02 | 2024

MAX PLANCK
Research

100TH ANNIVERSARY
Pioneers of International Law

MOBILITY
Cars with Internal Values

MATERIALS SCIENCE
Green Steel from Red Mud

LAW CREATES FREEDOM

COVER PHOTO: PICTURE ALLIANCE / ASSOCIATED PRESS | WINFRIED ROTHERMEL; INSIDE PHOTO: PICTURE ALLIANCE/DPA | ULI DECK

The Federal Constitutional Court monitors compliance with the Basic Law and guards both the fundamental liberal-democratic order and the democratic rule of law. In liberal democracies, judges decide what the law stipulates. When attempting to transform their countries into autocracies, governments often impinge upon the independence of judges. There are potential gateways for this process in Germany as well.

EDITORIAL

Dear Reader,

It appears that our last edition of MaxPlanckResearch struck a nerve: never before have we received so many letters to the editor. Some of them expressed approval or acknowledgment, others indignation. Many readers complained that we reported too little on the “pure or exact sciences,” that we had “conformed to the prevailing spirit of the times” and failed to portray “free, independent science” in the magazine.

But is science not at its most free and independent when it addresses controversial topics within a society and enriches debates by providing insights from basic research? That is exactly why we also report on the results of research from around 20 Max Planck Institutes that are dedicated to exploring current social issues in the humanities and social sciences.

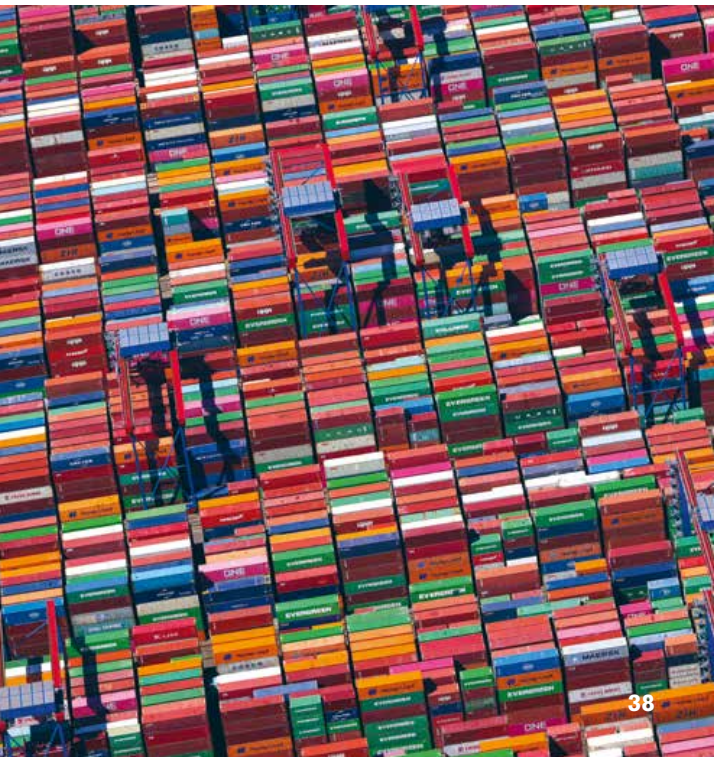
The Max Planck Society has a long history of successful research in legal studies in particular: the Max Planck Institute for Comparative Public Law and International Law is celebrating its 100th anniversary this year (counting the predecessor Institute within the Kaiser Wilhelm Society). This issue of the magazine illustrates how this Institute provided scholarly expertise that influenced German diplomacy.

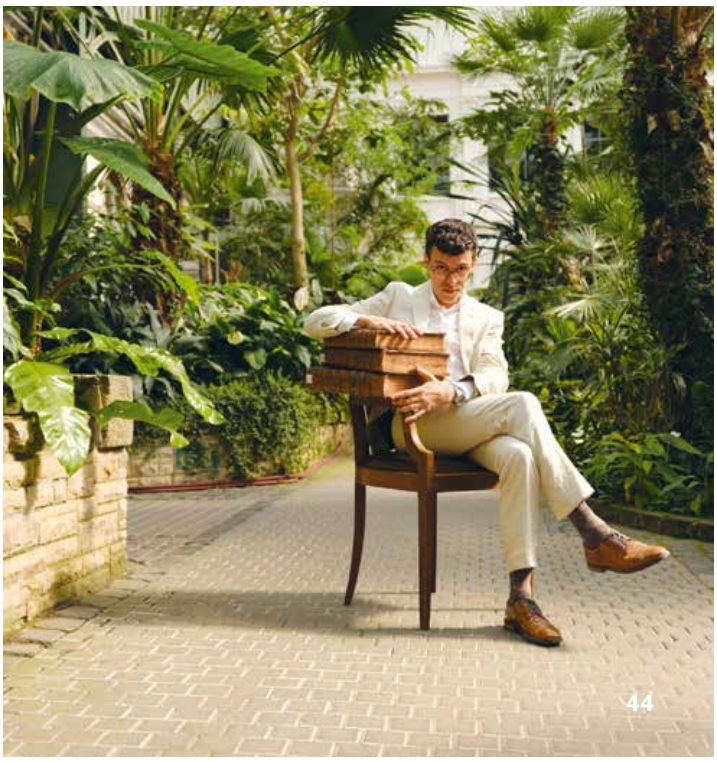
In this edition, we also address the theme of the 2024 Science Year: “freedom.” This time we explore how law and regulations create freedom. The Basic Law creates the primary framework for freedom in Germany, and the Federal Constitutional Court ensures it is protected. Whether and to what extent the highest court can be protected against attacks on freedom and democracy is one of the topics we discuss. We also address countries and people whose freedom is existentially threatened by climate change. International agreements create the basis for securing their freedom – including the freedom to seek refuge in other countries. Finally, we examine the considerable extent to which Germany has benefited from the freedom and opportunities that the EU has created, primarily through the European single market, and how it can guarantee freedom and prosperity in the future.

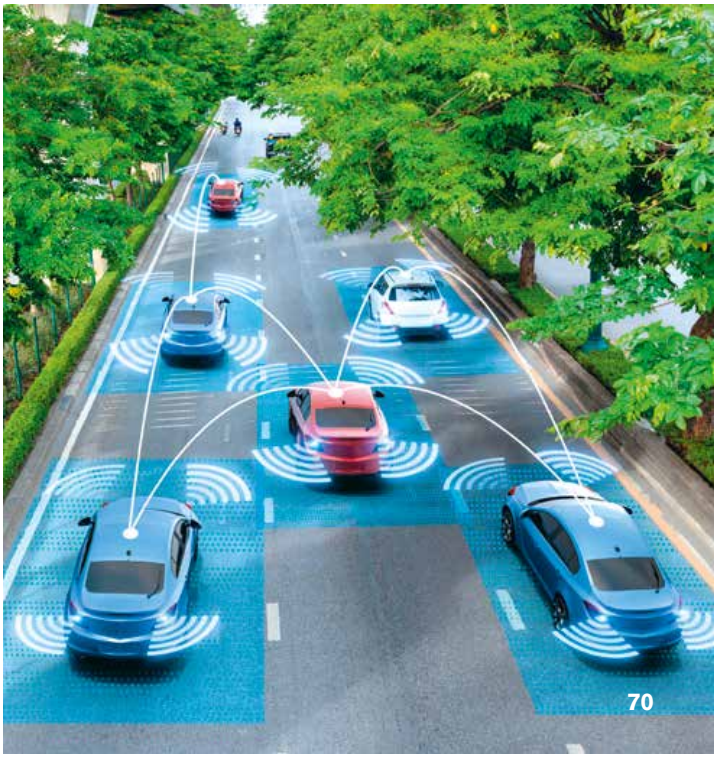
The fact that we are devoting several issues to one topic is unusual. But we have good reason to do so: freedom is indispensable in ensuring that both the “exact sciences” and “free, independent science” can perform research without prejudice and hindrances. Incidentally, the humanities and social sciences are the fields that are most often subject to regulations in autocratic systems. This is something that we should all be aware of.

In this spirit, we wish you a stimulating read!

Your Editorial Team







IMAGES: PICTURE ALLIANCE/DPA | CHRISTIAN CHARISIUS (TOP LEFT), KATRIN BINNER FOR MPG (TOP RIGHT), SHUTTERSTOCK/SUWIN66 (BOTTOM LEFT), ALEX JORDAN / MPI OF ANIMAL BEHAVIOR (BOTTOM RIGHT)

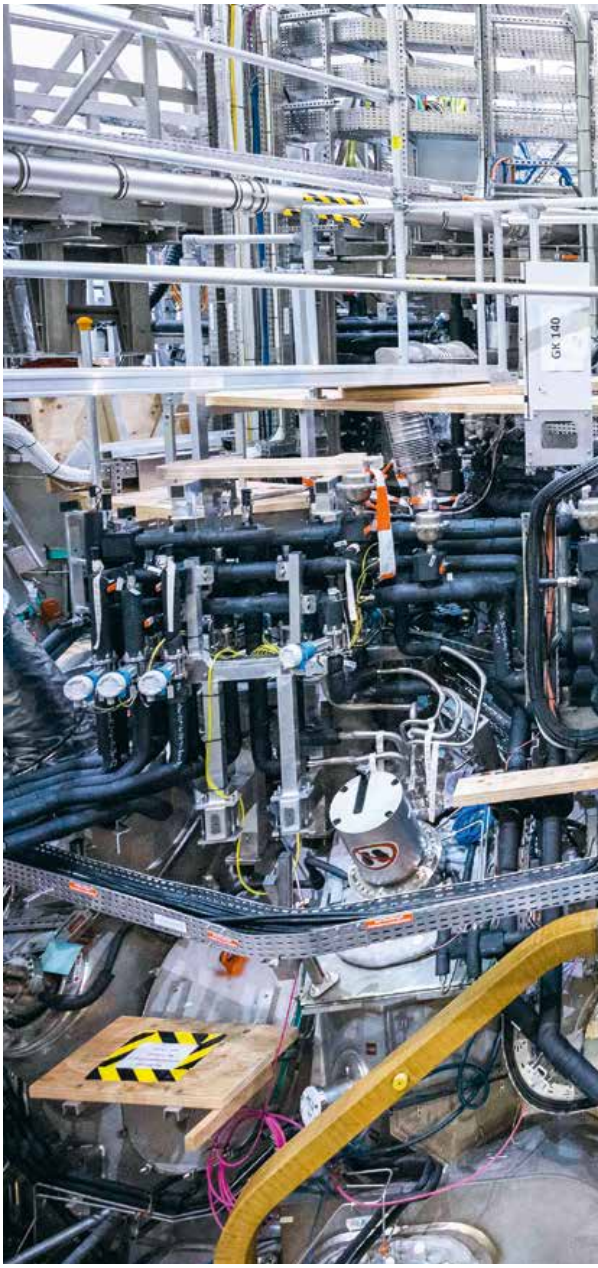
CONTENT

CAPTURED SUN

Cables and conduits, hoses and pipes surround this large apparatus like a cage. The assembly standing in the Max Planck Institute for Plasma Physics is Wendelstein 7-X, the world's largest and most state-of-the-art stellarator nuclear fusion installation. Researchers here are attempting to force atomic nuclei to fuse as they would in the sun. They have constructed an annular chamber from metal and graphite plates with a diameter of five-and-a-half meters for this purpose. The chamber will be filled with hydrogen gas that is to be transformed into plasma with a temperature of 50 million degrees. Plasma is known as the "fourth aggregate state," in which the electrons and nuclei in atoms separate from each other. When the plasma "burns," the atomic particles collide with great force and can fuse, which releases large quantities of energy that could be used to fuel power plants. That is the long-term goal of this research (see the infographic on page 24).

To generate plasma, electromagnetic waves heat up a few milligrams of gas. One of the greatest challenges is keeping the plasma, and thus the fusion reaction, stable over a longer period of time. Wendelstein 7-X is intended to prove that continuous stable operation is possible for 30 minutes. The stellarator uses 50 enormous magnetic coils for this purpose. They are positioned around the plasma chamber and essentially keep the plasma hovering in a magnetic field. To make the coils superconductive, the magnets are cooled to a temperature of -270 degrees Celsius.

Most of the conduits in the image are part of the cooling system. The other technology monitors and controls the plasma inside the chamber. Various measurement devices are located on the thick, protruding pipes. These measure values such as the temperature, pressure, density, and composition of the plasma. In the most recent phase of the experiment, the research team succeeded in heating the plasma to 20 million degrees and maintaining that temperature for eight minutes. Some 1.3 gigajoules of energy were used, and the goal is to increase this amount to 18 gigajoules in the coming years.



ON LOCATION

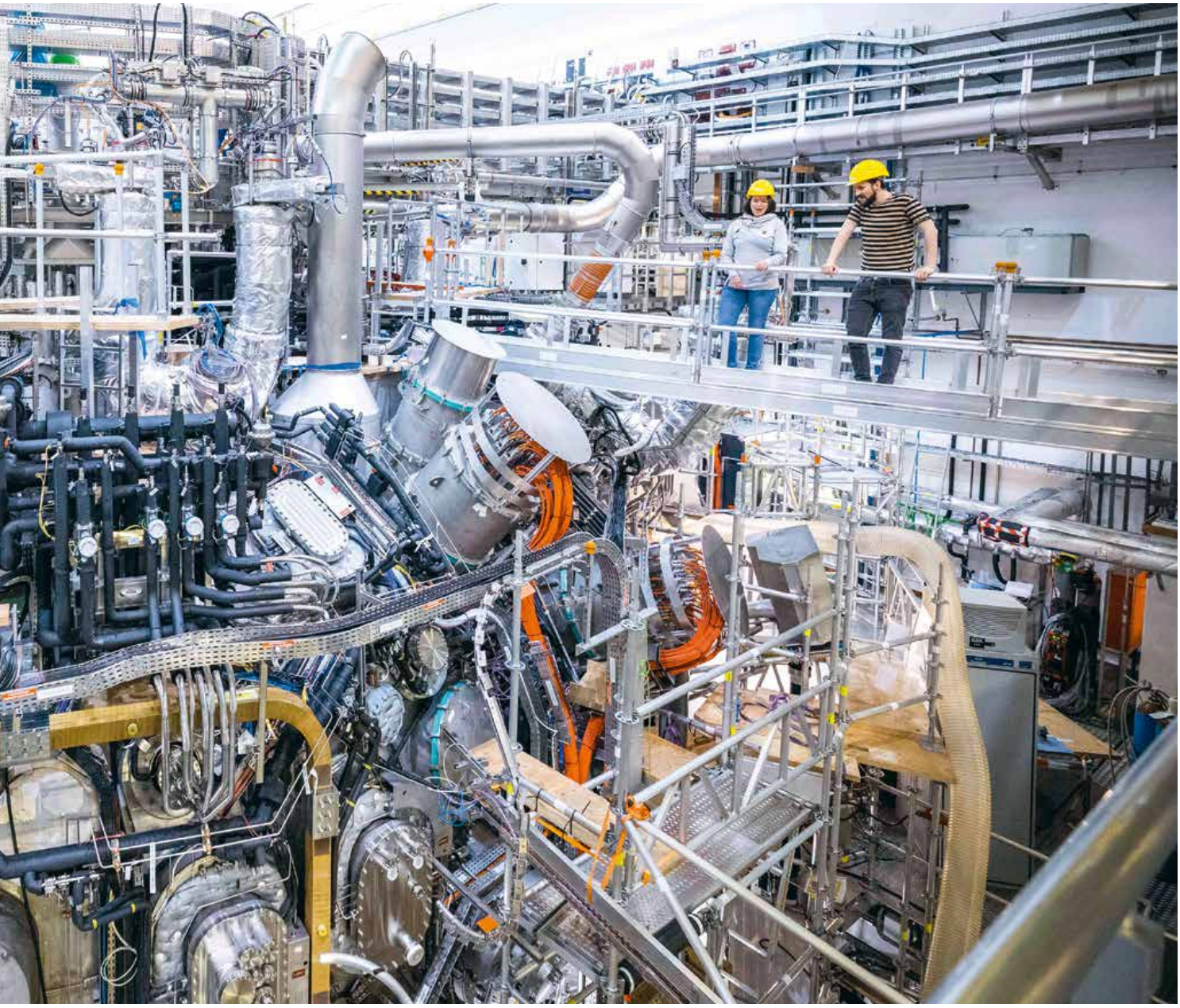


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PHOTO: IPP / JAN HOSAN

75TH ANNUAL ASSEMBLY IN BERLIN

At this year's Plenary Assembly, the focus was on the issue of climate change. It is one of the most urgent global problems, with enormous geopolitical implications. Among the speakers were Filippo Grandi, the United Nations High Commissioner for Refugees, Anne Peters, Director at the Max Planck Institute for Comparative Public Law and International Law, and Axel Ockenfels, Director at the Max Planck Institute for Research on Collective Goods. They discussed international legal issues and economic challenges in the context of climate change and climate-induced migration. The Foreign Office was represented by Marcus Hicken, Director of Energy Diplomacy, Climate and Security. In his speech preceding the discussion, Patrick Cramer emphasized that international climate protection remains the great challenge for the future, and that it is therefore crucial that the European Green Deal is rigorously implemented after the EU election. Of the Max Planck Society, he said: "Our greatest contribution to tackling climate change is our research."

www.mpg.de/22059937

PHOTO: DAVID AUSSERHOFER/MPG

Moderators Helene Bubrowski, Filippo Grandi, Anne Peters, Marcus Hicken, and Axel Ockenfels (from left) discuss climate change and migration.

