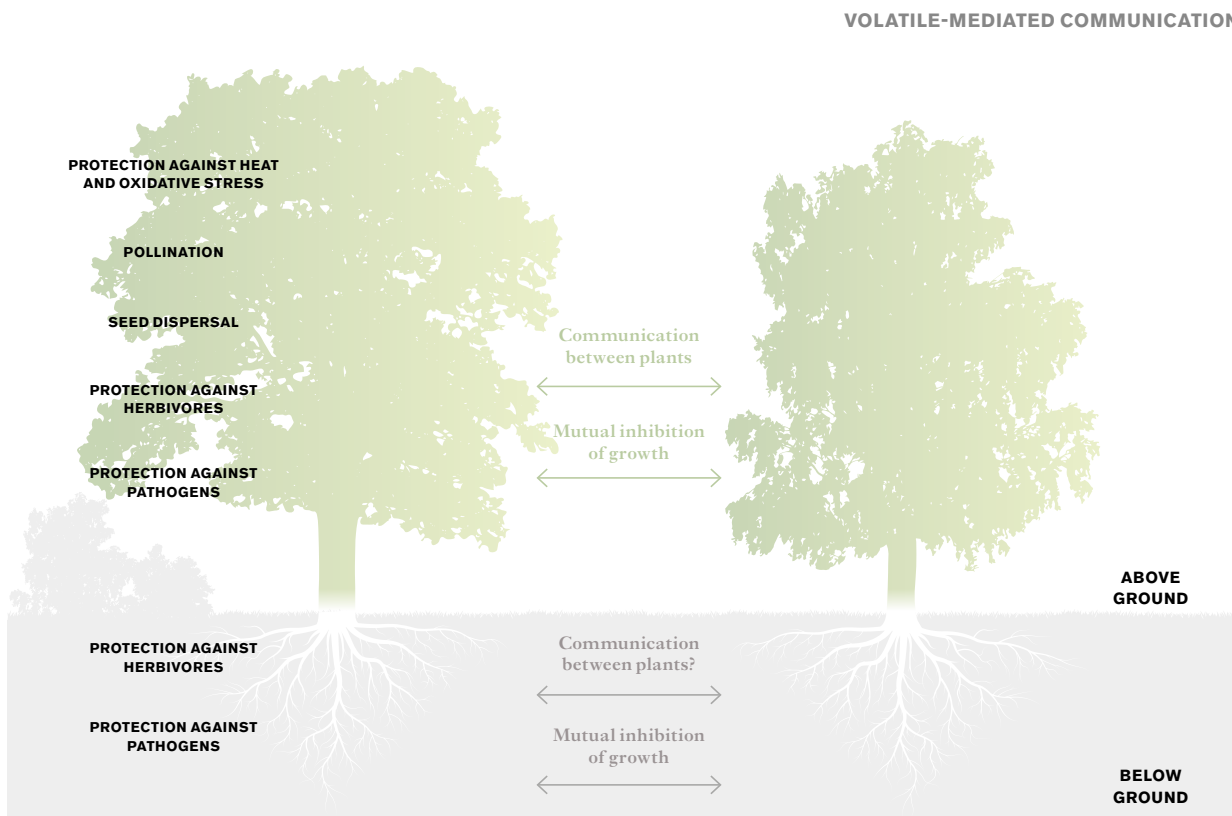
think it’s great that someone has managed to draw attention to the forest ecosystem,” says Unsicker.

While Wohlleben promotes greater appreciation of trees and the forest, Unsicker and her team continue to collect scientific data. In addition to the gypsy moth, trees usually have to deal with a host of other enemies. For example, black poplars are often attacked by rust fungi, which can spread to most of the tree crown in late summer. The fungal spores are blown onto the leaves by the wind or washed by rain onto lower parts of the crown. They then penetrate the leaves through the stomata. After a few days, they form spore deposits that penetrate the leaf surface as orange pustules from which new spores are released. In a pilot study, Unsicker’s co-worker Franziska Eberl sprayed some of the small poplars in

the greenhouse with rust spores and also put gypsy moth caterpillars on the leaves. An analysis of the leaf scents showed that leaves exposed to such a double attack gave off a completely different odor profile than leaves on which only caterpillars had chewed. “The leaves smell a bit like mushrooms. The proportion of terpenes is considerably lower, but the samples contain hydrocarbons that are typical for fungi,” explains Unsicker. The nitrogen-containing substances that predominate in the distress call to the parasitoid wasps are not affected by the rust.

Caterpillars love fungi

In particular, fungi can change the phenol content of leaves. For example,



GRAPHIC: BY GCO. ADAPTED FROM SYBILLE UNSICKER

Volatiles released from plants perform various tasks – both above and below ground. Trees thus attract beneficial insects such as pollinators, seed dispersers, and enemies of herbivorous insects. They are also in contact with each other – some volatiles can inhibit the growth of their neighbors or warn them of heat and pests.

GLOSSARY

GYPSY MOTH (*LYMANTRIA DISPAR*)

Moth belonging to the family of owlet moths. The name refers to the behavior of its larger caterpillars, which generally migrate each day from the leaves to rest in shaded spots. The eggs are laid on the trunks of the trees and survive the winter. The caterpillars hatch in the spring; they prefer to eat oak leaves but do not reject the foliage of other deciduous and coniferous trees.

Gypsy moths are among the most feared pests in oak forests. A single caterpillar can destroy one square meter of leaf surface from the time it hatches to the time it pupates. Their mass propagation can defoliate entire oak forests and cause permanent damage to the trees.

PHOTO: SYBILLE UNSICKER / MPI FOR CHEMICAL ECOLOGY



The researchers capture the gaseous odor signals of the leaves in plastic bags and pass them through a filter. They then determine the chemical structure of these volatile substances in the laboratory.

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they trigger the formation of catechins, the basic building blocks of various tanning agents, in the leaves. These are harmful to the fungus. Because rust can pervade the treetops in late summer, it could also influence the prevalence of other natural enemies of the poplars. But the real surprise for the researchers was that the fungal odor apparently does not bother the caterpillars! On the contrary: faced with the choice between healthy and fungus-infested leaves, the caterpillars clearly prefer the latter. Long-term observations even show that especially very young caterpillars are attracted by the odor. They first nibble the rust from the leaves before they attack the leaves themselves days later.

The researchers initially considered their findings to be a measurement error – the gypsy moth caterpillars

were thought to be pure herbivores. “We therefore conducted the same experiment with the closely related *Orygia antiqua* – with the same result: it is also crazy about the rust.”

High protein diet

At first, Unsicker suspected that the fungus-infested leaves might produce fewer toxins because the caterpillars develop faster on them and pupate earlier. But that is not the case. It is rather the components of the fungi that are the cause: the spores are rich in nitrogen and contain many amino acids and B vitamins essential for the development of the caterpillars. “Fungi and other microorganisms might therefore have had a stronger influence on the communal evolution of plants and insects than previously assumed,” says Unsicker.

The extent to which the findings can be transferred from poplars to other tree species is not yet fully understood. For example, during some years, oaks can suffer severe damage from massive infestations of gypsy moths. Forest rangers and forest owners currently spray forests with pesticides in order to limit the economic damage. “From an ecological point of view, it is quite natural that species like the gypsy moth repeatedly appear in great numbers. Nature would normally regulate this itself in each case because the natural enemies respond to the increased food supply and decimate the gypsy moth population again. Pesticides should therefore be used only in such a way – if at all – that enough predators will be left to keep future moth populations in check.”

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BEYOND THE EMERGENCY

TEXT: EVA VÖLKER

Five years ago, the arrival of thousands of refugees within a short period of time presented the administrative offices of the German municipal authorities with a huge challenge. Taking three towns in Lower Saxony as an example, Miriam Schader from the Max Planck Institute for the Study of Religious and Ethnic Diversity in Goettingen studied how the municipal authorities handled the situation.

um-sized towns (with 165,000 and 130,000 inhabitants) and one small town (with 80,000 inhabitants) in Lower Saxony, she analyzed examples of the structures and administrative procedures that were in place when the refugees were received. In 2015/16, the three towns took in up to 100 new arrivals every week. This presented them with an enormous challenge, since no information was provided in advance as to how many people would arrive and what their particular characteristics or requirements were. Furthermore, the legal framework in Germany was repeatedly changed by a large number of new or amended laws, which were passed in quick succession from 2015 onwards. The individual local authorities also found it hard to retain an overview of EU political developments.

Although the authorities often had to react spontaneously and an enormous amount of work was involved, the local structures certainly didn't collapse during this period. Instead, the administrations in many local authorities made sure that the new arrivals were received properly and that the departments involved coordinated with each other. "With reference to Merkel's famous words, the municipalities can say: 'We made it,'" says Miriam Schader, the author of the study. The administrations in all three towns studied first initiated an "emergency operation" so that decisions could be made quickly. This enabled them to overcome the period of uncertainty in the short term. However, clear differences emerged between the local authorities, particularly in terms of how they handled the medium- to long-term challenges. This was ascertained by the scientist following numerous interviews with staff working in the administrative offices at different levels.

We've arrived: during the peak of the 2015/16 migration, over 100 people seeking protection arrived in German towns and municipalities every week. This presented a challenge to the local authorities, but it was one that they were able to meet.

"We can do this." With these words, Germany's Federal Chancellor Angela Merkel attempted to reassure the country at the end of August 2015. Just a short time previously, Germany had suspended the Dublin Regulation for Syrians. This meant that the refugees were no longer sent back to the country in which they first entered the territory of the European Union. On 4 September 2015, the German and Austrian governments decided to accept thousands of people seeking protection who had become stranded in Hungary. Almost overnight, towns and municipal authorities had to find accommodation for the new arrivals. With incredible speed, gymnasiums were turned into temporary accommodation, and food and medical supplies were organized.

Today, five years later, the question arises as to whether Merkel's optimism was justified. Miriam Schader, a sociologist at the Max Planck Institute for the Study of Religious and Ethnic Diversity, has been looking for scientific answers. In two medi-

For example, the middle town of the three that were studied temporarily refused to accept any more asylum seekers. When significantly fewer asylum seekers entered Germany following the closure of the Balkan route in the spring of 2016, the local authorities quickly resumed their normal everyday business. Nothing was changed with regard to some structures, and reception capacities were quickly reduced again. Today, for example, there is now just a part-time employee working in the office for integration in the municipal authority, and with ten new asylum seekers arriving every week, reception capacities are already fully stretched. The two other municipal authorities developed a very different strategy. They turned a period of uncertainty into a period of fundamental change, by actively shaping the situation themselves and improving the structures for migration and integration





PHOTO: PICTURE ALLIANCE / DPA | ALEXANDER KOERNER

that had previously been in place. For example, the largest of the three towns studied merged two administrative areas responsible for migration and integration in order to make it easier for refugees to access various state support payments, such as child allowance, the services provided in accordance with the Asylum Seekers Benefits Act, and Hartz IV social support funds. The smallest of the three towns set up an advice center for administrative and legal issues, which worked closely with voluntary integration advisers. On its own initiative, it created a new bus link to the accommodation housing the asylum seekers, which was located outside the town center. Asylum seekers were also issued with an electronic health insurance card. These measures and the new structures in two of the towns were not only intended to deal with the consequences of the immigration wave in 2015/16, but also to better re-

flect the migration and diversity among the local population in the long term. In this way, two of the three municipal authorities studied proved their ability to cope and to develop a sustainable strategy.

However, the measures designed to improve participation also went hand in hand with a process of exclusion. Much of the accommodation offered was simply buildings that had been quickly converted, which were only suitable for habitation to a limited extent, and which offered almost no private space, even though large numbers of people lived there for longer periods of time. Other buildings were located in the middle of industrial estates. By only housing men in accommodation facilities, the refugees were further isolated in some cases, since there was no support from volunteers, for example. “Some buildings were also used for disciplining those who

did not fit in, and for disciplining those who preferred to be cautious for fear of being assigned to a certain accommodation building,” Schader explains.

Overall, the study concludes that municipal authorities made little use of orientation aids such as best practice models. This also created a patchwork of different municipal models for receiving refugees. The experience of the people seeking protection therefore varied between one place and another. The opportunity was not used everywhere of making long-term changes in order to receive the refugees. According to the Miriam Schader’s findings, this omission indicates a lack of far-sightedness. After all, it’s only a question of time before more people arrive in Germany seeking asylum. ←

A riot of color in the laboratory: among other projects, Lars Grunenberg, Bettina Lotsch and Julia Kröger (from left) are investigating the wavelengths of light at which their photocatalysts produce hydrogen from water. Here, Lars Grunenberg takes a sample to determine the gas content.



THE LIGHT CONVERTERS

TEXT: KARL HÜBNER

The sun sends more energy to Earth than humanity needs. Researchers led by Bettina Lotsch, Director at the Max Planck Institute for Solid State Research in Stuttgart, are working on materials that can help us put this abundant supply to use for a whole host of purposes – even beyond the energy revolution.

Every photovoltaic cell shows that sunlight can be converted into an electric current. But, anyone who intends to store this solar power for later use first has to charge a separate battery, and this battery is generally based on lead or lithium-ion technology. The reason behind this separation is that, until now, the production and storage of solar power has relied on completely different materials and components. Against that backdrop, a group of scientists at the Max Planck Institute for Solid State Research caused a minor sensation in 2018 when they revealed

a material that could do both at the same time: convert sunlight into electrical energy – and then directly store this energy. As the headline on the Institute’s website said at the time, the researchers had created a “solar cell and battery combined.”

The material responsible for this breakthrough is called poly(heptazine imide) (PHI) and belongs to the class of materials known as carbon nitrides. Akin to polymers, these molecules feature a strict alternation of carbon and nitrogen atoms arranged into recurring patterns. Although the molecular layers themselves are two-dimensional, they are stacked on top of each other – layer by layer – in a structure resembling “holey” graphite.

Bettina Lotsch has been investigating this group of materials for a long time. The chemist is now the Director of the Nanochemistry Department at the Max Planck Institute for Solid State Research in Stuttgart and an

honorary professor at LMU Munich and the University of Stuttgart. “We create functional materials and teach them new tricks, especially with regard to their energy conversion and storage,” explains Lotsch. “Some of them are indeed all-rounders.” One such group of materials are carbon nitrides, which are so appealing to researchers because they are not only highly stable, but also simple, sustainable and inexpensive to produce.

Initially, the group did not intend to develop a solar battery material. The discovery was a “by-product,” so to speak, of research into another property of carbon nitrides – namely, their ability to do photocatalysis. This term is used by chemists to describe the process where a substance absorbs (sun) light and uses this energy to drive a chemical reaction. Photocatalysis is one of the research foci in Bettina Lotsch’s Department, where the production of clean hydrogen from water is one of the key reactions

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in the team's experimental work. This reaction also serves as a model for other interesting applications of photocatalysis, such as the synthesis of important basic chemicals by the reduction of carbon dioxide or atmospheric nitrogen. However, hydrogen is also of interest because it is considered to be not only a clean fuel and hence, energy storage medium, but also an environmentally friendly raw material for the future. Indeed, there is a good reason why the German federal government adopted a "National Hydrogen Strategy" in June 2020, in which hydrogen is described as a "key component of the energy transition." At present, however, there is a lack of widespread infrastructure for handling this flammable gas. Moreover, most hydrogen is still