MERGER FOR THE HEART

Up to a billion euros, provided specific milestones are achieved – that's how much Europe's most valuable publicly traded company, the Danish pharmaceutical company Novo Nordisk, paid for the acquisition of Cardior Pharmaceuticals. Cardior develops therapies that prevent, repair, and reverse heart disease with the help of RNA (ribonucleic acid). The agreement covers Cardior's main product candidate CDR132L, which is based on findings from research conducted by the Hannover Medical School in cooperation with, among others, the Max Planck Institute for Multidisciplinary Sciences in Göttingen. The drug is currently in phase 2 of clinical trials for the treatment of heart failure. The acquisition was concluded on May 2, 2024.

www.mpg.de/21735306

OUTSTANDING! ✶

CLAIRE DONNELLY

PHOTO: PHUONG DAO

A researcher from the Max Planck Institute for Chemical Physics of Solids and the Dresden University of Technology, Donnelly received a Heinz Maier-Leibnitz Prize, which is awarded with 200,000 euros in prize money. She discovered a method for examining the magnetic properties of materials at a high spatial and temporal resolution. Over the next three years, she will use the prize money to study how nanomaterials with specific magnetic properties can be manufactured.

EUGENE KIM

PHOTO: MPI OF BIOPHYSICS

A researcher at the Max Planck Institute of Biophysics in Frankfurt am Main, Kim was another recipient of a Heinz Maier-Leibnitz Prize. She studies how chromosomes are organized and packaged with the help of condensin protein complexes. Kim discovered, for example, how several of these condensins work together without colliding and damaging each other when they form the structure of chromosomes. Her research also involves the development and use of new imaging techniques.

IN BRIEF

PHOTO: RENÉ VOLFÍK

Patrick Peter Fabian, Helena Reichlová, and Barbora Špačková (from left), who will head the Czech Dioscuri Centers, with Patrick Cramer at the opening of the Centers.

THREE DIOSCURI CENTERS IN THE CZECH REPUBLIC

To offset the performance gap between Western and Eastern Europe, the Max Planck Society developed the Dioscuri Program, which promotes outstanding researchers. Launched in 2019 in Poland, which now has eight Dioscuri Centers, the program is currently being implemented in a second country, the Czech Republic. Three innovative research centers are forming with financing from the Czech Ministry of Education, Youth and Sports in cooperation with the German Federal Ministry of Education and Research. They are based at the Czech Academy of Sciences and its Institute of Physics, as well as at Masaryk University. "The European research area offers incredible opportunities for transnational cooperation. Close collaboration is needed across the entire EU if we are to advance European science as a whole," said Patrick Cramer at the opening in May of 2024. The freedom and opportunities offered by the EU have benefited the scientific careers of many, including Helena Reichlová, Barbora Špačková, and Peter Fabian, who took advantage of mobility opportunities to conduct research in France, Germany, and Sweden. The two physicists and the developmental biologist were chosen from a pool of 30 applicants in Dioscuri's first call for applications.

www.mpg.de/21938923

COMMITED TO UKRAINE

The Ukraine Recovery Conference took place in Berlin on June 11 and 12, 2024. Its goal was to mobilize further international support for the reconstruction of Ukraine. The Alliance of Science Organizations had developed an action plan prior to the conference. It sketches out measures and priorities in the short, medium, and long term for the reconstruction of Ukrainian science and higher education. Patrick Cramer, who currently serves as spokesman for the Alliance, argued for consistent and complementary support from the scientific community, politicians, and various sponsors. "A robust educational, research, and development sector is of fundamental importance for the sovereignty of Ukraine with regard to both science and security policy, as well as for its integration into the European Union and for its reconstruction at the end of the war," said the President of the MPG. Since Russia began its war of aggression against Ukraine in violation of international law, the Alliance has stepped up its cooperation with research facilities and higher education institutions in Ukraine, while also providing funding and resources to support scientists and students alike.

IMAGE: MAX PLANCK INSTITUTE FOR EMPIRICAL AESTHETICS/F. BERNOULLY

If genes have anything to say about musicality, Beethoven was no more predisposed than the average person – which goes to show how little genes reveal about individual abilities.

GENES AND GENIUS

Genetically speaking, Ludwig van Beethoven was apparently not especially predisposed to music. Such was the conclusion reached by a team led by the Max Planck Institute for Empirical Aesthetics in Frankfurt am Main and the Max Planck Institute for Psycholinguistics in the Dutch city of Nijmegen. The researchers examined DNA from the composer's hair. Using genetic analysis, they calculated a "polygenic score" for beat synchronization, which is the ability to clap rhythmically, a skill closely related to musicality. Earlier studies have shown that, on average, around 42 percent of musicality is inherited. Beethoven's polygenic score did not stand out prominently, however, when compared to large population samples from the Karolinska Institute in Sweden and Vanderbilt University in the U.S. Nevertheless, the unremarkable polygenic score says nothing about Beethoven's musical creativity and compositional skills. The authors of the study view this as proof of the limited significance of genetic analysis. When conducted on large random samples, research into genetic influences can admittedly yield insights into how and why musical skills and musical behavior vary from person to person. However, an individual's abilities or behavior cannot be reliably predicted based on genetic analysis.

www.mpg.de/21817081

A SAFER WAY TO DYE

In the future, dyes and other chemical products will be much safer to manufacture. An intermediate step in the prevailing method for synthesizing these substances for over 100 years causes an accumulation of explosive aryl diazonium salts, which in the past has often led to chemical accidents. Chemists at the Max-Planck-Institut für Kohlenforschung have now discovered a reaction pathway in which the explosive salts react immediately and do not accumulate. It was while working on another project that the team from Müllheim accidentally discovered that aryl diazonium salts form and are immediately disarmed, so to speak, in the new synthesis process. There was nothing in the textbooks to indicate this would happen. As source materials, the new synthesis pathway requires only inexpensive chemicals that are already used in large quantities in the production of fertilizers and fuels. The new method will make the manufacture of dyes not only safer, but cheaper as well.

www.mpg.de/21879939

WEAK CENTER

In 2022, an international research team that included researchers from the Max Planck Society published the first image of the black hole Sagittarius A* in the center of the Milky Way. New observations with the Event Horizon Telescope reveal this black hole to have strong magnetic fields spiraling out from its rim – much like the mass monster in the center of Galaxy M87 was observed to have. These magnetic fields might point to a matter jet that hurled massive quantities of matter into space a few million years ago. Today, the jet is too weak for that. It is, to quote the specialists, "frustrated." Polarized radio light, which is difficult to measure, reveals these magnetic fields and makes it possible to map their structure. The discovery yields insights into the complex environment of Sagittarius A*, where gravitation, magnetism, and spacetime curvature collide. From Earth, the luminous environment of the black hole 27,000 light years away only looks about the size of a donut. To take pictures of it would require a telescope as big as Earth. The Event Horizon Telescope meets this requirement. It consists of eight radio observatories distributed across the globe.

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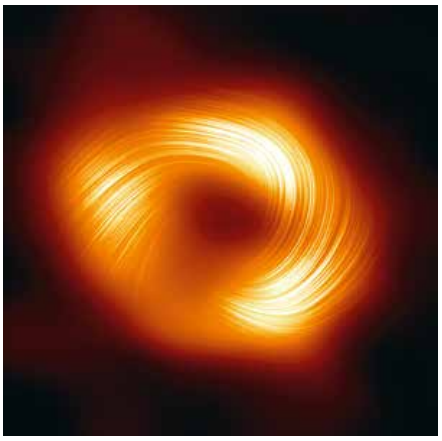

IMAGE: THE EHT COLLABORATION

Photo by the Event Horizon Telescope of the luminous environs of the black hole Sagittarius A* at the center of the Milky Way. The lines follow the direction of polarization of radio waves caused by a spiral-shaped magnetic field unwinding from the image plane.

PHOTO: SUTEISHI/ISTOCK

Dancers are more open and agreeable than other people – especially if they swing dance.

RHYTHM VS. NEUROSIS

Those who dance are less neurotic than those who don't. The proof is in a study led by the Max Planck Institute for Empirical Aesthetics in Frankfurt am Main. Researchers analyzed data from more than 5,400 people from Sweden and 574 people from Germany. They examined the Big Five Personality Traits, which are often used in psychology: openness, conscientiousness, extroversion, agreeableness, and neuroticism. And they found that amateur and professional dancers alike are more open and agreeable than non-dancers. What's more, the level of agreeableness depended on the type of dance, with swing dancers registering as even less neurotic than people who do Latin and ballroom dancing. However, the findings are still to be confirmed using larger data samples.

www.mpg.de/22051204

LED BY CULTURAL PREFERENCES

What are pull factors for migration? Researchers from the Max Planck Institute for Demographic Research have studied Facebook data to investigate the influence of cultural similarity on migration flows. They found that cultural similarity plays as important a role in the choice of target country as shared language and history. The researchers also showed that migration flows and culinary preferences are correlated. On Facebook, for example, Brazilians show far more interest in American food than Americans do in Brazilian food. Cultural aspects of daily life react sensitively to changes in the environment and can provide indicators for modeling and predicting migration.

www.mpg.de/21742745

ORANGUTAN HEALS ITSELF

Researchers have observed an orangutan treating an open wound in its face with sap. The animal was presumably wounded in the face during a fight with one of its own kind, after which it tore leaves from a liana, chewed them, and applied the sap to the wound several times. Finally, it covered the wound completely with chewed leaves. The leaves contain antibacterial and anti-inflammatory substances. They are used in traditional medicine to treat a variety of illnesses due to their ability to reduce pain and lower temperatures. However, it is not yet clear whether the orangutan "discovered" this type of wound treatment itself, for example when this wound or a previous one came into contact with the painkilling sap accidentally during a meal. It may also have seen one of its kind treating a wound. In any case, the behavior has never been observed in any other orangutan. Apes are known to take plants and rub them on their skin to alleviate pain caused by parasite infections, and chimpanzees in Gabon even treat wounds with insects.

www.mpg.de/21886982

PHOTO: ARMAS FITRA & TNGL & KLHK & MPI & UNAS & YEL

Wounded orangutan in Sumatra. Two days after this photo was taken, the animal applied sap from a liana plant to the wound and then covered it with chewed leaves.

JUST LIKE THEIR PARENTS

In times of climate change, scientists hope to meet the nutritional requirements of a growing world population by cultivating new, more resistant, and fruitful crop plants. Among them are hybrid plants, which descend from two different parent lines with beneficial characteristics. Hybrid plants lose their efficacy in later generations, however, because advantageous combinations of genes are lost when genetic material is restructured during gamete formation. As a result, hybrid seeds have to be made from scratch again and again. Researchers from the Max Planck Institute for Plant Breeding Research have now developed a method using tomatoes in which the gametes form not in the usual way through a special type of cell division called meiosis, but through simple division, or mitosis. The genetic material is no longer restructured, and the resulting gametes are genetically identical. All the beneficial properties of both hybrid parents are therefore united in the new plant. The technique can presumably be used on potato plants and other cultivated plants.

www.mpg.de/21914270

CLOUDS OF MOLTEN SALT

The climate on exoplanet Wasp-43b is inconceivable by terrestrial standards. Researchers from the Max Planck Institute for Astronomy and their colleagues have drawn a temperature map of the hot gas giant with the help of data from the James Webb Space Telescope. The nearby mother star heats one side of the planet to 1250 degrees Celsius, while the other lies in eternal night, making it a mere 600 degrees. The extreme temperature difference raises violent winds that blow hot gas to the dark side at speeds of up to 9,000 kilometers per hour. The temperatures there are low enough that the gas must condense and form a thick layer of clouds. But the clouds in question are not just made of water like on Earth; these clouds contain molten salts and other minerals, which the James Webb Telescope has detected in the atmosphere of Wasp-43b in the form of spectroscopic fingerprints. At a distance of 280 light years, the exoplanet is too far from Earth to allow its appearance to be studied in detail. Instead, the team has detected various molecules in the spectra of light that has passed through the exoplanet's atmosphere on the way to Earth.

www.mpg.de/21875918

IMAGE: T. MÜLLER (MPIA/HDA)

This is how the gas giant Wasp-43b might look as it orbits its mother star closely. Because the star always illuminates the same side of the planet, the climate on Wasp-43b is assumed to be extreme.

SUN PROTECTION FOR CELLS

Cells damaged by UV light form droplets in their cellular fluid with the protein DHX9 (green), where they sort and collect damaged RNA molecules.