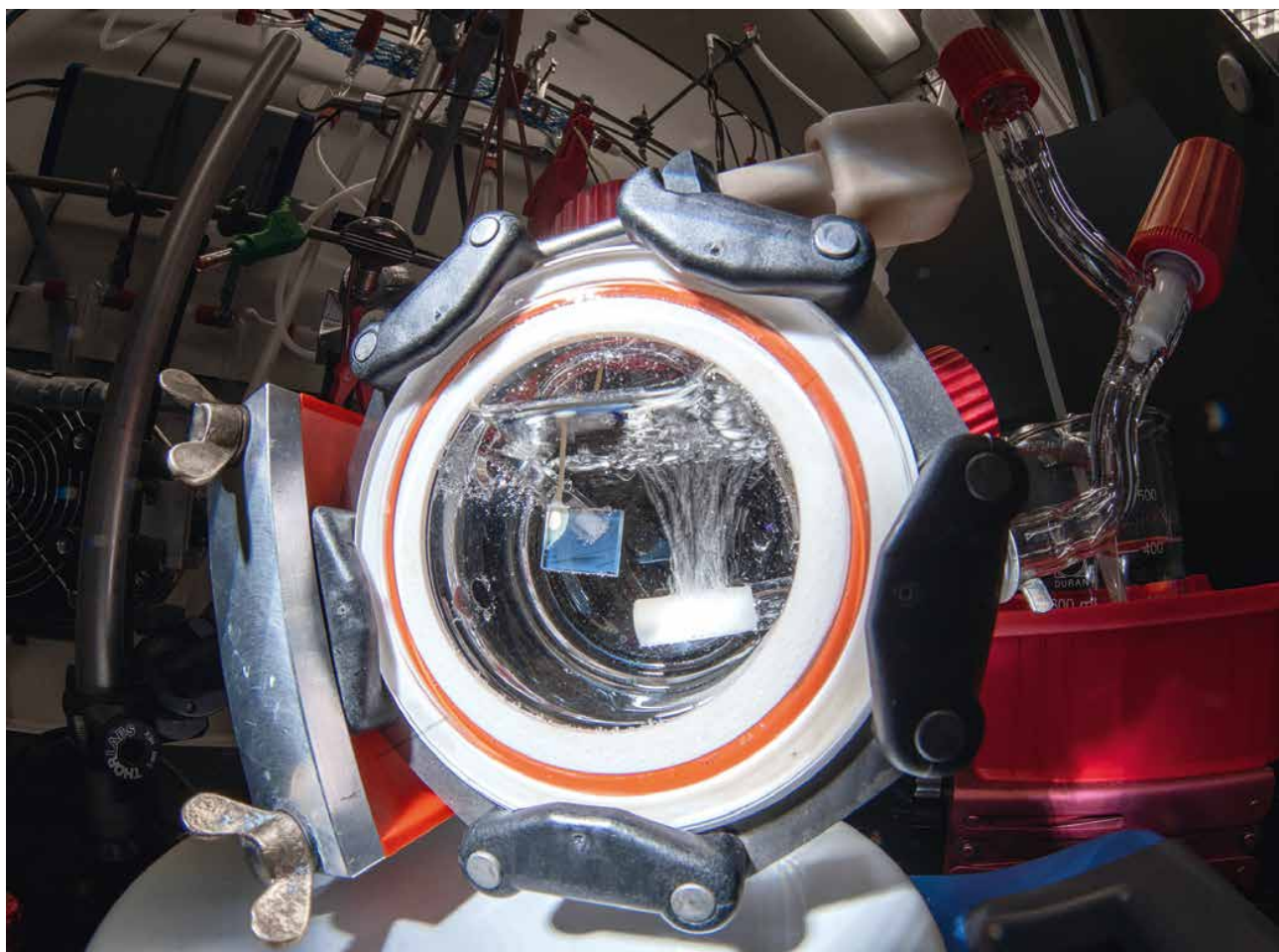
produced from natural gas and is therefore not only a fossil energy source, but also – for technical reasons – insufficiently clean for its use in applications such as fuel cells. Although hydrogen could also be obtained electrolytically from water using renewable electricity, the more economically viable – and more elegant – solution would be to split water directly into its components using sunlight. In other words, by using photocatalysis.

Electrons transfer energy to water

In principle, this process was already demonstrated almost 50 years ago, by

using titanium dioxide as a photocatalyst – but this approach never became widely used in industry. Modern research focuses on more promising material candidates, including carbon nitrides, which can now be observed in action at a laboratory in Stuttgart. At the bottom of a brightly illuminated glass apparatus, a yellow-colored powder is visible, immersed in a liquid. "The powder is a carbon nitride, the liquid is water, and the reason why the whole thing is so bright is that we're illuminating it from above with a solar simulator," explains Filip Podjaski, a physicist in Bettina Lotsch's research group.

Podjaski explains the underlying principle: "The light excites certain electrons in the material, which in turn



SUMMARY

Photocatalysts such as poly(heptazine imide) (PHI) or suitable covalent organic frameworks (COFs) use energy contained in (sun) light to drive chemical reactions and, for example, produce hydrogen from water.

PHI can store energy harvested from light and make it available at later times, either for a chemical reaction or in the form of electricity.

This property could be used to create a solar battery that is charged directly by light, to produce hydrogen or other substances, or to power microswimmers.

transfer their energy to the water and thereby produce hydrogen from it.” But the exact processes involved are not that simple. On the one hand, the absorbed light must be sufficiently energetic to excite an electron that can drive this reaction. On the other, the photogenerated electrons must be extracted from the material before they return to their ground state and lose their energy. To prevent this, the researchers in Stuttgart add compounds that provide electrons readily to the photocatalyst – “electron donors” – so that the ground state becomes populated again, and the excited electrons remain available for use. Besides, there is also the “co-catalyst,” which plays a crucial role in hydrogen production by acting as a matchmaker between the reaction partners. To facilitate most experimental purposes, the researchers currently use the common – albeit rare and expensive – metal platinum as their catalyst. However, they are also working on possible alternatives with a view towards developing a more economical and sustainable solution for future applications.

In principle, such hydrogen production already works well at the laboratory scale, but there are a number of technical issues to be resolved before a process of this kind is ready for widespread use, including in commercially available systems. However, as an aside to their research, the team also asked themselves: what would happen if we simply left out the co-catalyst? Theoretically, with continued exposure to light, more and more electrons would become excited but would have nowhere to go. “Usually, the electrons then decay to their ground state while releasing – or emitting – their energy without practical use, and heat is created,” says Filip Podjaski.

However, that was not the case with one particular material, namely with PHI. Provided that an electron donor was present, the photoexcited electrons retained their energy permanently and accumulated within the material,

even over the course of several days. In fact, the electrons remained in this state until the scientists added the co-catalyst, which triggered the hydrogen production to begin immediately. This phenomenon was an exciting – indeed an “electrifying” – discovery for the researchers. All of a sudden, they seemed to be able to decouple light absorption and catalysis for a long period of time – just as nature does with the light and dark reactions in photosynthesis, during which light energy is absorbed first and sugar is then produced in a subsequent process. So now, energy could actually be stored temporarily, like in a battery, and then be used for a chemical reaction at the touch of a button and at any point in time – even at night. In the scientific community, the paradoxical term “dark photocatalysis” began making the rounds. And so, the idea of the solar battery was born.

Hydrogen propulsion without a tank

Since then, the scientists have been working on understanding the underlying charging and storage mechanism. After all, how can it be possible for so many negatively charged electrons to accumulate in such a small space? The researchers have since learned that positively charged ions from the material itself and from the surrounding aqueous electrolyte play a stabilizing role.

A material that can store light energy electrically would be useful in a variety of applications. For example, Filip Podjaski envisages hydrogen engines that could work without a fuel tank: “You could use light to accumulate electrons in PHI at any time and then release them whenever you wanted in order to produce the required hydrogen from water.” For Bettina Lotsch, the battery-like behavior raises the possibility of “choosing whether to use the stored energy as electricity as



Testing nanomaterials: the Max Planck team in Stuttgart uses a specially developed reactor to analyze how efficiently photocatalysts can produce hydrogen. The gas produced at the catalyst-coated electrode (light blue) is not visible. The bubbles seen here stem from the noble gas argon, that is used by the researchers to remove oxygen from the reaction solution, which otherwise would distort the measurement.

well.” With a simple switch, users could then decide for themselves whether they wanted to use the charged battery to produce hydrogen for a car or to operate a lamp and refrigerator instead. In other words, this technology could provide a versatile solar battery for every household. Moreover, the ability to decouple light absorption from photocatalysis has now proven beneficial for a completely different application – namely, light-driven “microswimmers”, which are key topic of research at the neighboring Max Planck Institute for Intelligent Systems (see MaxPlanck-Research 3/2016). It was shown that these swimming micromachines can also be made from PHI particles, while photocatalysis can be used to propel them efficiently through a liquid.

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Microswimmers for medicine and environmental protection

Researchers have long known that this type of photocatalytic propulsion system works, but the ability to store the absorbed energy in PHI has now opened up a raft of new applications. “A microswimmer of this kind is not only powered by direct exposure to light, but also continues to move in the dark,” says Bettina Lotsch. The chemist even envisages that these microswimmers could one day be designed for use in the human body – once charged, they could continue to swim (in the dark) inside the organism. Another idea is to load microscopic vehicles of this kind with drugs for delivery to a specific location in the body. And perhaps, says Lotsch, a microswimmer made from a photocatalyst could even use catalysis to produce the necessary active agent in situ from substances available in its environment.

However, Lotsch also envisages medical applications of photocatalysis outside of the body. For example, microswimmers could potentially aid the chemical breakdown of metabolic products in the bloodstream during dialysis. Similar applications are conceivable in wastewater treatment – essentially, a photocatalytically active swimmer that would conduct light-powered patrols through dirty water in order to remove unwanted substances. In the future, the researchers led by Bettina Lotsch want to pursue ideas such as these in collaboration with their colleagues at the Max Planck Institute for Intelligent Systems.

But carbon nitrides such as PHI aren’t the only materials that the group uses for their photocatalysis research. The scientists also have great expectations for a group of materials known as covalent organic frameworks (COFs). Much like carbon nitrides, COFs form extended layers that then arrange on top of one another. These materials are characterized by their high porosity, with specific surface areas that can reach half the size of a soccer field per gram. This is an ideal characteristic for a photocatalyst, because it is the surface on which reactions catalyzed.

But the key advantage of COFs is that they can, in principle, be constructed from almost any kind of organic building blocks, and these precursor molecules are subject to just a few basic requirements. In other words, they provide huge scope for molecular design. This is particularly beneficial for chemists, in that it allows key properties of a COF to be “tailored” – as Lotsch puts it – by choosing suitable building blocks. In the context of photocatalysis, one key characteristic is light absorption, and the COF designers in Stuttgart have now created novel varieties that absorb from violet to orange – thereby covering almost all of the visible spectrum, which represents about 50 percent of the energy

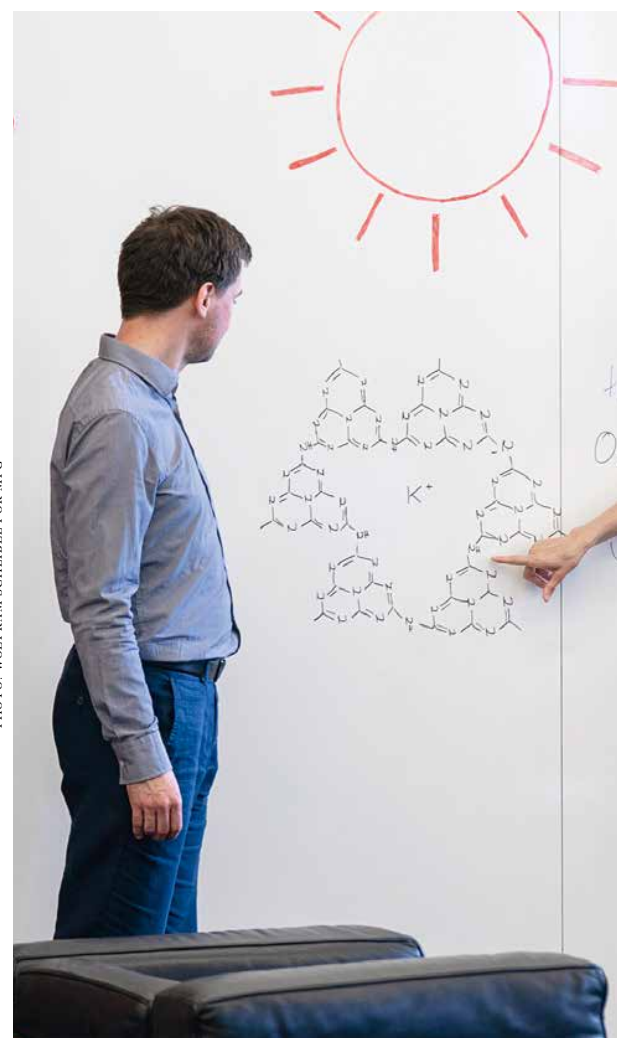


PHOTO: WOLFRAM SCHEIBLE FOR MPG

provided by sunlight. On the other hand, if carbon nitrides are used, absorption is limited to blue light only. There is a simple reason why the researchers are mostly interested in materials that absorb light over a broad spectrum: the more light a photocatalyst can absorb from the solar spectrum, the more charge carriers it can supply for catalysis.

Or rather, the more it can potentially supply – because, in order to actually put the absorbed energy to use, it’s also important that the electrons retain it for as long as possible and pass it on efficiently. So far, COFs have been unable to rival the effectiveness of the carbon nitrides, but Bettina Lotsch’s group is working to change that by subtle variations of the COF building blocks. One day, this may



Searching for the optimum catalyst: Filip Podjaski, Bettina Lotsch, Lars Grunenberg and Julia Kröger (from left) discuss the electronic processes involved in splitting water molecules. An understanding of these processes helps them to develop materials that work more efficiently.

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pave the way for something the researchers have high hopes for: the direct, stable storage of solar energy in a completely new type of battery.

Yet the question of sustainability remains unanswered. Indeed, the team in Stuttgart isn't merely looking for functional materials that are particularly effective at tasks such as photocatalysis. "Of course, we also want these substances to be easy and sustainable to produce, ideally from renewable resources," explains Lotsch. Carbon nitrides are absolutely perfect for this, because they can be readily obtained from urea – a natural resource. Depending on the building blocks used, COFs are still ultimately derived from crude oil, but it doesn't stay that way. "As they are organic substances, they are potentially re-

newable," says Lotsch. In this context, her colleague Filip Podjaski points out that, for historical reasons, the chemical industry can obtain many of its important basic chemicals – and therefore also the derived products, such as the COF building blocks – from a hydrogen/carbon monoxide mixture known as syngas. And although these two components have previously been obtained from fossil sources, they could also be produced from water and carbon dioxide with the help of photocatalysis. Therefore, if suitable recycling concepts were incorporated, these versatile light converters could pave the way for a fundamentally sustainable circular economy, as Podjaski explains. One day, therefore, photocatalysis could potentially turn large parts of chemical production "green".

GLOSSARY

GROUND STATE

The electronic state of an atom or molecule in which it has a minimum of energy. Electrons can be excited by (visible) light with a suitable energy – that is, light of a suitable color. The so absorbed energy can then be transferred and, hence, released in different ways, while the electrons return to their ground state.

COVALENT ORGANIC FRAMEWORKS

Known as COFs for short, these materials are made from organic building blocks; they have a large specific surface area and are highly variable in terms of their structure and composition, which is due to the variety of potential starting materials.



RISKY COOLING

TEXT: TIM SCHRÖDER

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Volcanoes are sources of ideas. When they erupt, they emit large amounts of sulfur dioxide, cooling the climate. This has prompted experts to discuss whether geoengineering involving the targeted release of the gas could reduce global warming. Ulrike Niemeier from the Max Planck Institute for Meteorology in Hamburg is investigating the feasibility of the idea and the dangers it might entail.

The Pinatubo eruption was enormous. When the Philippine volcano blew off its summit in June 1991, a gigantic ash cloud ascended into the sky. It plunged the island of Luzon into darkness in the middle of the day. Huge amounts of ash rained down on an area as large as Baden-Wuerttemberg, Bavaria, and Hesse combined. It buried streets under a layer that was sometimes several meters deep. Hundreds of people died, and tens of thousands lost their homes. The eruption was so powerful that ash and gases

were blasted into the stratosphere, three times higher than commercial airliners fly. The mountain shook for hours, simultaneously spewing out eight million metric tons of sulfur dioxide. Within just a few days, long-range air currents in the stratosphere dispersed the gas over the entire northern hemisphere. And this led to an interesting phenomenon: the Earth became cooler.

We've long known why such cooling occurs. Sulfur dioxide reacts in the atmosphere with water vapor to form sulfuric acid, which reacts further to form sulfate particles. These remain airborne for a period, reflecting a portion of the Sun's rays striking the Earth. This cools the underlying layers of the atmosphere, explaining why climate researchers find the eruption of Pinatubo, one of the strongest vol-

canic eruptions in the previous century, so intriguing.