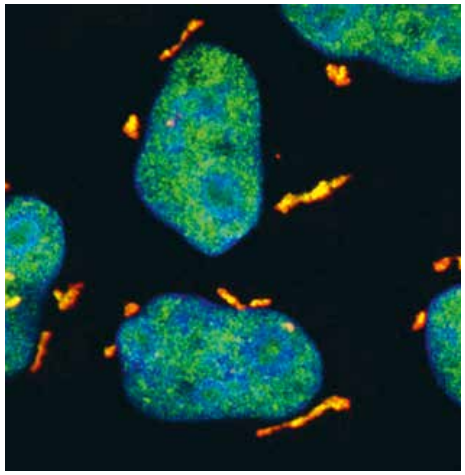

IMAGE: MPI OF IMMUNOBIOLOGY AND EPIGENETICS

When cells divide, DNA and other molecules are passed on to the daughter cells. However, the latter may contain mutations or be damaged in other ways, for example, when a cell was exposed to strong sunlight. UV radiation damages not only DNA, but also RNA molecules, which form during DNA transcription. Among other things, the RNA contains genetic information on the site where proteins are formed. Researchers from the Max Planck Institute of Immunobiology and Epigenetics have recently discovered a cellular protective shield that cells use to protect against the negative consequences of damaged RNA. They irradiated cells with UV light and found that droplets of a protein called DHX9 appeared in the cellular fluid. Analysis of the droplets confirmed them to be full of damaged RNA molecules. Apparently, cells are capable of sorting RNA that was damaged by UV light and gathering it in these droplets of DHX9. Experiments by the researchers show that irradiated cells die faster when they are unable to form the droplets. The researchers also observed that droplets do not form in the mother cell damaged by UV light. To the contrary, DHX9 first emerged in both daughter cells. Cells therefore pass down sun protection during cellular division. These findings could lead to new methods for treating sunburns and cancer.

www.mpg.de/21712407

CELTIC DYNASTIES

The Celts laid high-status individuals to rest in burial mounds. Many of these monuments have survived, and some are massive. To this day, however, it remains a mystery who was buried in them. Researchers at the Max Planck Institute for Evolutionary Anthropology have now reconstructed genetic material from over 30 people from various burial mounds in Baden-Württemberg. Their analysis shows that the individuals were related to each other. For example, the people who were buried in the mounds known as princely tombs in Eberdingen-Hochdorf and Asperg-Grafenbühl must have been uncle and nephew; the sister of the prince in Hochdorf was the mother of the prince in Asperg. Other people buried in the two mounds and in the mound erected in Magdalenenberg a century prior were also related. The findings show that political power was inherited by succeeding generations among the Celts, and that consequently they must have had dynasties. ***www.mpg.de/21995036***

IMAGE: LANDESMUSEUM WÜRTTEMBERG, FABERCOURTIAL; THOMAS HOPPE (SCIENTIFIC RECREATION)

Reconstruction of the central tomb of the Eberdingen-Hochdorf burial mound in Baden-Württemberg.

PHOTO: COETZEE/PEOPLEIMAGES.COM/ADOBE STOCK

Through conversations with partners, Dyad programs promote a positive world view, which helps alleviate depression.

PAIRING UP AGAINST LONELINESS

In Germany, the number of people who feel alone, anxious, or depressed has increased, especially since the Covid-19 pandemic. In a large-scale study of psychological health, researchers from the Social Neuroscience Lab of the Max Planck Society polled thousands of Berlin citizens during the pandemic. The results show that loneliness, stress, depression, and anxiety increased with each lockdown. In the second phase, researchers offered online training programs. The team compared the effectiveness of all the mindfulness programs with the effect of what are termed Dyad programs, in which two people converse. They take turns discussing certain topics, while the other person simply listens without judging. The new findings show that daily engagement in Dyads can increase resilience, compassion, and empathy, and deepen social relationships. While both mindfulness exercises and Dyad programs mitigate psychological problems, only the latter reduce loneliness, depression, anxiety, and a negative attitude towards life. The researchers plan to continue developing the Dyad programs so that they can be implemented on a large scale in areas of society where burnout rates and stress are a daily struggle, such as healthcare and education.

www.mpg.de/21926353

SWIMMING IN SYNC

When two fish swim together, they synchronize their movements. That was the conclusion drawn from movement analyses by researchers from the Max Planck Institute of Animal Behavior. The studies have shown that fish make swimming movements alternately rather than simultaneously. However, they only do it when both are paying attention to the other's movements. Computer models and experiments with virtual fish have shown that reciprocity has a significant influence on the swimming behavior of fish. Furthermore, fish that alternate their movements in sync possess stronger social bonds with each other. Reciprocity plays a central role in most paired activities for humans as well, whether dance, sports, or conversation. By contrast, other species synchronize even when a partner doesn't react to its companion. Fireflies, for example, will synchronize their glow with a blinking artificial light source.

www.mpg.de/21966809

PHOTO: CHRISTIAN ZIEGLER/MPI OF ANIMAL BEHAVIOR

A school of Zebra fish.

NERVE CELLS AGAINST APPETITE

An impending exam, a sea voyage, spoiled food – all of these can lead to nausea. And when someone feels bad, they generally have no appetite. Why is that? Researchers from the Max Planck Institute for Biological Intelligence have identified a circuit in the brains of mice that prevents them from eating when they feel nauseous. A group of nerve cells in the amygdala, a brain region that deals with emotions connected with eating, plays a key role here. When the organism experiences nausea, the nerve cells are activated and transmit appetite-suppressing signals. When researchers activated the cells artificially, even hungry mice stopped eating. Conversely, activating the cells caused the mice to eat even when nauseated. The newly discovered cells send their suppressive signals to several areas, including a region of the brain where information about the state of the body comes together. The cells differ from another group of nerve cells that suppress the appetite when the mouse is full. These exert control almost exclusively over neighboring nerve cells. In conclusion, the findings show that there are different forms of appetite loss, for which different brain circuits are responsible.

www.mpg.de/21757561

IRON PROTECTION FOR TEETH

Human tooth enamel could potentially be hardened with iron-rich material to protect it from acid attacks. Iron has long been known to strengthen the tooth enamel of rodents incisors, but researchers previously believed that iron also gave these animals' teeth their orange-brown color. So this layer of the incisors is currently called pigmented enamel. Now, however, a team from the Max Planck Institute for Solid State Research has discovered that iron-rich material does not cause teeth to color. Using electron microscopy, among other techniques, the researchers analyzed the structure of the enamel of beavers, coypus, squirrels, along with some other rodents down to the nanostructure. In doing so they found that ferrihydrite-like material was embedded between the elongated hydroxyapatite crystals, the main component of enamel. This layer is whitish in color. The Max Planck team therefore suggests to rename it as iron-rich enamel. Only a very thin layer on the surface of the incisors, consisting of inorganic nanoparticles and organic component, gives the typical orange-brown color. The researchers are now investigating how iron-rich material can be incorporated into human tooth enamel and how it changes its properties. ***www.mpg.de/22034748***

PHOTO: ADAPTED FROM ACS NANO 2024

Strengthened by iron, but not colored: the lower incisors of nutria (coypu, left) and beaver.

PHOTO: CZECH UNIVERSITY OF LIFE SCIENCES/JAN ŠOBOTNÍK

Digestive help: termites (*Porotermes adamsoni*) that thrive exclusively on wood with the help of symbiotic microorganisms in their guts.

FROM BENEFICIAL TO HARMFUL

Microorganisms in the gut aid digestion in both ruminants and humans. Termites, for example, could not process wood without them, so their guts are packed with single-celled flagellates. These, in turn, are inhabited by bacteria that live in or on the flagellates and provide them with nutrients from the termite gut. Researchers at the Max Planck Institute for Terrestrial Microbiology have studied a group of bacteria called Endomicrobia to understand how the partnership between flagellates and their symbionts has evolved. Genetic comparisons between symbiotic and free-living Endomicrobia bacteria have shown that the symbiotic forms have lost many genes over time, and this loss has been compensated for with the acquisition of genes from other gut bacteria. As a result, some bacteria have completely lost the ability to break down carbohydrates and can now only use molecules that are more energy-rich than carbohydrates, which is typical of parasitic organisms. It is possible that the originally mutually beneficial relationship between bacteria and flagellates is in evolutionary decline, and that some bacterial strains have evolved from beneficial to parasitic.

www.mpg.de/21900902

Turn of time

As we age, we gain cognitive advantages through growing knowledge. At the same time, this is marred by a decline in neuronal functions that may take a dramatic turn in late stages of life. We support Anne Schaefer at the Max Planck Institute for Biology of Ageing so that this puzzling correlation can be deciphered and we can turn the clock of aging a bit in days to come.

The Max Planck Foundation has supported the Max Planck Society for more than ten years by providing targeted funding for top-level innovative and cutting-edge research at the more than 80 institutes, enabling breakthroughs in frontier science. As a patron, you can make a crucial difference by creating additional scope to keep this research ahead of the curve in the international scientific competition. Join us!

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PROFITABLE CLIMATE PROTECTION

The impact of CO_2 emissions on climate change has been known for several decades. However, the global community has not yet managed to reduce it. Understanding the reasons behind this and what action must be taken are questions for the social sciences, as economic sociologist Jens Beckert explains. The Director at the Max Planck Institute for the Study of Societies also outlines directions for a more successful climate policy.

In 1988, NASA scientist James Hansen issued a strong warning to the US Congress about anthropogenic global warming. Hansen's statement brought the dangers of climate change to the attention of the general public. A few years later, Klaus Hasselmann, who played a key role in setting up the Max Planck Institute for Meteorology in Hamburg, used statistical methods to prove the human influence on the climate for the first time. For this work, he was awarded the Nobel Prize in Physics in 2021. More than three decades have now passed since the threat of climate change became widely known. During this time, however, annual global emissions of greenhouse gases from the combustion of fossil fuels have not decreased, but rather increased by around two-thirds. At the same time, the average global temperature has risen by almost 1.2 degrees Celsius compared to pre-industrial times, and last year an increase of almost 1.5 degrees was measured for the first time. The world is heading almost unchecked towards further significant global warming.

→

VIEW POINT

JENS BECKERT

Jens Beckert is Director at the Max Planck Institute for the Study of Societies and Professor of Sociology in Cologne. He researches the social, cultural, and political conditions underlying the social order of markets. Against this backdrop, he also analyzes the reasons for the lack of incentives for societies to move towards a climate-neutral economy and why climate protection policy is often encountering resistance. He explores these questions in detail in his book *Verkaufte Zukunft*, which has been nominated for the German Non-Fiction Prize. The English translation of the book will be published under the title *How we sold our future* by Polity Press later this year.

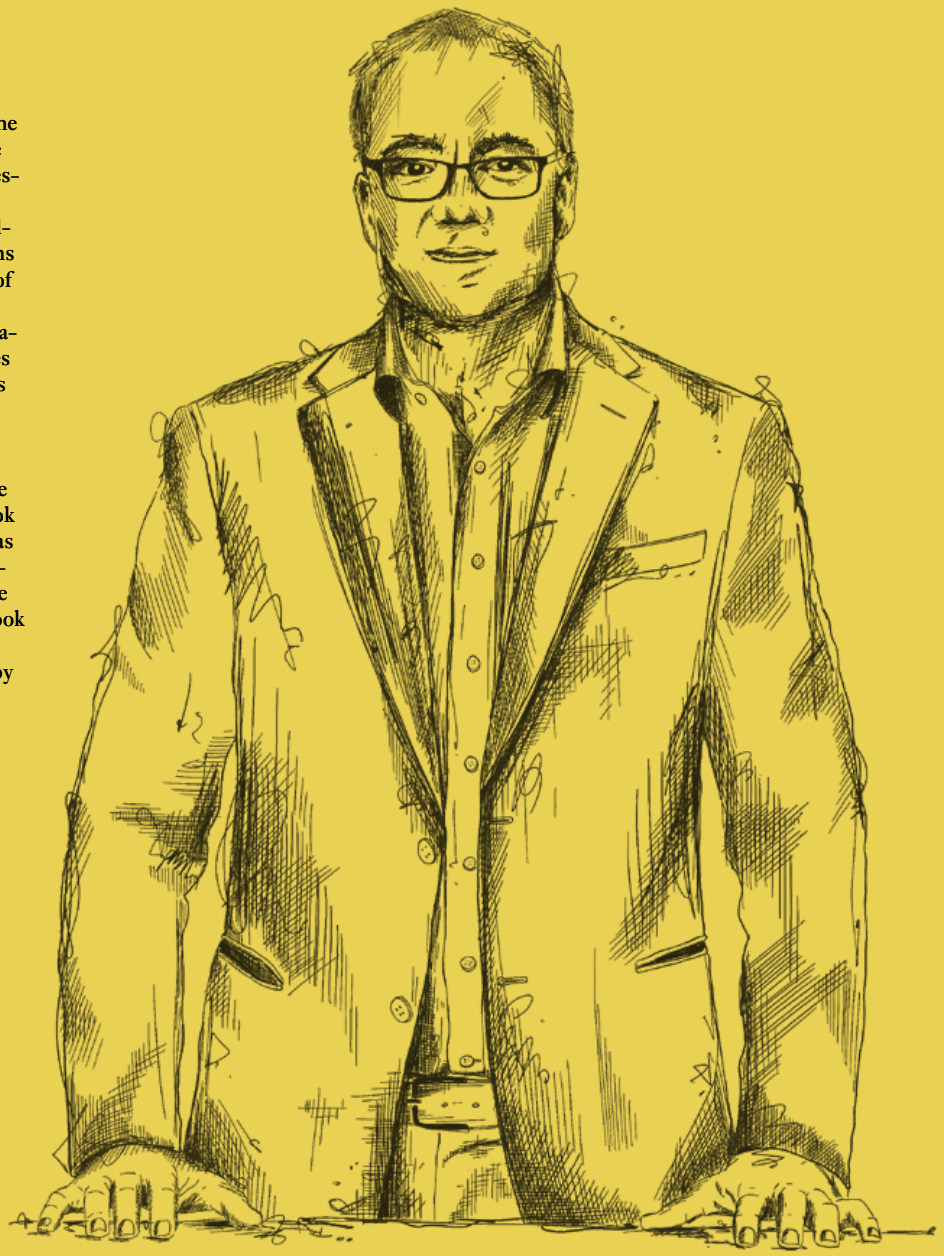

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Forecasts by the United Nations and the International Energy Agency predict a total rise in temperature of 2.5 degrees Celsius, possibly even 3 degrees Celsius, by the end of the century. Although the consequences can be described in general terms, the specific effects on individual societies cannot be precisely predicted. Extreme weather events will increase, precipitation patterns will change, infectious diseases will spread, and densely populated coastal regions will be at risk from rising sea levels. The rapid destabilization of natural living conditions will cause considerable economic damage, exacerbate social and political tensions, and cause severe suffering for many people.

It is no longer possible to stop the predicted further rise in temperature. This is not least because more and more energy is needed in a global economy that is growing by three percent a year, and in view of economic, political, and cultural structures that are geared toward continuity and further growth. While the transformation of the energy supply has already begun, it is nevertheless moving too slowly to phase out the burning of fossil fuels in the decades ahead. Progress in saving energy and the expansion of renewable energies is lagging far behind what is required. Even if the increasing share of renewables in the electricity mix is being celebrated in Germany, across the globe only two percent of primary energy consumption is covered by wind and solar energy. Even in Germany, almost 80 percent of the primary energy used comes from fossil fuels. Populous countries such as India, Indonesia, and Nigeria are just getting started with the next phase of their economic development and will rely heavily on coal, oil, and gas.

IT IS WISHFUL THINKING TO BELIEVE THAT THE PARIS CLIMATE TARGETS ARE STILL ACHIEVABLE.

A largely defossilized energy supply is certainly conceivable at some point in the future. However, the transformation will take far longer than is permitted by the climate targets agreed in Paris. Assuming the combustion of fossil fuels peaks by the end of this decade, as projected, even if existing energy transition plans are implemented, oil, gas, and coal will still be burned in such large quantities until the middle of the century that the resulting greenhouse gas emissions will only be reduced by about a quarter – this according to the International Energy Agency.

These are sobering figures. What can be derived from this? First of all, this state of affairs needs to be recognized. It is wishful thinking to believe that the Paris climate targets are still achievable. Wishful thinking, which is understandable, but which also obscures our view of what is necessary.

After all, closing our eyes and believing that everything will work out in the end is simply an exercise in time wasting. It distracts from the obvious challenge; societies must prepare themselves to deal with the consequences of further global warming. Investments must be made in infrastructures that stabilize living conditions when the consequences of climate change become increasingly severe. Be it flood protection, the greening of cities, the expansion of disaster protection, the conversion of agriculture, or the protection of vulnerable population groups from high temperatures during heat waves, considerable investment is needed in public goods for collective welfare.