“The eruption clearly proved that sulfur dioxide has a measurable effect when it enters the atmosphere,” explains Ulrike Niemeier, a scientist at the Max Planck Institute for Meteorology in Hamburg. For years, Niemeier has sought to describe how the sulfur dioxide and ashes emitted by volcanoes affect the Earth's atmosphere. She uses computer simulations to model the effects of volcanic gases on the climate. These include major eruptions in prehistoric times of so-called super-volcanoes, which were many times more powerful than Pinatubo. The eruptions of the Yellowstone volcano about two million years ago, for example, released approximately 200 times more matter than Pinatubo did in 1991. Using computer simulations,

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Models for climate engineering: active volcanoes such as Nishinoshima, 1000 kilometers south of Tokyo, release huge amounts of sulfur dioxide. Particles form from this gas and remain suspended in the atmosphere, reflecting sunlight back into space.

A change of course in research: Ulrike Niemeier researches the impact of volcanic eruptions on the climate, increasingly focusing on the possible effects of seeding the Earth's atmosphere with sulfur dioxide.



PHOTO: TOM PINGEL FOR MPG

Niemeier has calculated how these gigantic quantities may have been distributed throughout the Earth's atmosphere – how the matter cooled down and ultimately altered the global climate.

Over the last 15 years, volcanic sulfur dioxide's cooling effect has led to a shift of Niemeier's research from her original focus – the role volcanoes play in the climate – toward a different field of climate research. The impetus has been anthropogenic warming of the Earth's climate, raising the question of whether we might be able to artificially cool it down. One of the first scientists to suggest this idea was the atmospheric chemist Paul Crutzen, who for many years was the Director of the Max Planck Institute for Chemistry in Mainz. Crutzen published a provocative paper on the subject in 2006. To counteract the impact of the continuous increase in carbon dioxide emissions, he asked whether humanity might need to use technology to intervene in the climate in the future to mitigate the worst effects of climate change. Such climate fixes became known as geoengineering or climate engineering (CE), which now encompasses a wide range of technical strategies. Targeted climate interventions generally fall into two categories: carbon dioxide removal (CDR) and radiation management. The aim of CDR is to remove carbon dioxide from the air, bind it, and safely store it in the long-term. The reforestation of huge, previously unforested areas is under discussion, as is fertilizing the sea with iron to stimulate algal growth. "At present, the most realistic and reasonable solution appears to be systems that filter carbon dioxide out of the air or capture it from the exhaust gases of power stations and industrial plants," says Ulrike Niemeier. This method is known as carbon capture and storage (CCS). The Dutch are already working on implementing it. As part of the Porthos project, in the coming years, a pipeline is to be laid at the Port of Rotterdam parallel to the refineries, power plants, and cement works, into which carbon dioxide from exhaust gases will be fed. The carbon dioxide will then be pumped

down the pipeline into a depleted natural gas reservoir under the North Sea.

A controversial idea

The second climate engineering category, known as radiation management, includes methods that directly impact the Earth's heat balance. One particularly bold idea in this category is solar radiation management (SRM), shading the Earth in space with huge sunshades – a plan that is still considered to be in the realm of science fiction. But there are also options on a smaller scale: aircraft, for instance, could scatter particles into the atmosphere, which could then reflect some of the Sun's radiation back into space. This idea, however, exposed Paul Crutzen to a storm of indignation. It is always hubris, so the detractors, to try to alter the Earth's radiation budget using technology. Furthermore, the impact of such a massive climate intervention would be impossible to predict in the various regions of the world. After many years of research, Ulrike Niemeier agrees with this view. "While CDR only reduces carbon dioxide concentration in the atmosphere, radiation management influences the amount of solar energy reaching the whole of the world's surface."

Aerosols could slow down heating

All the same, Paul Crutzen's paper triggered considerable scientific interest in climate engineering. As experts in simulating sulfur clouds from volcanic eruptions and their impact on the climate, Ulrike Niemeier and her colleague Claudia Timmreck were also much in demand. At that time, they had just developed a unique simulation tool: a stratospheric aerosol model, which could be employed to calculate the impact of sulfur dioxide or sulfate particles in the stratosphere. Aerosols are particles of a few nano-

meters to several micrometers in size, which are so small and light that once they have been thrown up into the atmosphere, they almost never sink back to the ground. Sulfate particles in the stratosphere are also aerosols. Ulrike Niemeier was able to use her model to calculate how quickly and ef-

SUMMARY

Geoengineering, or climate engineering, is viewed as one way of halting anthropogenic climate change – whether through reforestation, subterranean storage of carbon dioxide, iron fertilization of the ocean, or shading the Earth by means of sulfate particles produced from sulfur dioxide.

According to simulations, the average global temperature could be maintained at the level of 2020 without reducing greenhouse gas emissions if five to eight times more sulfur dioxide were released into the atmosphere each year than from the 1991 Pinatubo eruption.

According to the calculations, the reduction in energy input from the Sun would disrupt large air currents in the tropics, for example, with unforeseeable consequences for the global climate. Aerosols formed from sulfur dioxide would also likely reduce average global rainfall. This could trigger conflicts between nations, some choosing unilaterally to go on releasing the gas and others suffering from the reduction in rainfall.

ficiently small sulfate particles form from sulfur dioxide, and how quickly they clear up once again by gradually clumping together and sinking down from the stratosphere.

"At the time, along with colleagues we tried to clarify whether climate change induced heating of the Earth could theoretically be compensated



for by sulfur dioxide,” explains Niemeier. Their investigations were part of Implicc, a large EU project led by her colleague Hauke Schmidt, which examined “Implications and risks of engineering solar radiation to limit climate change.” The findings were clear and – much like Crutzen’s article – controversial: yes, global warming could indeed be compensated for, even in the worst-case scenario outlined by RCP8.5, the Intergovernmental Panel on Climate Change. In this “business-as-usual” scenario,

CO₂ emissions would continue to rise in the coming years. The Implicc partners calculated that the temperature level of 2020 could be maintained by means of large-scale sulfur dioxide injections into the atmosphere. “On average, the climate would remain milder worldwide,” says Ulrike Niemeier. “However, average global rainfall would slightly decrease.”

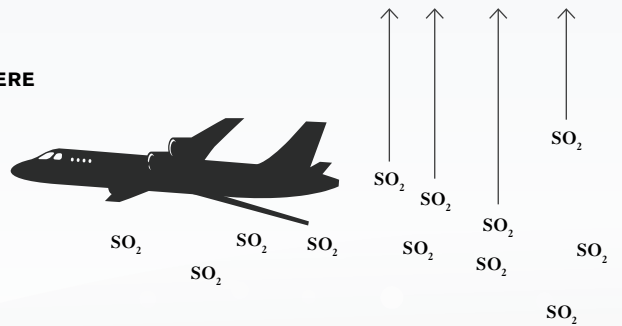
This would however be problematic to put into practice. “If, despite rising CO₂ emissions, we were aiming to

maintain 2020’s climate through to 2100 with the help of sulfur dioxide alone, humanity would have to release five to eight times as much sulfur dioxide into the stratosphere each year than that from the 1991 Pinatubo eruption,” says Niemeier. That would be absurd. A Japanese research team arrived at similar conclusions, calculating that 6,700 airplanes would have to distribute sulfur dioxide in the stratosphere every day to reduce global warming by one single degree Celsius. For comparison, at London’s

METHODS OF GEOENGINEERING

AEROSOLS IN THE ATMOSPHERE

Aircraft, balloons, or drones, for example, introduce sulfur dioxide into the stratosphere. There, particles form that reflect a portion of the sunlight.



CO₂ CAPTURE AND STORAGE

The greenhouse gas is separated from the exhaust gases of power and cement plants, for example, and pumped into former oil and natural gas sites or into deep aquifers.



DIRECT CAPTURE OF CO₂

Huge filters extract CO₂ from the air, which is then stored underground.

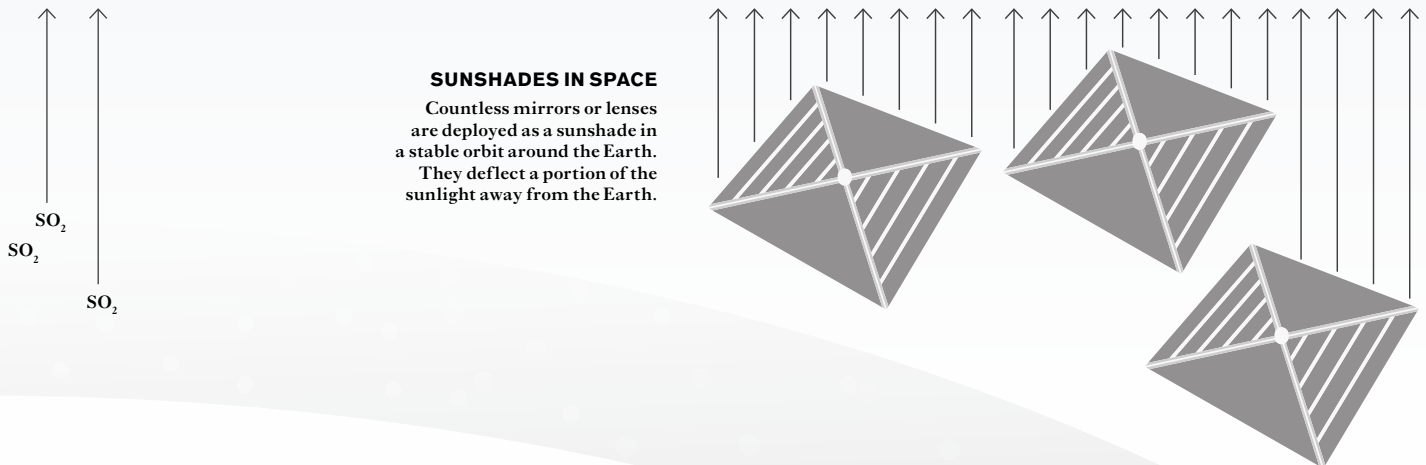


Heathrow Airport, 1,200 aircraft take off every day at peak times. Ulrike Niemeier also stresses that such sulfur dioxide releases would have significant side effects. Bright blue skies would be likely to take on a milky appearance. Worldwide, rainfall would decrease on average, and the monsoon and large air currents in the atmosphere would change due to our efforts to reduce solar energy input. Solar radiation would drop more steeply in the tropics than at the poles, thereby reducing the temperature

gradient between the two regions, which could weaken air currents. The quasi-biennial oscillation (QBO), one of the large stratospheric air currents in the tropics, would be affected. Every two years it changes its direction – from west to east and then back again. Coupling her aerosol model with the MPI-ESM, the large climate model of the Max Planck Institute for Meteorology, Ulrike Niemeier investigated what would happen to the QBO. “The calculations clearly show that a large-scale sulfur dioxide injection

would lead to the collapse of the QBO,” says Niemeier. “We have no way of predicting what impact this would have on the global climate.”

Andreas Oeschle from the GEOMAR research center in Kiel considers research such as Ulrike Niemeier’s to be groundbreaking. “She’s one of the very first to have analyzed in detail the chemical-physical processes in the stratosphere,” says Oeschle, who is an expert in climate engineering. “She has supplied quantitative, robust



SUNSHADES IN SPACE
 Countless mirrors or lenses are deployed as a sunshade in a stable orbit around the Earth. They deflect a portion of the sunlight away from the Earth.

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GRAPHIC: GCO



REFORESTATION
 Plants, especially trees, bind CO₂, removing it from the atmosphere.



IRON FERTILIZATION OF OCEANS
 Iron sulfate is a micronutrient for algae, causing them to proliferate and absorb CO₂. When they die, they sink to the seafloor.

data, which can be used to correctly calculate the climate in the future if we implement such climate engineering.” The discovery, for example, that sulfate particles clump together over time has been pivotal. In other words, it won’t help to pump ever more sulfate into the stratosphere, because the aerosols will just clump and sink at a higher rate. Saturation is bound to occur at some point, no matter how much sulfate airplanes spray. “Niemeier’s findings have been essential in enabling us to assess how effective such radiation management methods might be,” says Oschlies. Ulrike Niemeier has also analyzed the effect of different sulfur dioxide release methods, for example, whether daily releases of the gas or releases at other particular intervals would be more effective. She discovered that releasing large quantities into the

stratosphere over a period of one month would result in far less particle clumping than daily releases. Not only that, the cooling effect was highly dependent on where on Earth the sulfur dioxide was released. The models suggest that injections at several points around the tropics would have the greatest impact.

Such findings make it sound like Niemeier and other experts have already worked out a climate-engineering master plan. But, according to Ulrike Niemeier, nothing could be further from the truth. “I believe there’s only one way to halt climate change: reduce CO₂ emissions as quickly as possible. Because one thing’s clear: radiation management would only be treating the symptoms. It wouldn’t do anything to solve the real problem, carbon dioxide.” Never-

theless, investigating climate engineering is important. If the climate were to change extremely rapidly, climate management measures could at some point be placed on the political agenda as an emergency option – the lesser of two evils in comparison to massive climate impacts. “If it ever came to that, we would need to know precisely what we would be getting into.” Nor can it be ruled out that at some point in this century, individual countries may embark on climate engineering on their own initiative – without consulting the worldwide community of nations. Politically, that would be a fiasco, as it would affect the whole world. A solo initiative by individual nations or a small group of nations could therefore lead to conflicts, for example if rainfall decreased in other countries. Hence, for Ulrike Niemeier, the Ceibal project

GRAPHIC: GCO FROM MICHAEL BÖTTINGER/DKRZ



Historical cooling effect:
Ulrike Niemeier has calculated how the sulfur dioxide cloud that formed after the eruption of the Yellowstone volcano about two million years ago is likely to have spread over the Earth. Her results indicate that after eleven days, it covered large areas of the northern hemisphere. After about a month, it covered almost the entire northern hemisphere.

has been one of the most interesting she has worked on. Together with Hauke Schmidt, lawyers, political scientists, economists, and philosophers, she helped investigate whether and how climate engineering could be uniformly regulated internationally. The focus was on whether individual nations could be held liable for damage caused by their climate engineering activities.

In her work for Ceibral, Ulrike Niemeier attempted to deduce from models where the world's winners and losers of climate engineering measures would be. "However, it's incredibly difficult to causally link damage to a particular climate engineering measure," she says. "As an example, a five-week drought in Poland led us to ask whether climate engineering measures in Australia were to blame." She couldn't give a definitive answer. "But it was enormously exciting working with experts from the other disciplines, while developing a common language and mutual understanding of each other." It became clear that, at present, it would be difficult to prosecute a nation for climate engineering activities. No court in the world has ever tried such a case. Which institution would be responsible? "And in this respect, I think climate engineering also represents a crucial political issue," says Ulrike Niemeier. "Should we ever actually consider climate engineering, humanity will have to be extremely vigilant not to stumble into starting wars. At any rate, an international agreement regarding the matter of liability should be ratified beforehand."

Her collaboration in the Ceibral project and also her long-standing cooperation with other climate researchers as an expert in aerosols have shown Ulrike Niemeier how important academic exchange between disciplines is. "We have no idea whether we'll ever employ climate engineering," says Niemeier. "But we still need to prepare ourselves for it and, above all, be aware of the risks."

GLOSSARY

AEROSOLS are particles dispersed in the atmosphere, ranging in diameter from a few nanometers to several micrometers. They reflect solar radiation but also play a role in the formation of cloud droplets.

RADIATION MANAGEMENT is a method of climate engineering which would shield the Earth from a portion of the Sun's light by means, for example, of sulfate aerosols.