IT IS NOT POSSIBLE TO SLOW CLIMATE CHANGE WITHOUT TECHNOLOGICAL PROGRESS.

However, climate adaptation requires more than just the development of resilient material infrastructures. It also involves strengthening social resilience. If societies face more frequent losses in the future, this will lead to politically charged social tensions. How will the losses be distributed? How can social solidarity be maintained in the face of the costs arising from the increasing "unreliability of nature?" The writing is on the wall that climate change will become a significant further cause of social inequality and exacerbate social conflict. Climate change thus also represents a challenge for democracy, which is increasingly less able to alleviate social tensions through the distribution of an ever-expanding pie. Increasing tensions will also build up between the rich industrialized countries and the Global South. After all, these countries will have to bear the brunt of the ecological crisis, they have far fewer resources to protect their populations, and they bear no historical responsibility for climate change.

However, climate adaptation alone is not enough. The destructive and costly consequences of climate change can only be countered by eliminating its causes. The means of achieving this are well known: stop burning fossil fuel by expanding renewable energies and reducing energy consumption. Many of the technological prerequisites for transforming energy systems already exist. Nevertheless, there is a considerable need for further research. Only through research can new technologies be developed that enhance the efficiency of solar and wind power, reduce energy consumption, facilitate greater reuse of raw materials, and enable more cost-effective carbon capture during production or its removal from the atmosphere. It is not necessary to blindly believe in technological development as a panacea for the climate crisis to see that advancing scientific and engineering knowledge is crucial for mitigating climate change.

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Nevertheless, technological progress alone is not enough. The slow transition to renewable energies is partly due to technological limitations. But all too often, available technological possibilities remain unused. The failure of global climate protection over the past three decades clearly illustrates this point. In 2022, electric cars accounted for just two percent of the global fleet. Their share of new sales in 2023 was just under 16 percent. The targets for the ban on new registrations of combustion vehicles, if they exist at all, are constantly being postponed. The expansion of renewable energies is being delayed by lengthy planning procedures, high financing costs, material shortages, and resistance from the public. In both the Global North and the Global South, new coal, gas, and oil deposits are constantly being tapped, even though it is known that these must remain in the ground if global warming is to be stopped. Climate protection policy cannot succeed if existing knowledge is bypassed and technical possibilities are implemented hesitantly, if at all.

SOCIAL SCIENCES DEAL WITH INCENTIVE STRUCTURES – INCLUDING WHEN IT COMES TO CLIMATE PROTECTION.

The question of why societies are so far behind what is technologically possible is a topic to be addressed by the social sciences. It is the social sciences that deal with the power and incentive structures which determine the actions of companies, politicians, the electorate, and consumers – including in the context of climate protection. The social sciences address issues relating to social change, the functioning of political processes, dilemmas of collective action, the causes and consequences of social inequality, and the spread of new technologies. Understanding the precise social mechanisms that influence responses to the climate crisis is crucial for deriving political decisions that could enhance the efficacy of climate protection.

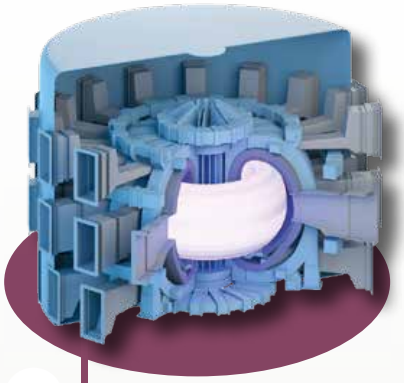
A look at the social sciences reveals how companies, which are guided by economic incentives, defend existing profitable business models, provided that the costs of the associated environmental destruction can be externalized. It is primarily the focus on profit and growth that makes capitalist economic systems too hesitant to take costly measures to protect the climate. However, organizations are also influenced by path dependencies; existing structures, employee skills, and culturally shaped routines determine how interests are perceived. Politicians are not prepared to make costly decisions for voters when the benefits – a less heated climate – are decades away. Citizens resist the costs of the energy transition and

defend existing lifestyles against change. Countries in the Global South want to pursue their path toward greater prosperity, even if it entails increasing greenhouse gas emissions. All of these are social science issues, encompassing questions about the political and social conditions required to alter existing behaviors.

The book *Verkaufte Zukunft* by Jens Beckert was published by Suhrkamp-Verlag. 240 pages, EUR 28

To make progress in climate protection, we must uncover the mechanisms that cause obstacles, while also understanding what can drive transformative actions. Below are a few examples. Companies can be persuaded to defossilize their business models by changing their incentive structures. This requires regulatory measures or subsidies, such as those created in Germany for the restructuring of the steel industry. Resistance to wind turbines among the local population is reduced if local people receive a share of the income from the electricity they generate. A climate levy that provides financial assistance to lower-income groups to offset the costs of transitioning to clean energy boosts acceptance for climate protection measures, especially among those who are typically skeptical of environmental policies. However, societies also have moral resources, which enable individuals to gain fresh perspectives and advocate for the collective good, even if it contradicts immediate personal gain. This is evident in the widespread support for climate protection seen in surveys, as well as in tangible changes in behavior, participation in social movements, and engagement in local climate initiatives.

Understanding these foundational aspects in detail can facilitate the closer alignment of political decisions with the imperatives of climate protection. The question of the conditions under which desirable decisions can be implemented politically is a matter for the social sciences. Their knowledge of social processes is an indispensable prerequisite for successful climate protection policy.



TOKAMAK
The government-funded JT-60U facility, Asdex Upgrade (an MPG project), and the Iter (under construction), enclose plasma with an external magnetic field in a donut-shaped chamber and heat it externally.

ADVANCED STELLARATOR
A coiled magnetic field encloses plasma in a similarly shaped container, such as the one used in the Wendelstein 7-X. The heating is done externally.

PATHWAYS TO A FUSION POWER PLANT

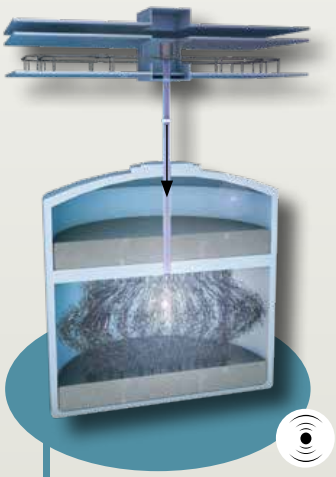
Nuclear fusion occurs when the nuclei of lighter atoms, usually hydrogen, fuse to form heavier ones such as helium, releasing energy in the process. Fusion powers the Sun, but on Earth, the process can only be simulated in plasma at temperatures exceeding a hundred million degrees. No material can withstand such heat. As a result, research facilities and companies are exploring a variety of concepts for controlling plasma. The Max Planck Institute for Plasma Physics, for example, is researching the tokamak and the stellarator.

CONTINUOUS OPERATION VERSUS PULSE OPERATION

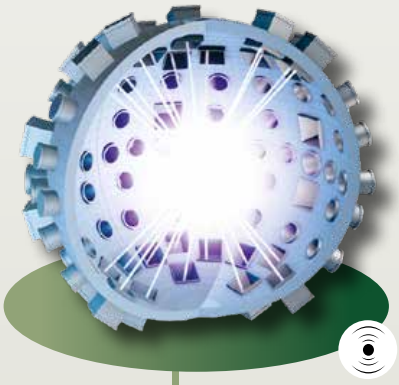
Conventional power plants generate continuous energy. Several fusion concepts likewise provide for continuous operation (∞). In others, nuclear fusion takes place in pulses, or intermittently ((•)). It remains unclear how to trigger successive fusion reactions quickly enough in pulse operation.

∞ **REACTORS IN CONTINUOUS OPERATION**

(•) **PULSED REACTORS**

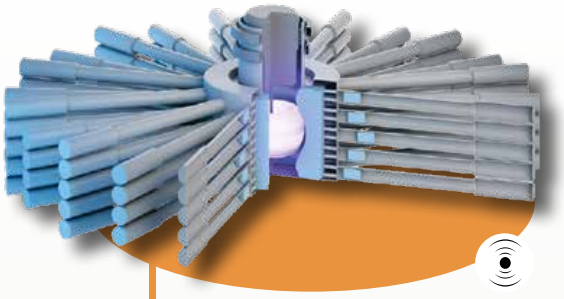


PROJECTILE FUSION
The spin-off First Light Fusion drops a capsule of fusion fuel into a reaction chamber and shoots it with a metal projectile. The impact generates shock waves in the capsule, compressing and igniting the fuel.



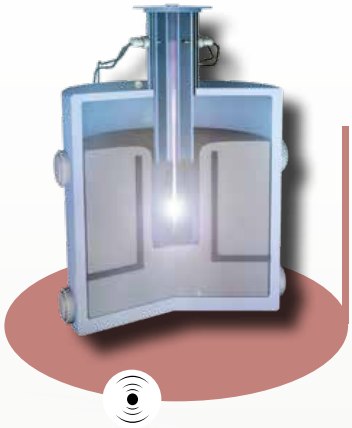
LASER FUSION
Powerful lasers condense and heat plasma in the center. In indirect operation ●, the lasers cause a metal ball to produce X-rays, which heat and compress the fuel inside. As a result, the US research facility NIF was able to generate more fusion energy than it invested in laser energy. In this way, it has spent decades researching the processes involved in the hydrogen bomb. In direct operation ●, a capsule with the fuel is shot directly, causing it to implode.

INFOGRAPHIC: P. BALL, THE RACE TO FUSION ENERGY, NATURE, VOLUME 599 ISSUE 7886, 25 NOVEMBER 2021; GCO ACCORDING TO NIF, ZAP ENERGY AND FIRST LIGHT FUSION



TOKAMAK WITH EXTERNAL COMPRESSION

General Fusion generates a tokamak plasma in a container made of rotating liquid metal, which is compressed and heated with pistons until it ignites.



STABILIZED Z-PINCH

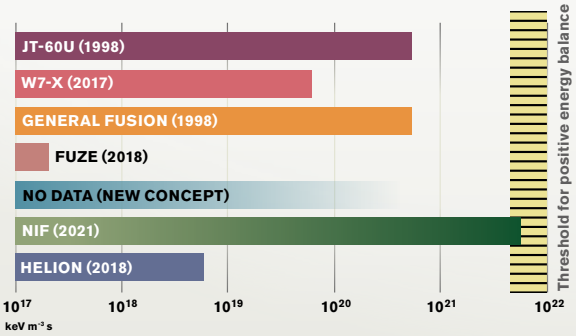
The startup Zap Energy generates a thin plasma tube between two electrodes with current flowing through it. The current creates a cylindrical magnetic field around the tube, which compresses and heats the plasma to extreme levels.

STATE OF DEVELOPMENT

Three criteria give a rough assessment of how much progress is being made with each fusion concept:

TRIPLE PRODUCT

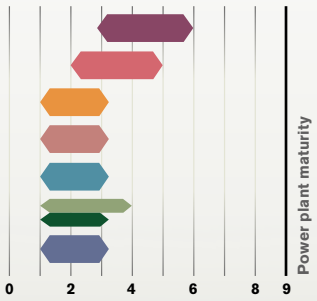
Product of the plasma density, temperature, and how long the temperature can be maintained without heating. The higher the value, the higher the energy yield from the fusion reaction. The vertical bar indicates the threshold at which a positive energy balance is achieved. The threshold values differ slightly depending on the plasma control.



Source: US Department of Energy; doi: 10.1063/5.0083990

STATUS OF POWER PLANT MATURITY

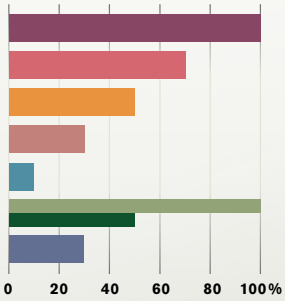
A fusion concept with a physically positive energy balance still faces technical obstacles, for example, the total energy balance of the power plant (energy required for magnets, lasers or heating plasma) or the need for frequent ignitions in the case of pulsed fusion.



Source: Müller & Zohm 2022 (hdl.handle.net/21.11116/0000-000D-EBAF-6); Häfner et al. 2023 (publikationen.bibliothek.kit.edu/1000164488)

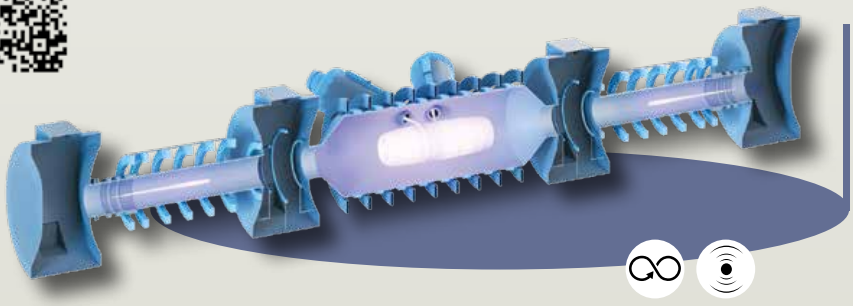
AGREEMENT WITH PIONEER CONCEPTS

Decades of research have been done on tokamaks and stellarators, as well as on laser fusion at the NIF. The more a concept deviates from these established processes, the less clear it is how long the road to a power plant might be.



Source: K. Lackner, IPP

More information on the different concepts for nuclear fusion:

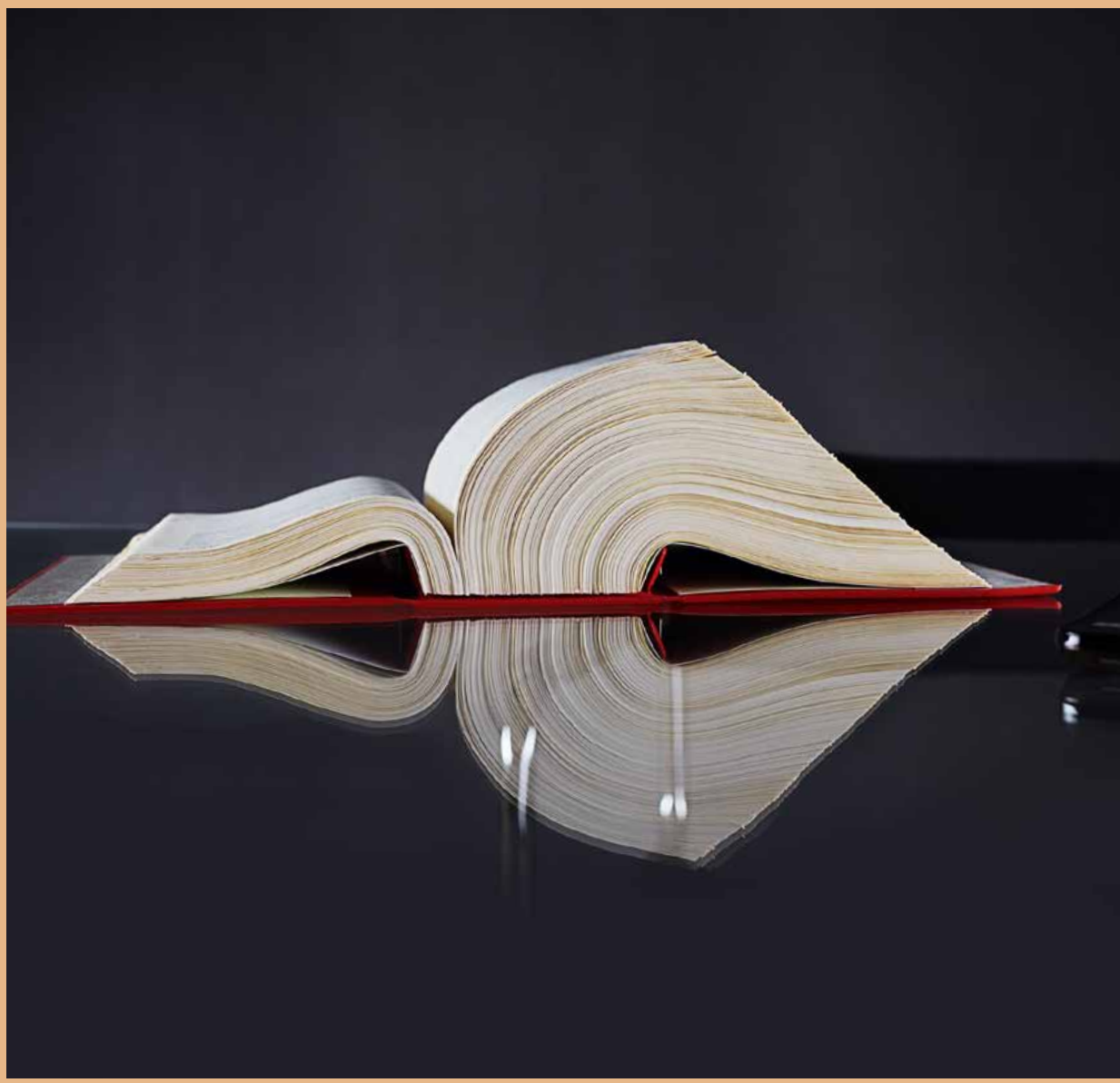


STABILIZED FIELD-REVERSED CONFIGURATION (FRC)

The companies TAE and Helion shoot two plasma packets at each other, causing them to fuse into a hot ellipsoid. This plasma is heated further, either through compression by an external magnetic field or by being enriched with fast particles.