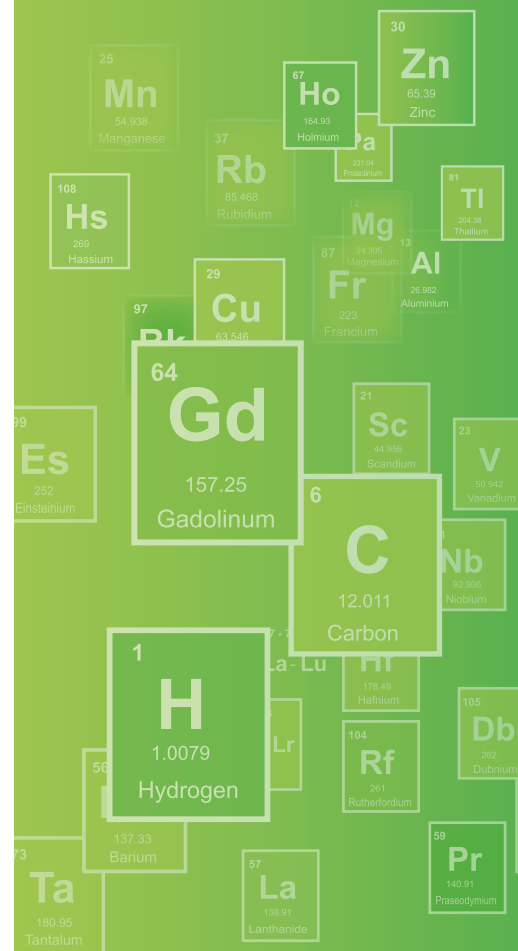
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The Koffler Tower is not just the symbol of the Weizmann campus, but also contains particle accelerators, an observatory and a seminar room with a breathtaking view.

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Max Planck researchers cooperate with partners in more than 120 countries. Here they write about their personal experiences and impressions. The physicist Elina Fuchs spent four years conducting research at the Weizmann Institute in Rehovot, after receiving a scholarship from the Minerva Stiftung, a subsidiary from the Max Planck Society. She reports on generous hospitality, unusual public holidays and colleagues who were happy to help.

On the first day, we were given a taste of the incredible hospitality in Israel. A colleague collected us at the airport and gave us a short guided tour of the campus site. When we entered our apartment that evening in October 2015, we saw that someone had filled the refrigerator with food. It turned out that the secretary had bought food for us, so that we would have enough to eat the next day, when the shops

were due to close early before the start of the Shabbat. My husband and I were immediately made to feel welcome.

We are both physicists and had both been given a job at the Weizmann Institute in Rehovot. For researchers, Israel is a paradise for a number of different reasons. The laboratories and the infrastructure are phenomenal, and there are plenty of opportunities for networking as well. Since we weren't far away, we met with particle physicists from Tel Aviv, Haifa, Jerusalem and Be'er Sheva nearly every week, and discussed new research. Also, guest scientists were very often invited to the Institute, and it was great to be able to discuss ideas with them and make contacts.

In my research, I focus on which particles might exist beyond the Standard Model, and how existing models can be tested and excluded. I am particularly interested in how the properties of the Higgs boson change in new models. Discovered in 2012, it is an elementary particle which helps give

other particles their mass. I'm also interested in any new particles we could be searching for. As it happened, a new model was presented just before I arrived, and my colleagues and I were able to use it to produce some very interesting results. I also got to be involved in the development of a new method at the interface between particle and atomic physics.

Israel is also a good place for pregnant women and young parents. Children are given a very high priority in a nation with the highest birthrate of all industrial countries (3.1). Since nearly all Israelis serve in the army before they study, with the women serving for two years, and the men for three, it's no exception for doctoral students to have a child. In fact, it's generally the rule. During my pregnancy and after the birth of our daughter, we benefited from flexible working hours, working from home and the Institute kindergarten. We were also offered help by individual colleagues. One Weizmann employee, whom we always came across on the train in the morning, gave us huge quantities of



REHOVOT, ISRAEL

baby clothes. And when our daughter was born, two colleagues brought home-made food to our door.

Of course, the greatest experience was the birth of our daughter. We were also very moved by the various festivities and family dinners to which we were invited. One colleague invited us to celebrate Pesach (Passover) with him and his family twice. This is the equivalent of a professor inviting a postdoc from another country to spend Christmas Eve at home with their family.

Overall, I found the Jewish holidays very interesting. The biggest “culture shock” was Passover. This commemorates the departure from Egypt, which is why most Jews do not eat leavened food, such as bread. A religious neighbor asked us to buy his entire stock of cornflakes, toast and spaghetti for a token amount, since he was not allowed to own leavened food. After Passover, he bought everything back, insisting that he pay more than we had paid him. In the four years I

spent in Israel, I had a few surprises when it came to the way people behaved. If you see someone approaching you on the sidewalk, it's better to get out of the way, otherwise they might simply barge into you. In Israel, it appears to be socially acceptable to talk loudly on the phone in buses and trains, or to watch films without headphones.

Overall, I really enjoyed the scientific and cultural and human experiences during my stay, and can thoroughly recommend a visit to Israel, whether as a tourist or a researcher. You'll discover delicious dishes, see breathtaking landscapes and be astonished by places of historical interest. You'll be smothered in hospitality – and on Yom Kippur, the most important national holiday, when the country comes to a standstill, you can cycle along the freeway.

*For information
on the Minerva Stiftung, see:
minerva.mpg.de/*



PHOTO: PRIVATE

Elina Fuchs

32, studied physics in Goettingen and Helsinki. For her Masters thesis, she switched to DESY in Hamburg, where she also gained her doctorate from 2012 to 2015. Since then, she has conducted research into theoretical particle physics beyond the Standard Model, and worked for four years as a postdoc at the Weizmann Institute of Science in Israel, with the support of the Institute and the Minerva Stiftung of the Max Planck Society. She is currently researching at the Fermilab and the University of Chicago as a Feodor-Lynen fellow.

“AN ESSENTIALLY CREDIBLE SCENARIO”

The ARD feature film *Ökozid* shows the legal re-appraisal of the climate crisis in the not so distant 2034. The two scriptwriters consulted experts at the Max Planck Institute for Comparative Public Law and International Law, including the scientific advisor and coordinator Alexandra Kemmerer.

Ms. Kemmerer, in the film, 31 countries of the global South sue Germany before the International Court of Justice because Germany had done too little to combat climate change. How realistic is such a scenario?

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ALEXANDRA KEMMERER: Of course, a feature film must always make compromises between real-life circumstances and a story that is exciting and understandable for the audience. However, despite the necessary reduction in complexity, the scriptwriters Andres Veiel and Jutta Doberstein have succeeded in conveying basic legal principles and an essentially credible scenario.

How did the cooperation work?

I had met Jutta Doberstein at a conference in 2018. In the summer of 2019, she told me about the film project and asked whether we would be able to support it. Jutta Doberstein and Andres Veiel are known for their thoroughly researched and scientific work – both for their film documentaries and fictional material. So I was happy to support them. A year ago, we held a kind of workshop at the Institute with the two scriptwriters and several scientists. For a whole day, we went through options on how such a process could be conducted and what the verdict would be. It was a joint effort – an exchange in which my colleagues Tom Sparks and Guillaume Futhazar and our Director Anne Peters were also substantially involved – and not just simply a consultation session. Of course, we cannot accept any liability for the result.



PHOTO: RBB/ZERO ONE FILM / JULIA TERJUNG

Unease among the population: the film *Ökozid* paints a dark picture of the future. In 2034, the Federal Republic of Germany is facing criminal charges for breaching its international statutory obligation to counteract the increase in the concentration of CO₂ worldwide.

Did people from the Institute also benefit from the cooperation?

Definitely. As a lawyer, you are trained to assess facts in court proceedings retrospectively. For the film, however, we had to imagine ourselves in the year 2034 and create scenarios for the future. That is a completely different way of thinking. Instead of assuming existing constraints, it is possible to open up potential spaces. This kind of thinking is certainly relevant to the legal field. Ministries often seek expertise in legal impact assessment. When drafting bills, it is essential to think ahead and classify future developments. In science, too, such “thinking in scenarios” based on precise factual and legal knowledge opens up possible solutions and promotes dexterity and flexibility in dealing with unforeseen risks, conflicts, and environmental changes. In this respect, we have learned a lot from the exchange with the scriptwriters.

Were you involved in the film production in any other way?

During the process, there were always questions of detail – for example about legal terminology or how lawyers and judges behave in court. Of course, we helped – even if not everything that we suggested was implemented. I was also able to read the finished script in advance and got the cut version for a screening. One interesting development was that the scenario we discussed a year ago has now turned out to be far less fictional than we had thought.

In what way?

There has been an incredibly dynamic development in the area of climate complaints. Just to name a few examples: in December 2019, the Dutch Supreme Court ordered the country’s government to meet its climate targets. This July, the Irish Supreme Court ordered the government to draw up a new climate plan for the period up to 2050. Proceedings are also under way at the Hamm Higher Regional Court, the Federal Constitutional Court, and the European Court of Human Rights, all of which are concerned with climate protection.