FOCUS

LAW CREATES FREEDOM



The legal code: What are the tasks of the law? Should it be fair? Does it create security? Or does it protect freedoms granted by the Basic Law and European integration? Researchers provide answers to these questions on the following pages.

PHOTO: ADOBE STOCK / INGO BARTUSSEK

FOREVER AND EVER?

TEXT: NINA SCHICK

Democracy can be abolished through democratic means. This lesson from the Weimar Republic has not seemed as relevant as it does today for several decades. To what extent can laws protect democracy, and where are their limitations? Researchers from the Max Planck Law network explore the need for statutory regulations and how they function.

The door in the wood paneling opens, and eight people in red robes enter, each of them wearing an equally red cap on their head and a white jabot on their chest. When they walk in procession below the mighty carved federal eagle, almost everyone in Germany knows what is happening: The Federal Constitutional Court is convening and will deliberate on or announce a ruling. The next sentence in the media report about the event will most likely mention Karlsruhe. This provincial city in southwest Germany was appointed as the seat of the country's most important court in 1951. Here the judges work in an unpretentious, expansive, flat building made of lots of concrete and even more glass.

For some time now, it is not because of its decisions that Karlsruhe has been in the spotlight, but rather because of its special position in the constitution: does the court have to be protected against political influence? For instance, if there are large factions of anti-constitutional political parties in parliament? And if so, how? The Federal Ministry of Justice has drafted a bill concerning the protection of the Federal Constitutional Court in the German Basic Law. The federal states and the left-wing party Die Linke have also created a draft. Now multipartisan discussions are being held.

A look at other countries demonstrates the central role the judicial system, and particularly constitutional courts, play in the autocratic restructuring of states. In Poland, the national conservative party PiS restructured the country's judicial system over a period of eight years, the effects of which will long outlive the change in policy begun in October 2023. Immediately after he was first elected in Hungary in 2010, Viktor Orbán reduced the authority of the Hungarian constitutional court and staffed the courts with people who were loyal to his party. In the United States, the judges Donald Trump appointed to the Supreme Court are impacting its current rulings during Joe Biden's term of office. The list goes on.

Can Germany learn how democracies are damaged by autocratic endeavors based on these examples – and take necessary countermeasures in time to make a difference? All Max Planck Institutes that work with the law are connected through the Max Planck Law network. They share their knowledge on socially relevant topics through research projects, identify regulatory gaps, and develop solutions at events such as their annual symposium. What defines democracy and how it can be protected was the focal topic this year and in 2023. Florian Kriener works as a senior research fellow at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg. One of his main research topics is the promotion of democracy. "Autocracies don't take shape overnight," he says. "Instead, they often develop through the law."

"Autocracies don't take shape overnight. Instead, they often develop through the law."

FLORIAN KRIENER

SUMMARY

The judicial system plays an important role in transforming democracies into autocracies. It is often the first place autocrats begin making changes. A functioning judicial system can slow down autocratic aspirations, but one that has been restructured by autocrats can accelerate the autocratic transformation of a country.

Lessons from the Weimar Republic and the Nazi regime were incorporated into the German Basic Law. It contains the eternity clause concerning human dignity, democratic form of government, and democratic rule of law. It features various instruments that are intended to protect democracy from its enemies, such as the party ban and forfeiture of basic rights.

Mechanisms that protect democracy limit it at the same time. That is why they must be used with caution, carefully structured, and well-balanced.

The rise of right-wing populist parties across Europe was demonstrated by more than just the European elections in June 2024. National conservative parties are also enjoying great popularity in Germany. In the state elections in the Federal State of Saxony, Brandenburg, and Thuringia in September, the AfD could receive up to 30 percent of the vote and become the strongest party. Even if the AfD did not become part of the state government, the party would still have considerable influence – despite the fact that AfD state associations in the Federal State of Saxony, Saxony-Anhalt, and Thuringia have been classified as confirmed right-wing extremist movements by the respective state offices for the protection of the constitution. These associations are suspected of being extremist movements in Brandenburg and four other federal states. A new evaluation issued by the Federal Office for the Protection of the Constitution may soon classify the entire AfD as a confirmed right-wing extremist party.

What happened in Poland shows just how quickly democracies can be dismantled. "The constitutional court was politically instrumentalized within a few years. Because of politicized judges in the highest courts and a politicized state president, it is yet to completely return to a democratic rule of law despite the change of government," Kriener says. Germany is also facing the question of whether it must better protect its constitution, and if so, how? Does the country need new laws? There are already specific considerations regarding

the Federal Constitutional Court. "The judicial system is usually one of the first institutions autocrats begin manipulating, because the constitutional courts are the ones that can prevent an increase in autocracy. Conversely, a restructured judicial system can accelerate the implementation of autocratic aspirations," explains Kriener.

The German Basic Law has few provisions regarding the Federal Constitutional Court. Only Articles 93 and 94 stipulate details concerning the "guardian of the constitution". The Federal Constitutional Court Act, a law that can be amended via a simple majority in parliament, addresses all other matters. Amendments to the Basic Law, however, require a two-thirds majority. "It would make sense, for example, to safeguard the fact that there are two senates under constitutional law," says Kriener. "That way, it would be impossible to create a third senate that would be responsible for all the important processes or allocated the ultimate decision-making authority." Provisions regarding appointments and terms in office for judges, the organization of the court, and procedural law could all be incorporated in the Basic Law.

The Basic Law is now 75 years old and celebrated its "birthday" in May. Those who wrote it were fully aware that the Weimar Republic had failed; the National Socialists did not come to power as the result of a revolution. They did not even need an absolute majority. The Nazi Party received 33.6 percent of the vote during the last Reichstag election in November 1932, before Adolf Hitler was appointed Reich Chancellor on January 30, 1933. Half a year later, Germany was a single-party state. The National Socialists used the means provided by the constitution, especially the strong role of the President of the Reich, and the ability to issue emergency directives without the involvement of the parliament.

Lessons from Weimar

Weimar is not an outlier: democracy carries in itself the seeds of its own dissolution. When applied to legislation, "Democracy means that the sovereign people can, in principle, enact and repeal laws without restrictions," says Marietta Auer, Director at the Max Planck Institute for Legal History and Legal Theory in Frankfurt on the Main. A constitution thus not only guarantees, but also restricts democracy. "The Basic Law restricts the freedom that is inherent in democracy," says Auer. The lessons from the Weimar Republic resulted in what is referred to as the "eternity clause" in the Basic Law. Article 79 Paragraph 3 exempts the guarantee of human dignity,

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PHOTO: ARNE SATTLER FOR MPG

State and constitutional law: Florian Kriener researches at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg and at the Humboldt University in Berlin (photo).

form of government, and the core of democratic rule of law from constitutional amendments. In the end, legislation that can change the constitution is also legitimized by the constitution. This does entail a certain circular reasoning, but at least it guarantees one thing: the constitution cannot be disestablished in a constitutional manner.

At the Max Planck Institute for the Study of Crime, Security and Law in Freiburg, Jakob Hohnerlein researches basic rights in state and constitutional law. He says, "There are different ways of understanding democracy. However, it has basic standards that cannot be questioned." Above all, the open nature of political processes. "Access to power must be available to all groups in fair elections, and minority positions must also be given a voice in political discussions. At the same time, individual people must have a secure legal status."

Fortified democracy

In good times, democracy stabilizes itself through its institutions and open discourse. "Democracy has an immunizing force," says Ralf Poscher, Director at the Institute in Freiburg. And for periods when this force diminishes, the Basic Law contains protective mechanisms within the scope of "fortified democracy" that were created in the wake of what happened to the Weimar Republic. "All of these mechanisms cut both ways. All of them intervene in democratic processes," says Poscher. One of the mechanisms is the party ban, which is the subject of controversy now with regard to the AfD. Powers have shied away from using this mechanism thus far, even though some voices in the political discourse explicitly demand its implementation. The problem is that the AfD party program is not openly anti-constitutional. It does not suggest that the AfD aims to abolish basic standards of democracy. That is why the Federal Office for the Protection of the Constitution would have to make a case for anti-constitutionality based on many fragments of evidence. "The legal question here is: which statements made by individual politicians can be attributed to the party as a whole?" Jakob Hohnerlein explains.

This instrument has been used sparingly to date owing to its considerable encroachment upon basic rights. There have been two party bans in the history of the Federal Republic, both of them in the 1950s. Two proceedings were conducted against the NPD. The first failed, and the second established that the party was anti-constitutional but did not issue a ban owing to the lack of danger it posed. The second set of proceedings lasted four years. "A party ban cannot provide immediate help," says Heidelberg law expert Kriener. "It would probably come too late for the state elections this year." The same is true for the federal election in 2025.

At the individual level, the equivalent of the party ban is the forfeiture of basic rights as per Article 18 of the Basic Law. There have been four motions for this forfeiture in the history of the Federal Constitutional Court, all of them unsuccessful. They were all filed against Germans who were closely associated with National Socialist ideologies. "To date, Article 18 has been relegated to the shadows both in practice and in the study of public law," says Hohnerlein. Now the article is being discussed for the first time in a long time. Some 1.7 million people have signed the petition "Wehrhafte Demokratie: Höcke stoppen" ("Fortified Democracy: Stop Höcke"). However, the number of signatures makes no difference. As per Article 18, the motion can

Basic researchers: What distinguishes democracies? At the Max Planck Institute for the Study of Crime, Security and Law in Freiburg, Jakob Hohnerlein explores the duties of basic rights in constitutions.

PHOTO: MARKUS HERB FOR MPG

"A lived system of checks and balances protects against autocracy. If too many players break rank, the law becomes powerless."

SVENJA BEHRENDT

only be filed by the Bundestag, the federal government, or a state government. A massive encroachment on basic rights that would have one advantage over the party ban: the anti-constitutional effect of an individual person is considerably easier to judge than that of an entire party. And Björn Höcke, party and faction leader in Thuringia, is a man whose political relevance is indisputable, unlike the earlier respondents. However, no decision concerning forfeiture of basic rights could be expected soon, either. As part of its Thuringia project in April of 2024, the legal portal "On Matters Constitutional" recommended seven specific actions that should be taken to protect democratic institutions at the state level before the state elections in September. They concern protecting public broadcasting, the country's Constitutional Court, and staffing certain functions, among other matters. Head Editor Maximilian Steinbeis' team has identified "gateways" for authoritarian populist parties in the Thuringian constitution. The blog states that failing to close these gateways would be an act of negligence.

Clever consideration

The blog also maintains that not every authoritarian populist strategy can be weakened by changes to the constitution and laws. A look back at the possible safeguarding of the Federal Constitutional Court under the constitution shows that this task is by no means trivial. In some cases, a simple majority may be too low a hurdle for a decision with great consequences. On the other hand, requiring a two-thirds majority means the blocking minority is more quickly reached. A higher hurdle can thus make it easier for a 30-percent party to exert destructive effects through a blockade. Another important question is how judges would be appointed if the Bundestag were filled with people opposed to democracy. Should the other federal courts make that decision? Should the Bundesrat take over? Many questions are still open. Florian Kriener says, "It is necessary to be very careful and ensure provisions are well balanced."

After all, laws also harbor the risk of over-regulation. In his research, Kriener has critically examined the "Defense of Democracy Package," which the EU Commission introduced as a reaction to the corruption scandal in the European Parliament known as "Qatargate." "Transparency mechanisms can also be misused to control non-government organizations," Kriener concludes. Transparency can also be at odds with the freedom of civil society. Kriener mentions one example: if every donation made to an organization must be approved, that means the organization is monitored, which impinges upon the freedom of association. "Making laws stricter is often a double-edged sword."

Society counts

Even proponents of safeguarding the "guardian of the constitution" advise caution. "Precipitousness and over-constitutionalization only lead to damage," according to former constitutional judge Ferdinand Kirchhof in a post for the portal "Legal Tribune Online". He wants to close the "open flank" of the Federal Constitutional Court. However, he says, "Changing the Basic Law, which serves as a permanent framework for democracy and the democratic rule of law, or overburdening it with legal details as a result of current political fears would be fatal." With all due caution and despite the need for action, Germany must not simply rely on (new) laws. Many forces work together here. Political decisions are among them, including the decisions that capitalize on the existing instruments of fortified democracy: a strong civil society and election decisions.

"No law in the world can completely prevent people from behaving illegally, just as no law in the world can, in itself, guarantee that it will be interpreted in only one specific manner," says Svenja Behrendt. As a Junior Professor at the Max Planck Institute for the Study of Crime, Security and Law in Freiburg, she researches what stabilizes democracies from within and the role human rights play in that process. "A lived system of a separation of powers and checks and balances is essential. In the end, democracy depends on a large number of players making decisions that are conducive to a society based on solidarity and equal freedom. And for system-relevant decision makers, this is downright fundamental. This system becomes endangered when too many players break rank, because it is no longer possible to curb that with statutory regulations." This system is complex, and laws are one of its elements. The network for legal and social studies will be exploring the other elements during its next annual conference in October. The topic of this symposium is "power."

www.mpg.de/podcasts/recht-schafft-freiheit (in German)

Shrinking climate niches: In 50 years, large parts of the world will become too hot for human habitation if global warming continues unabated.

PHOTO: ADOBESTOCK/SAWITREELYAON

DISPLACED BY THE CLIMATE

TEXT: CHRISTIAN JAKOB

According to UNHCR, over 116 million people were displaced globally in 2023 – due to violence, armed conflict, and, increasingly, as a result of extreme climate events, rising sea levels, and resource conflicts such as those caused by water shortages. However, the creators of the 1951 Geneva Refugee Convention did not consider climate impacts as a reason for leaving one's homeland. International law and migration research now explores how climate change-induced migration could be managed.

Kausea Natano gave Anthony Albanese a shell necklace to hang over his Hawaiian shirt, but Australia's Prime Minister had brought Natano something far more valuable. In November 2023, Albanese visited the President of the Pacific island state of Tuvalu. In a tropical garden, shaded by palm trees, the two leaders signed a treaty granting the 11,000 residents of Tuvalu the right to relocate to Australia if climate change renders the islands uninhabitable. They "deserve the choice to live, study, and work elsewhere as climate change impacts worsen," said Albanese.

The Australian offer, made at Tuvalu's request, did not stem from any legal claims by the people of Tuvalu or because they "deserved" it. Australia made this concession by choice. But what about the millions who will be displaced by climate change in future?

"Climate change could become the biggest driver of displacement," said António Guterres, then UN High Commissioner for Refugees, at the 2009 World Climate Summit in Copenhagen. According to the UN, floods, storms, droughts, and wildfires displaced around 22 million people in 2019, and as many as 32 million in 2023. Last year, a study led by Timothy Lenton from the University of Exeter revealed the consequences of the shrinking "temperature niche" – the regions where average annual temperatures allow for human settlement. This range extends from about -5 to +35 degrees Celsius, with the optimal range being 11 to 15 degrees Celsius. Areas outside this niche, particularly those with a combination of high temperatures and high humidity, are considered potentially life-threatening. With a global temperature increase of 2.7 degrees Celsius, regions currently inhabited by about one-third of the world's population would fall outside this habitable niche by the end of the century. This would affect people in India, Nigeria, Indonesia, Pakistan, and the Philippines, as well as large areas of countries such as Burkina Faso, Mali, and Qatar.

However, climate-induced displacement is difficult to distinguish from other dynamics of flight and migration. "There are many reasons behind displacement and flight; there is no one single factor," says Steven Vertovec, a social anthropologist and founding Director of the Max Planck Institute for the Study of Religious and Ethnic Diversity in Göttingen: "Reason A, consequence B – that's overly simple, linear thinking." It is difficult to establish rigid criteria, he explains, such as those that apply to political refugees. With climate change, the direct climate impacts are mixed with phenomena such as food insecurity or violence. Even naming them is not easy; "survival migration" is one suggestion. "But here, too, it depends on the nuances – forms of mobility that do not pose an acute threat to life would not be included." Nor is Vertovec satisfied with the much-used term "displacement": "This often overlooks people's autonomy in their own actions and decision-making in relation to their migration."

Vertovec is equally skeptical about the sometimes wildly divergent forecasts. "They are often nonsense," he says. "Some claim there will be more than a billion climate migrants, while others simply take the entire Sahel region and say that these are potential climate refugees. The figures you get from this are crazy." International organizations are expected to make preparations on the basis of forecasts. Yet many of these forecasts, he says, are used "less for preparation and more for the shock factor."

It is clear that climate change will increasingly become a factor that forces people to leave their homes. For many, it may even become the primary driver of migration. These people need prospects: is their only hope that someone will voluntarily take them in – as with the people of Tuvalu? Or do they have legal claims?

SUMMARY

It is difficult to attribute migration unequivocally to climate change – multiple factors influence mobility. For this reason, it is also hard to forecast how many people are likely to leave their homes primarily as the result of climate change in the future. However, these numbers will increase.

Current international law governing refugees does not recognize a right to protection for those affected by climate change, and it is difficult to establish such a new right. It is conceivable that the principle of non-refoulement enshrined in international, EU, and national law also applies to climate migrants, but this has not yet been sufficiently clarified by the courts.

It may be possible for victims of climate change to derive legal claims against its main perpetrators on the basis of existing law, but the possibilities for legal enforcement are weak.

Binding commitments are needed to help with adaptation to climate change – most significantly in the major cities of the Global South, which are likely to be the major centers of climate migration.

The right to protection and admission is enshrined in the 1951 Geneva Refugee Convention (Refugee Convention). The Refugee Convention recognizes five grounds for flight, namely well-founded fear of persecution by reason of race, religion, nationality, membership of a particular social group, or political opinion. "Climate refugees" are therefore not included. The lawyer Laura Kraft conducts research at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg. She says that, given the cur-

rent political climate, it would be risky to add "climate change-induced displacement" to the Refugee Convention. "This would open Pandora's box, because existing protection standards could be renegotiated."

Enshrining protection rights for climate migrants in an additional protocol would be less risky. "An additional protocol cannot limit existing treaty protection," says Kraft. However, it would only be binding for the signatory states, and currently few governments are likely to enter into such a voluntary commitment.

"Human rights are a building block of climate justice."

ANNE PETERS

But does the existing law already potentially establish a right to protection for climate refugees? The first person to seriously attempt to clarify this question is Ioane Teitiota, a citizen of the island state of Kiribati. He moved to New Zealand in 2007 and worked there as a cabbage picker. When his work visa expired in 2010, he applied for asylum as Kiribati was at risk of being flooded. He invoked the Refugee Convention and the non-refoulement principle. This principle prohibits deportations if, for example, the right to life guaranteed in the UN International Covenant on Civil and Political Rights is in danger. The Covenant has been signed by 196 states, including New Zealand. New Zealand nevertheless rejected Teitiota's application: New Zealand claimed that neither of the standards was applicable, and his life was not in immediate danger.

Teitiota, along with his family, was deported to Kiribati in 2015 and appealed to the UN Human Rights Committee. The Committee rejected the complaint in 2020, stating that Teitiota's life was not under threat in Kiribati at the time of his deportation. However, the Committee found for the first time that deportations can violate the Covenant if those affected are exposed to conditions caused by climate change that jeopardize their right to life. It was a "historic case" for the UN Committee that allowed for asylum applications based on climate change – this is how the Committee assessed its own decision in January 2020. Nevertheless, the number of "climate change-induced displaced persons" will reach such proportions in the future that potential host states are unlikely to follow this interpretation of the Covenant in the long term.

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Sinking islands: In 100 years, Pacific island states like Tuvalu will be completely flooded, warn climate researchers – these states are fighting for their very existence.

PHOTO: PICTURE ALLIANCE / GLOBAL WARMING IMAGES | ASHLEY COOPER

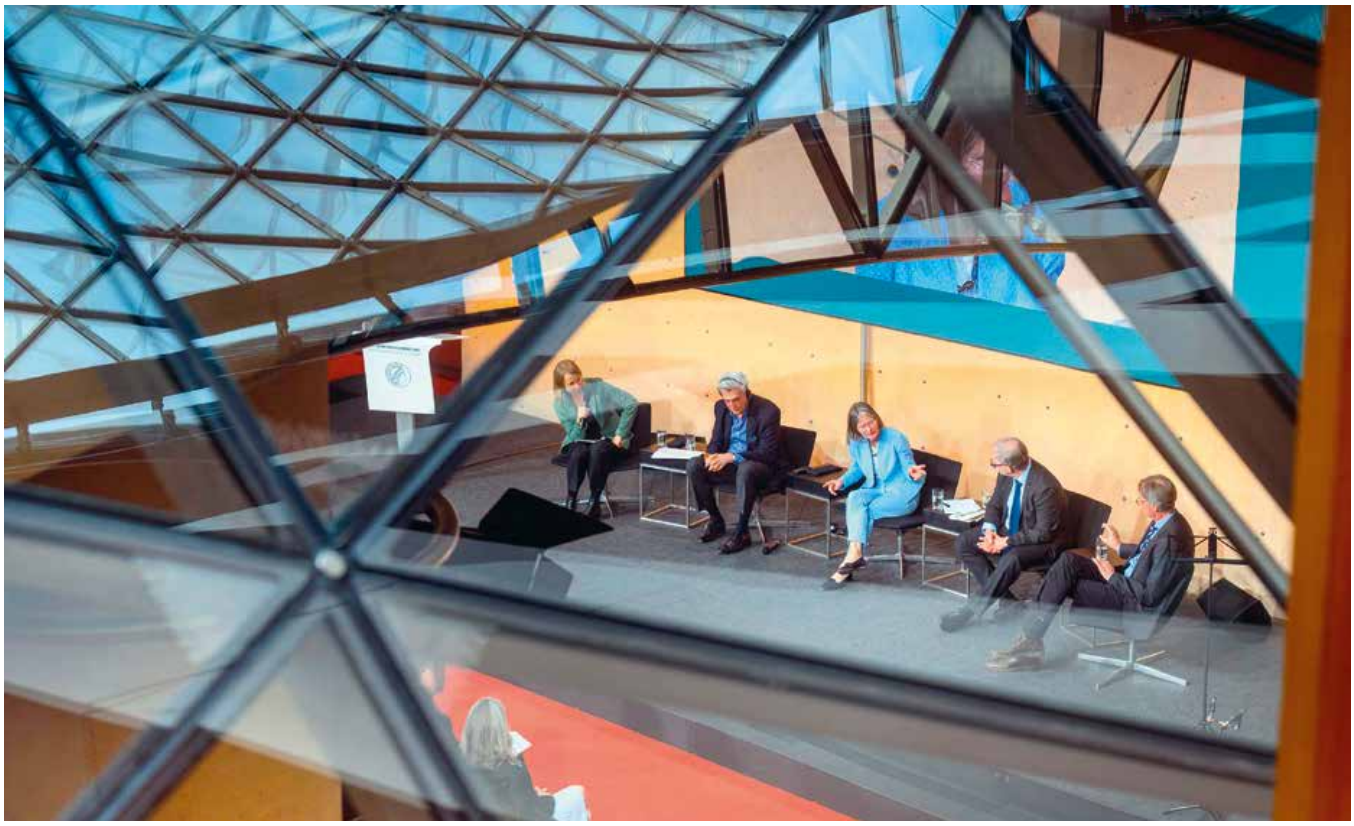


PHOTO: DAVID AUSSERHOFER / MPG

Panel at the Max Planck Society Berlin: Filippo Grandi, UN High Commissioner for Refugees (second from left) and Marcus Hicken from the Federal Foreign Office (second from right) discuss legal and economic aspects of climate migration with Max Planck Directors Anne Peters (middle) and Axel Ockenfels (right). Moderation: Helene Bubrowski.

The non-refoulement principle is also enshrined in the European Convention on Human Rights (ECHR). "Deportation to areas affected by droughts, heat waves, or floods caused by climate change could be considered inhuman or degrading treatment and thus give rise to a right to protection under EU law or national law in conjunction with Article 3 ECHR," says Laura Kraft.

However, neither the European Court of Human Rights (ECtHR), which interprets the ECHR, nor the European Court of Justice (ECJ), which interprets EU law, have yet made any decisions on this issue. In some expulsion cases, the ECJ has ruled that a generally poor humanitarian situation is not sufficient for a protection claim. Under EU secondary legislation, an actor must actively or at least culpably cause the "inhuman or degrading treatment" – for example, if a militia destroys hospitals and thus prevents access to healthcare.

Kraft considers it likely that the ECJ will also adhere to this actor requirement in the event of a lawsuit by a climate migrant. It also remains to be clarified whether industrialized countries, which have emitted particularly large amounts of greenhouse gases, could be understood as such actors – creating an obligation to accept migrants. The ECtHR does not necessarily require an actor within the framework of Article 3 of the ECHR – and neither do German administrative courts when they refer to the case law of the ECtHR in expulsion cases. Rather, they assess the general humanitarian situation in a country of origin, for example, on the basis of country reports by the Federal Foreign Office. The crucial point, according to Laura Kraft, is that the individual situation of a person must be so severe that returning them to their country of origin would be considered "inhuman."

Are certain climatic-ecological conditions sufficient to merit this? And at what threshold exactly? For example, how significantly must crop yields decline due to global warming for a person not to be considered merely a poor farmer and economic migrant leaving an already barren region in search of a better income? What individual factors must be added to establish the necessary individual vulnerability and need for protection?

"Courts will provide answers to these questions in specific cases through the interpretation of the law and its application in individual circumstances," says Kraft. However, the non-refoulement principle derived from human rights only protects against deportation. It does not establish a right to enter a country. Without a visa, however, entry for people from the Global South is only possible by irregular means, which are often expensive and very dangerous.

The 1969 African Refugee Convention, adopted by the Organization of African Unity (OAU), is one example of an attempt to establish a broader definition of refugees. It extends protection to individuals whose countries are experiencing events that are "seriously disturbing public order." In 2011, Kenya and Ethiopia admitted people from Somalia on this basis, where drought, hunger, insecurity, and armed conflict prevailed. However, other African states have previously refused to classify environmental events as a "serious disturbance of public order" within the meaning of the Convention. The UN Refugee Agency (UNHCR) has a mandate to officially determine a person's refugee status. This mandate includes a definition beyond that of the Refugee Convention, similar to the OAU's, and could apply, for example, if persistent crop failures significantly disrupt public order. Nevertheless, individuals recognized by UNHCR may live in its refugee camps, but do not have the right to resettlement in a third country.

International law expert Anne Peters, Director at the Max Planck Institute for Comparative Public Law and International Law, does not believe that new international legal norms are needed in response to climate mobility. "We already have legal starting points for reaching fair and equitable outcomes," she says. International human rights, in particular, are an important legal tool, says Peters. They can directly be applied by regional and domestic courts, and this is one of the reasons why many climate lawsuits invoke human rights, she explains. Such lawsuits also demand government measures to reduce greenhouse gas emissions. "However, human rights seek to protect individuals, and are not per se an instrument to remedy systemic problems," Peters says.

The UN Global Compact for Migration adopted in 2018 is also relevant. The Compact contains a section on "natural disasters and the adverse impacts of climate change," in which the signatory states promise support for adaptation and resilience measures in countries adversely affected by climate change, guarantee access to humanitarian aid, and announce cooperation in the design of resettlement measures and visa policies. "This section is an important point of reference in the discussion about climate mobility," says Peters – but the Compact for Migration is not a formal treaty of international law; rather, it is soft law. International law-making is mostly cautious because international organizations are dependent on acceptance and financing from the member states. "And often the organizations and international courts do not want to jeopardize this acceptance," says Peters. If international law becomes too ambitious, states will refuse to cooperate.