Do you think that climate protection will actually be enforced by courts in the future?

That is my assumption – but we also should not overestimate the role of the judicial system. The film itself is quite realistic, I guess. It also shows the tension between courts and democratic procedures. Courts can lead the way in climate protection – but they remain embedded in political processes and public debate. In the film, interaction with the public plays a major role. Subversive forces use social media bots to incite the population against the plaintiffs and their concerns. In the end, there are large public protests. This shows that the biggest challenge is to convince the broad majority that climate protection is important. Courts alone cannot create the global solidarity that is essential to meet the challenges of climate change.

Interview: Mechthild Zimmermann

WE DON'T HAVE TO LIVE IN A DOG-EAT-DOG SOCIETY

In the first round of the new event format “Science Meets Literature”, Matthias Sutter, Director at the MPI for Research on Collective Goods, and Marc Elsberg, author of bestsellers such as *Blackout* or *Zero*, discussed Elsberg’s novel *Greed*, which was published in 2019.

It was a lively and exciting discussion moderated by Maja Brankovic, editor at the *Frankfurter Allgemeine Zeitung*. The topic: cooperation as a basic model of the economy – a departure from previous doctrines such as competition and subsidiarity or even the model of homo oeconomicus, which assumes that people think exclusively in economic terms. The novel is based on calculations by the London Mathematical Laboratory, the purpose of which is to question currently widespread economic models. Marc Elsberg developed the farmer’s fable from a part of these complicated mathematical calculations. It illustrates the fact that merging and dividing is not a zero-sum game, but leads to increased prosperity for all concerned.

But as positive as cooperation may seem in fiction, there are limits in reality. According to Elsberg, this is the case, for example, when the effort involved in organizing and coordinating cooperation is greater than the resulting benefit for those involved. Sutter mentioned three additional factors that are essential for functioning cooperation: successful communication, the fact that people can rely on each other and on what has been agreed upon, and institutions that ensure that agreements are honored.

Elsberg believes it is quite possible that the idea could cause a similar epiphany as in the book because people have always cooperated intuitively. The idea of mutual support and sharing is embedded in the DNA of many philosophies and religions. “The paradox is: although humans have successfully cooperated

over thousands of years, the economic models of the last decades try to persuade us to do something else,” the author explains. “This is being refuted and it is demonstrated that what people like to do – namely to work together – is the right thing to do.”

We don’t have to live in a dog-eat-dog society. Instead, the principle of subsidiarity should be rethought: we should all work together – unless “together” doesn’t make sense. This would result in a completely different organization of society. According to Sutter, however, studies have shown that simply knowing that cooperation means success for everyone does not automatically lead to the appropriate behavior. The most important driver is communication, such as the promises of cooperation and, even better, the positive experience of cooperation. Both strengthen trust in the principle. On the question of when the ability to work together arises, Sutter cited studies showing that small children appear to have a natural predisposition for cooperation.

Marc Elsberg emphasizes the fact that merging and sharing do not create a communist or socialist society: “All ‘-isms’ kill cooperation – be it communism, socialism, fascism or liberalism. Because cooperation needs difference, which leads to increased growth – so it doesn’t mean that everybody is the same. Competition is not bad per se, but it is given a different role.” However, Matthias Sutter comments that “research also shows that the more different the participants, the more difficult cooperation becomes.”

Are you interested in different aspects of how cooperation works in fiction and science? Watch the discussion on the Max Planck Society's Youtube channel: [youtube.com/watch?v=sQEGMzHjtVE](https://www.youtube.com/watch?v=sQEGMzHjtVE) (in German)

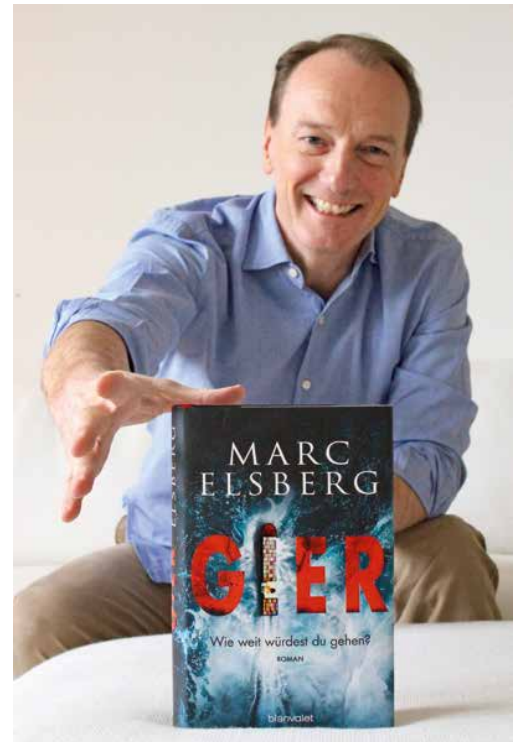


PHOTO: URSULA KUCHAR

How does cooperation work? For his novel *Greed*, author Marc Elsberg looked at the results of basic mathematical research.



FIVE QUESTIONS

ABOUT ENVIRONMENTAL PROTECTION IN BRAZIL

FOR RAQUEL SIROTTI

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The Brazilian government under President Jair Bolsonaro has been the target of international criticism for its lax environmental policies. The outrage was particularly great when, at a cabinet meeting in April, environment minister Ricardo Salles suggested taking advantage of the coronavirus crisis to relax the rules on protecting the rainforest. Did the protests against this have any effect?

RAQUEL SIROTTI Since the video of the meeting was published by court order, Jair Bolsonaro's government has received intense criticism – especially from international investors and funds supporting conservation projects. They threatened to withdraw their capital if the government didn't do more to protect the rainforest. In response, the president announced a decree banning slash-and-burn clearance for 120 days. The government is attempting to distance itself from the idea that it is opening the rainforest up to profiteers.

Is compliance with the decree being monitored?

There is a governmental agency called Ibama, which is in charge of monitoring compliance. The problem here is that Bolsonaro has replaced a number of Ibama officials with members of the military with no experience in environmental policies. Similarly, the director of the agency responsible

for producing data on deforestation in the Brazilian rainforest was dismissed after announcing that deforestation had risen by 88% during the first year of Bolsonaro's administration when compared to the previous year. His position was also given to someone from the military, generating a lot of debate about the continued reliability of data published by that agency.

Is no one doing anything to resist this process?

At the beginning of May, Brazilian federal prosecutors filed a lawsuit against Ricardo Salles, the minister of the environment, in which they accused him of violating his duty to protect the environment and called for his dismissal. So there is a movement going in the opposite direction, trying to replace Salles with someone more concerned with environmental policies.

How can the international community influence Jair Bolsonaro to protect the rainforest in the long term?

I think the most successful strategy has been the threat by international investors and entrepreneurs to pull money out of Brazil if the environment minister continues to open up the rainforest to investors to do whatever they please there. Import restrictions on Brazilian products may also be useful. Unfortunately, that appears to be the only language that Bolsonaro understands. Especially now that his government is facing

huge economic problems because of the coronavirus pandemic, everything related to investments, money, and donations is very important – even more so than before the crisis.

This year, the fires in the Amazon rainforest are raging stronger than they have done in a long time. Is there resistance to the slash-and-burn clearances among the Brazilian population?

Yes, definitely! Even though there is a large group of people involved in agribusiness, as well as landowners, who have a great vested interest in laxer environmental laws, the rainforest in Brazil is generally seen as one of our greatest assets – one that should be preserved, maintained, and not sold to international interests. The left-wing and more progressive parties are very concerned about the deforestation, and there is also a great deal of dissatisfaction among the middle class – even those who voted for Jair Bolsonaro in the election.

Interview: Barbara Abrell

Raquel Sirotti is a researcher at the Max Planck Institute for European Legal History, where she studies the development of criminal law in Latin America, as well as political crime.

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- Sub-institute / external branch
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- Nijmegen

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- Manaus

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mpf@gv.mpg.de
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Content Authority

Dr. Christina Beck (-1276)

Editors-in-Chief

Peter Hergersberg (Chemistry, Physics, Technology; -1536)
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Photo editor

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Annabell Kopp (-1819)

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@vogeldruck.de

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