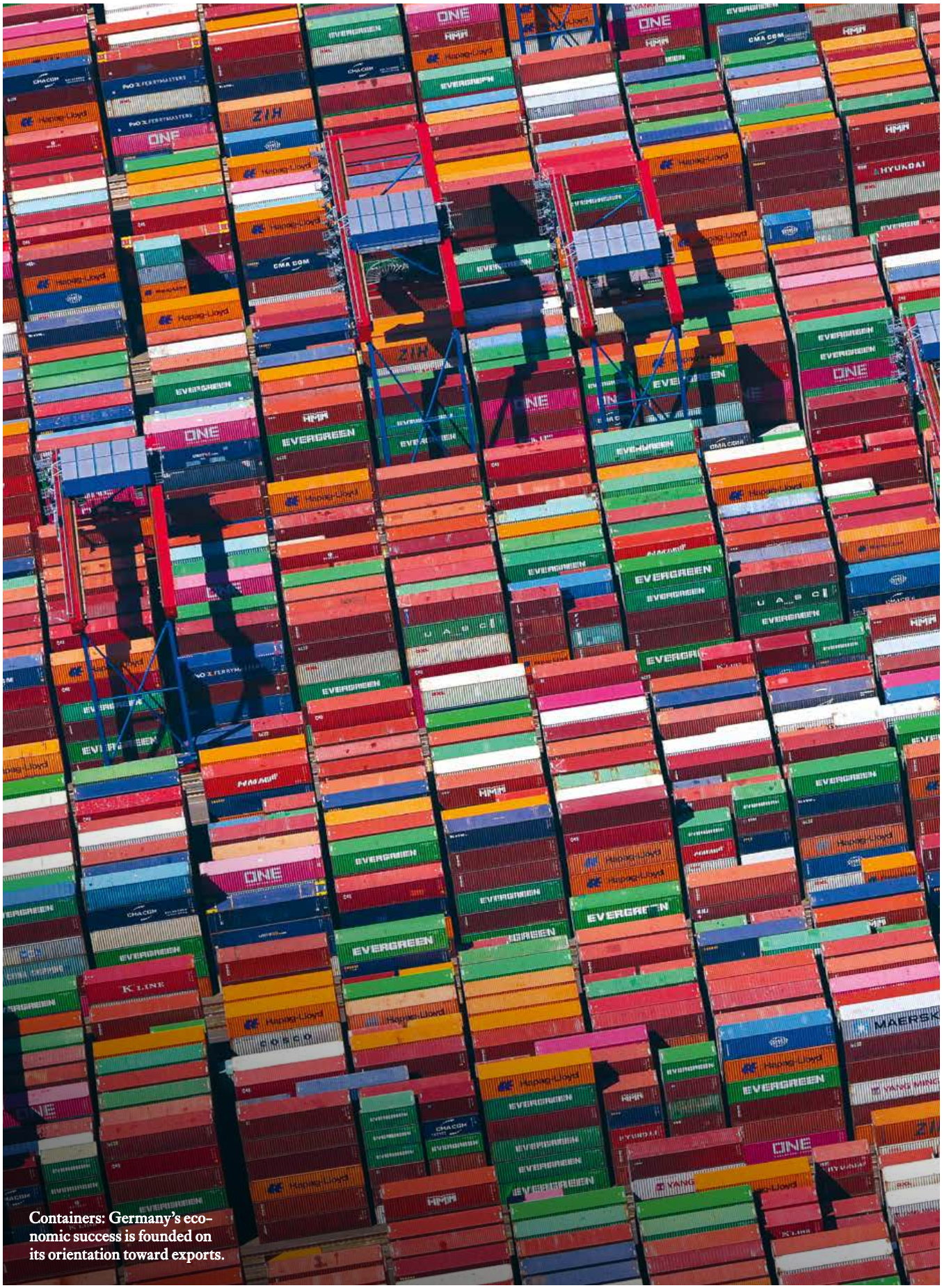
Therefore, voluntary cooperation is prevalent. One example of such voluntary cooperation is the "Platform on Disaster Displacement", an association of 15 countries founded in 2012 to help climate migrants. The Expert Council on Integration and Migration, which was set up by the Bundestag and funded by the German Federal Ministry of the Interior, pointed out in its 2023 annual report that the "immediately necessary" responses to increasing climate migration are "most likely to come from national governments." The panel therefore suggested three new instruments, such as a "climate passport" as a humanitarian permanent residence permit for those severely affected, or a temporary "climate card" for those less at risk. Finally, the "climate work visa" would help people from less affected countries to gain access to the German employment market.

People need a right to stay in their homeland

Psychologist Birgit Leyendecker from the University of Bochum is Vice Chairwoman of the Expert Council. She believes that in addition to instruments for the admission of climate refugees, their "right to stay" in their regions of origin must be supported. "This emotional aspect is often underestimated," she says. Even for the people in the Ahr Valley, it was very difficult to learn that they could not rebuild their homes in the same place. "Attachment to one's homeland is often very strong," says Leyendecker. "The 'right to leave' should therefore only be a last resort." For Leyendecker, this means that industrialized countries must invest more in adaptation mechanisms in regions particularly affected by climate change.

Steven Vertovec agrees. "It's clear that many people will head to the outskirts of major cities in their own regions first." These have to be able to prepare for the growing demands, he says. "It's all a problem of planning, first and foremost: how do people in the outskirts of the big cities get access to water and sanitation? How can food supplies be ensured?" According to Vertovec, extending international protection to include the expansion of such infrastructure is one of the most important tasks.

www.mpg.de/podcasts/recht-schafft-freiheit (in German)



Containers: Germany's economic success is founded on its orientation toward exports.

PHOTO: PICTURE ALLIANCE/DPA | CHRISTIAN CHARISIUS

GERMANY'S ADVANTAGE

TEXT:
SABINE FISCHER

Relationship status: it's complicated. For many people, the European Union is a source of both identity and excessive bureaucracy. However, it gives its member states economic opportunities that one country in particular has used to its advantage: Germany. Martin Höpner and Lucio Baccaro at the Max Planck Institute for the Study of Societies explore why Germany has been able to benefit to such an extent and why a course correction is nonetheless advisable.

"Take good care of democracy when I'm gone." A woman in a colorful blouse calmly reads this sentence from a letter she has written to her grandson. She is sitting beside other elderly people in a bright room. All of them experienced how democracy in Europe changed their lives – such as in France, the Czech Republic, and Latvia. They all talk about the moments when being part of the European Union made a difference for them and connect these reminiscences with an emotional appeal to the following generation: protect democracy, protect the EU.

This emphatic video was part of a social media campaign headed by the European Parliament in the run up to the second-largest elections in the world. More than 180 million people voted to determine who should represent their interests in the European Parliament, headquartered in Strasbourg in France, for the next five years. The voter turnout of 51.08 percent across the EU was the highest since 1999. Germany even witnessed its highest voter turnout since 1984: 64.78 percent, which was considerably higher than in 2019. Rarely has so much attention been given to EU issues as in the run up to this year's election. Another aspect that stands out here is that, despite war and crises, most people in Europe are optimistic about this unique association of states uniting 27 countries.

The Eurobarometer commissioned by the European Commission in April 2024 shows that the EU is an anchor point for many people, especially in times of global insecurity. More than two-thirds of all EU citizens agree that the Union is a place of stability in a difficult world. In Germany, trust in the European Union even increased by five percentage points during the last year. The freedom to travel, work, and study; the uniform currency; and lasting peace are considered its greatest advantages. At the same time, the EU has a reputation for being "particularly bureaucratic." That's no surprise. The most recent EU Commission can boast of having created an exceptionally large number of regulations. Steffen Kampeter from the employers' association BDA told the newspaper Frankfurter Allgemeine Sonntagszeitung that companies that have been burdened by additional reporting obligations are groaning the loudest under those regulations. Around half of the people surveyed by the 2023 Eurobarometer considered the EU to be undemocratic.

Martin Höpner, leader of the Research Group on the Political Economy of European Integration at the Max Planck Institute for the Study of Societies, understands why they feel that way. "When citizens believe it doesn't make a big difference whether they participate in the EU parliamentary election, they're not exactly wrong," he says. The reason is that the actual "government" of the EU, the European Commission, does not come from the European Parliament and thus cannot be elected. Additionally, the Parliament cannot propose bills, which is a basic function of a democratic parliament. Consequently, many people feel they cannot influence what is happening in Europe.

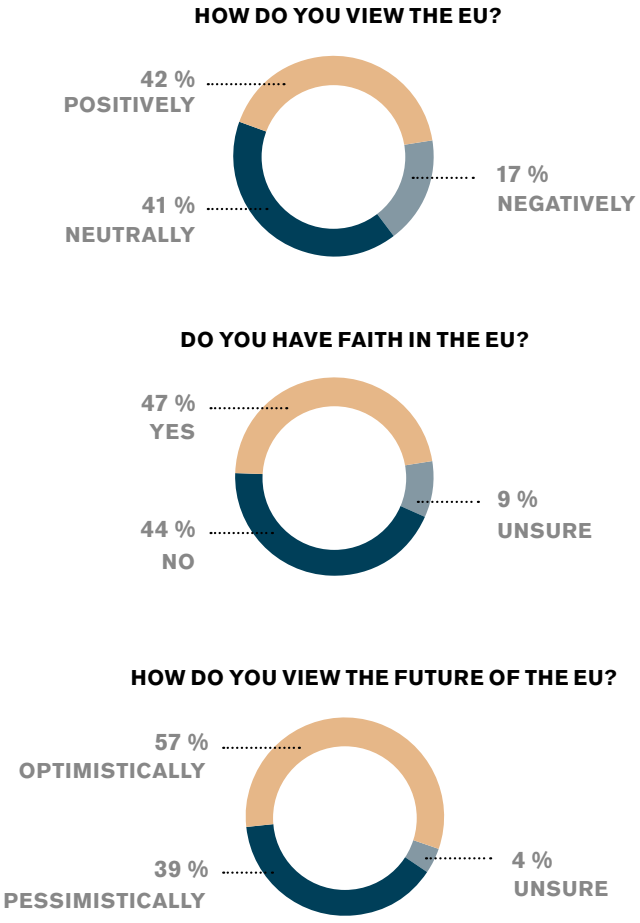
Despite this feeling of powerlessness, Höpner says the EU's lack of democracy is actually not as extensive as people often perceive it to be. He continues, "Using the criteria of a parliamentary democracy to judge the EU is not fair. It is the uppermost layer of a multi-level system that functions in a completely different manner. A complete democratization of the EU in the near future is neither possible, nor desirable." The reason for this lies in the way the system works: the EU is legitimized by states whose citizens endow them with authority in a democratic manner. As long as this chain of legitimation functions, it absolves the EU of having to structure its institutions more democratically. A democratic deficit, however, does arise when the EU dysfunctionally overstretches its powers, warns Höpner. He therefore sees less need for reform in the EU's political system than in its constantly growing areas of activity.

"The European Union should only become involved in areas where truly transnational problems exist."

MARTIN HÖPNER

To become more democratic and transparent, and thus receive greater support from the citizenry, he believes other adjustments are needed. For instance, skeptics constantly complain about the increasing "regulation frenzy;" with a growing number of directives and ordinances, the EU is increasingly placing restrictions upon its members. While the European Commission, the guardian of agreements, actually should be guaranteeing prosperity and reliability, many critics believe that its reform ideas are overshooting the mark. Höpner also sees a need for action in this regard: in principle, the EU does create economic freedom for its member states, but this comes at a price. "The EU excels at asserting individual rights. For instance, consumers can choose products as they please, and pro-

ducers are free to sell their goods outside their country's borders. However, the states lose room for maneuver, which happens at the expense of collective freedom," Höpner elaborates. He says certain projects, including animal welfare projects, experienced difficulty owing to this restricted latitude. Höpner believes that the Union should be less strongly involved in the internal development of its member states than it is now, for example, in matters of family and social law. Bureaucracy must be reduced in places where it has no business existing according to European ideals, which is to say, where there are no transnational problems to solve. Höpner mentions one example: the standby times of volunteer firefighting services. In various rulings, the European Court has regulated when standby duty for these services must be considered working time. "Of course, someone has to regulate how standby times are limited and counted. But since there is absolutely no transnational problem here, it is difficult to understand why this regulation must take place at the EU level," says Höpner.



GRAPHIC: GCO BASED ON THE SPECIAL EUROBAROMETER 101 – SPRING 2024 – PUBLIC OPINION IN THE EUROPEAN UNION

Opinions: faith in the EU is rather high in Germany in April 2024 and has even increased compared to the previous fall. (The Eurobarometer is compiled every six months. Participants: 26,400 citizens across the EU, of which 1,559 were resident in Germany.) *Source: Standard Eurobarometer 101.3, figures for Germany*

However, a fundamental reform of the Union's areas of activity is difficult to achieve, says Höpner: the EU requires contractual changes before it can renounce individual areas of activity. These changes are not only difficult to negotiate with 27 member states – in some countries, such changes also need to win a popular vote. "It's not as easy to win these referendums as it once was. In the past, they were often a way for people to express their dissatisfaction with the EU," says Höpner. According to Höpner, that creates a dead end: many citizens would like to have a more transparent and effective EU that creates freedoms and is less bureaucratic, but any attempt to move in this direction is quickly boycotted. "Popular votes are rarely approached in a nuanced manner. They are more of a blanket means of expressing discontent and voting against the proposals from the EU." Höpner sees a clear mandate for the European bodies here: the EU needs to make it clear that it wants to withdraw from non-transnational areas of activity. Following this, the switch to a more streamlined system, one perceived as more democratic, could succeed.

Germany, the super profiteer

Streamlined or not, the regulations of the European single market create economic opportunities and constraints for member states. Researchers, including Lucio Baccaro, Director at the Max Planck Institute for the Study of Societies, have found that integration into the European single market has been advantageous to Germany in particular thus far. According to Baccaro, European integration is an important component of Germany's new national identity post World War II. Together with Martin Höpner, he has explored Germany's economic development in detail in the research project "Das deutsche Wachstumsmodell, 1991 bis 2019" (The German growth model from 1991 to 2019). One of his findings is that where economic growth is concerned, the European Union has played a decisive role. "After World War II, Germany experienced a huge identity crisis," says Baccaro. "It left the war as a defeated, deeply shaken country. After that, it was important for the German state to redefine and reinvent itself not as a military power, but as a trading nation. Economically speaking, being a part of Europe has become a core facet of the German identity." →

PHOTO: PICTURE ALLIANCE / CARO | RUFFER

Berlaymont building in Brussels: Most of the new legislative initiatives at the EU level originate in these offices of the European Commission. The building was constructed in the late 1960s.

According to the results of Baccaro's and Höpner's research, Germany's reorientation succeeded primarily because the European single market often had answers to some of the greatest economic problems facing the country. After the German reunification and the direct 1:1 exchange of Eastern German marks to Deutschmarks, for example, approximately 18 million former citizens of the GDR received a sudden injection of purchasing power, which put existing production capacity under pressure. The result? "At the time, the country was less stable than before. Demand exceeded supply, there was inflation, and there were, unusually, current account deficits. That meant that, at the time, Germany had to import more than it could export. The Bundesbank intervened decisively to cool the economic overheating by raising interest rates," Baccaro explains.

As a result of these developments, Germany entered a phase of semi-stagnation that lasted into the new millennium. However, the stagnation tendencies were less acute than they could have been because, where growth was concerned, Germany channeled all of its efforts into exports – with great effect. Between 1995 and 2007, approximately 85 percent of Germany's economic growth resulted from the export sector. A large part of this significant increase was possible thanks to Europe. This is because, at least until the euro crisis, a considerable portion of the goods produced in Germany were destined for the European single market. As a result, the EU and the uniform euro currency ensured prosperity in Germany for years. "At some point, Germany's economy became so competitively viable that the growing export demands formed a counterbalance to the shrinking domestic demand," Baccaro explains.

Export alone is not enough

However, Baccaro elucidates that this model was never guaranteed success. "Germany was, to a certain extent, just lucky." Driven by the export sector, its economy grew between 1995 and 2007. Baccaro says the situation was quite different in the EU countries that relied on domestic demand-led growth. "Since the

2008 financial crisis at the latest, the countries in the euro zone have been economically worse off than the USA. The export markets in Europe were shrinking as a result of protracted recessions. Germany was the only country that was hardly impacted by this trend. This is the case because the country continued developing its export-led model by increasingly exporting out of Europe."

Does Germany's unique path, which saved the country from stagnation at least in the short term, set an example other EU states should follow? Lucio Baccaro shakes his head. The whole development was a nightmare for the single currency. While Germany became increasingly competitive with its export push, other countries developed in the opposite direction. For instance, Spain's economic growth focused on domestic tourism and the construction industry, which at times accounted for nearly 11 percent of its gross domestic product and more than in any other European country. This boom came with an increasingly deteriorating external balance, which eventually led to a sharp correction. Baccaro believes the EU has been unable to address this imbalance to this day. If all the members of the euro zone grew more quickly, this would also benefit Germany.

Germany's one-sided focus has consequences: the German model is starting to reach its limits beyond Europe as well. "The model is now approaching its end. After the geopolitical shock caused by the war in Ukraine, the energy crisis, and the Covid-19 pandemic, accessing export markets has become increasingly difficult," Baccaro says. He also maintains it is already clear that trade relationships with China and Russia, for instance, have become quite difficult. The challenges posed by the green transformation and digitalization have become so great that export-driven growth, which Germany depends upon, will fall short.

There are already signs of stagnation: according to the Federal Statistical Office, Germany's gross domestic product sank by 0.3 percent in 2023. In the first three months of this year, it increased by only 0.2 percent (adjusted). Based on their research, Lucio Baccaro and Martin Höpner think that, in order to remain economically stable in the long term, the Federal Republic needs a more balanced model. They explain that export-driven growth models normally make sense for small, open national economies such as Ireland or Sweden. It is extremely unusual that a giant like Germany, with over 80 million inhabitants and a large domestic market, is using this model. After all, the strong export sector has another side: a weak domestic economy. "Traditionally speaking, Germany ignores its own domestic market and makes its prosperity dependent on external demand as a result. If the export market does not continue to grow, domestic growth also comes to a halt," says Höpner. Both researchers consider this unilateral focus to be a bad strategic decision. To have stable long-term growth, they believe the model should be oriented towards a balance between the export market and the domestic market.

What Germany needs is the courage to take an honest look at the economy in the country and address problematic areas. "Actual wages in Germany have been stagnating for several years, above all in the service sector, commerce, the construction industry, and the public sector," Baccaro criticizes. Höpner adds that the export sector currently ties up a good deal of the workforce, which is lacking in fields like care work and the public sector.

At the same time, the state is hardly spending money on investments. "Germany is not investing enough in its infrastructure – not even in areas where this is urgently required owing to changing international competition, such as digitalization," Baccaro observes. The researchers believe this is exactly where Germany needs to make changes to ensure healthy growth in the future and thus guarantee economic security and freedom. "To ensure that domestic demand contributes to prosperity, real wages and public spending need to increase. We need enormous investment for the green transition, among other things," Baccaro concludes. "The effects on the debt level in relation to the gross domestic product depend on the effects investments have on growth and the development of interest rates. More public investments do not necessarily increase the debt ratio." In any case, Germany can afford to increase its debt ratio to make reasonable investments in infrastructure and for other purposes, such as decarbonization and digitalization.

The course German economic policy will take remains to be seen. One thing seems clear: only if Germany – the economic heavyweight – and with it all of Europe prospers economically will people's faith in the EU be rewarded.

www.mpg.de/podcasts/recht-schafft-freiheit (in German)

SUMMARY

As an association of states, the EU cannot be measured by the standards of a parliamentary democracy. It is not a state, but rather the highest layer of a multi-level system borne by the member states. The EU creates freedom, especially economic freedom: its provisions assert individual freedoms for EU citizens and member states and create security. The German export economy has profited well from the advantages of the single market and the euro. Researchers argue that, to remain stable in the long term, Germany must concentrate less on exports, focus more on its own domestic market, and create a more balanced system that is less dependent on external demand.

Luiz Gama, first a slave himself, then a lawyer, liberated hundreds of people from slavery. But does anyone still know him today? Bruno Rodrigues de Lima, scholar at the Max Planck Institute for Legal History and Legal Theory, is keeping his memory alive. As the young lawyer from Brazil says, the human rights activist's work is anything but done.

TEXT: MARTIN TSCHECHNE

At some point, this image will almost surely make its way to the screen – a Hollywood movie, or perhaps a Netflix series: A boy, still a child, is leaning over a railing. The ship, the Saraiva, a floating death trap weighing 152 tonnes, puts out to sea from the quay wall in November 1840 to take a shipment of slaves from Salvador de Bahia to Rio de Janeiro, 1600 kilometers to the south along the coast. There is crowding on board and rats running around on deck; they gnaw away at ropes, papers, everything. Just then, the boy understands what is happening to him. "Father," he cries out as the mainland recedes from him, "Father, you've sold me!" That is how the first turning point in Luiz Gama's life could have unfolded. The life of the Brazilian lawyer, a slave who became a liberator of slaves.

Nearly 200 years later, at the Max Planck Institute for Legal History and Legal Theory in Frankfurt, Bruno Rodrigues de Lima moved a reading chair in front of the window in his office. The bookshelf beside him is full of old books, legal texts from his Brazilian homeland behind fragile leather spines, comments, tracts, and documentation. Lima, just 35 years old, slim with black curls, contemplates the collection. His search for the causes of the state of his country and its prospects for the future constantly leads the researcher deep into the sediments of archives and libraries.

Copies of case records are stacked on the table, their calligraphic flourishes attesting to the respect and zeal the court clerks had for the cases written down 150 years ago. Lima salvaged the originals piece by piece from the courts of his homeland. For nearly 20 years, he traveled across that vast country from one end to the other, yet it was here, in the overwhelming library collection of the Max Planck Institute in Frankfurt, that he found the texts that are helping him discern patterns, the ideas behind the legislation, political intentions, and economic and ecological impacts. Every now and then he leaps to his feet, shuffles through the mighty stack of papers, pulls one of the tomes from the shelves, and swiftly locates the proper passage, a footnote, a cross-reference, or a quote. "Here, you see?" He is talking about a life emerging from the lines before him. Or rather, at least two lives – strictly speaking, 500 or more. Lima has a remarkable story to tell.

Salvador de Bahia on Brazil's Atlantic coast, November 10, 1840. Luiz Gonzaga Pinto da Gama is a ten-year-old who had, until that point, grown up in a two-story house at Rua do Bângala, and is torn

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VISIT TO

BRUNO RODRIGUES DE LIMA

PHOTO: KATRIN BINNER FOR MPG

Bibliophile researcher: the extensive library at the Max Planck Institute for Legal History and Legal Theory has proven to be a treasure trove for Bruno Lima.

away by the turmoil of the times. His father came from a family in the Portuguese upper class – a gambler and drinker, affluent at first but frivolous and soon so deep in debt that the only way for him to acquire credit was to sell his son. From now on, his father will no longer play a role in Luiz Gama's life. His mother, Luiza Mahin, had been brought to the country as a slave from West Africa. A beautiful woman, her son would later report, strong and full of ire. She sold fruit on the street and saved up the money until she had enough to buy her freedom. Her outrage seethed on. When African slaves in the city rebelled against their enslavers in 1835, she made her house available to them as a command center. She got involved and was the only woman among the leaders of the revolt. But the rebellion was put down. The leaders were shot or imprisoned; Luiza Mahin's trail disappears in Rio. Like many others, she was probably taken onto a ship bound for Africa and banished. The mother would never see her son again.

Scenes with the color and dynamics of a film appear repeatedly throughout the story of Luiz Gama's life: 1847 in São Paulo, the grandiose house of the slave trader Antonio Pereira Cardoso. Luiz, now 17, has made his way here after years of humiliation. He works as a domestic servant and is treated decently. A student who lives in one of Cardoso's rooms even takes the time to teach the boy to read and write. Since law is his discipline, he also kindles his young friend's interest in this field. Luiz must have felt the possibilities that were opening up for him. Less than two years later, he has gathered all the papers he needs to become a free man. His mother was a slave who legally bought her freedom, his father a man who cannot assert any claim to ownership concerning his son – since the sale eight years ago was illegal. Luiz has everything in black and white. Today no one can say how he managed that. A very young man who could not even spell two or three years ago. At the age of 19, he started working as an assistant to the inspector and law professor Furtado de Mendonça in São Paulo. And what a stroke of luck for the young man, who craves knowledge, that his sponsor not only teaches in the law school, but also has a key to its library...

There would be a hard cut now in the film, a jump a century and a half in the future to the year 1996. We would see a very thin boy almost eight years old in the New York neighborhood of Queens. The boy is wearing a printed T-shirt and extra-wide pants like many in the neighborhood, yet he seems singularly alien in his setting. "We were in the U.S. illegally," Lima says today, bluntly, "undocumented immigrants." Fleeing social insecurity in their own country, the family sought refuge with relatives; his father cleaned at a golf club, and his mother worked in a kitchen. The boy's quick grasp of concepts stood out, and since the school years of his old and new home countries didn't quite line up, it was decided he would start classes in the next grade up. The fact that he hardly understood the language was not a problem. That was the case for many people there. He learned it. He also learned the rhythm of the street, rap that had evolved from the speech songs of Black slaves on the plantations in the South of the United States. When English was not enough, the boy simply added words and rhymes from his native language, Portuguese. He was really good back then, Lima says. But he disliked the country, the foreign culture, and a language that, for him, did not come close to his own in terms of poetry and nuance at the time and still fails to do so.

Two years later, the family returned to Brazil. And since his academic leap repeated itself, Bruno Lima

Lima learned. He also learned the rhythm of the streets, rap, which originated from the chants of Black slaves.

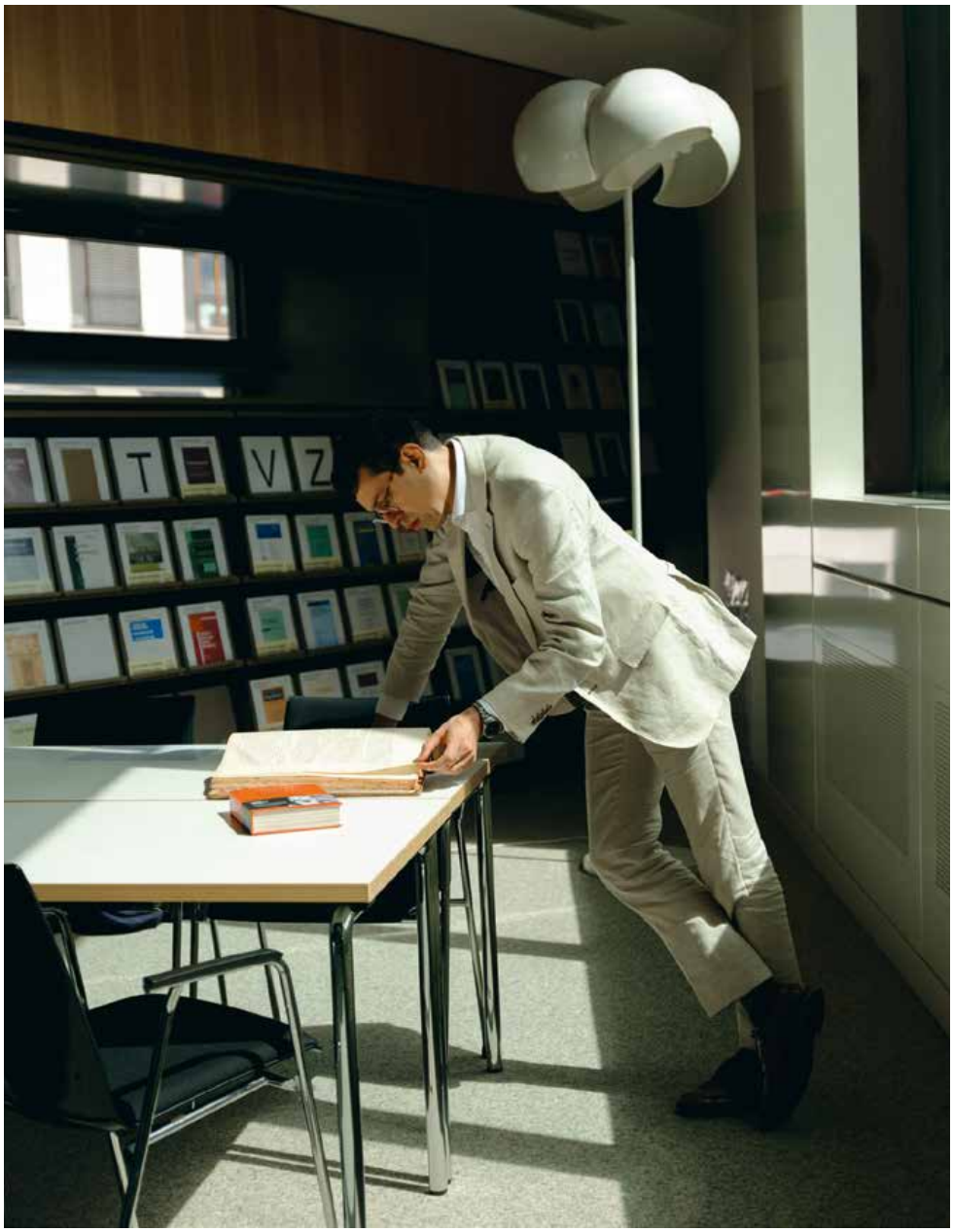

PHOTO: KATRIN BINNER FOR MPG

The researcher spends a lot of time in libraries and archives. He has already gathered thousands of Gama's writings to make them accessible to the public.

reckons he entered fifth grade at the age of nine, law school of the Catholic University of Campinas at 16 and made it into the newspaper. The youngest student in the history of the law school, extremely gifted, sponsored early on by the Brazilian Ministry of Education. Accredited as a lawyer in Brazil at the age of 25, he received his doctorate at the Goethe University in Frankfurt with the distinction summa cum laude, was awarded the 2022 Walter-Kolb-Gedächtnispreis for his dissertation, a legal biography about Luiz Gama, as well as the 2023 Otto Hahn Medal of the Max Planck Society. And he always had the same clear goal in sight: to gain a deep understanding of the aftermath of slavery in his country, so as to redress the legal situation of the most vulnerable members of society, the descendants of former slaves.

Now the film could cut to a scene in November 2002. His family is living in Itatiba, north of São Paulo. A

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very elderly woman from the neighborhood, the daughter of a former slave, has entered the house and is speaking with his mother. A few days before, on October 27, Luiz Inácio Lula da Silva, had been elected president the first time. Bruno Lima's parents had been amongst the founding members of the labor party PT in 1980. Now the desperate woman hoped for intervention: the mayor had ordered her family and 33 others to leave their quilombo, the settlement on the outskirts of the city where they had lived for more than a hundred years.

Quilombo, Bruno Lima explains, is a key concept for understanding Brazilian politics to this day. The destruction of these residential settlements is invariably driven by economic interests: husbandry or crude oil, deforestation, expansion of plantations for coffee or soy. And the inhabitants, many of them descendants of former slaves, are driven from their land. In principle, a new constitution adopted in 1988 clearly regulated their right to property. However, it was quite a different matter in practice, as the adolescent learned in his mother's kitchen. It remains that way to this day: Lima estimates that a good 5,000 quilombo communities are still fighting for recognition and continued existence before the courts – even for their lives, he says.

At the time, his mother suggested he could find out whether the visitor's quilombo really did exist before slavery was officially abolished in 1888. That was the criterion stipulated by the Constitution 100 years later that determined whether the woman could remain. But did anyone who wanted to establish a palm oil plantation in the jungle heed it? At that moment, he remembers, he was aware of hearing the name Luiz Gama for the first time. According to the elderly woman, he was a person who, like a hero, had taken a stand against the land barons, a corrupt government, a complacent justice system on behalf of the slaves – both those who had been set free and those still in bondage. And he used everything at his brilliant mind's disposal: pieces of evidence and intricately developed arguments, the power of the published word, and legal shrewdness, mockery, and sarcasm.

Bruno Lima's award-winning doctoral thesis, a biography of Luiz Gama, has been published as a book.

PHOTO: KATRIN BINNER FOR MPG

The 14-year-old set out on a search, digging for days in the local archives. In the end, he managed to discover papers needed to help the inhabitants of the quilombo gain their rights. The incident laid the foundation for Lima's research on the life of Luiz Gama – he collected and read everything of Gama's he could find. It was not much at first, he remembers, 51 poems and 25 newspaper articles. But today, four voluminous tomes of writing are lying on his desk at the Institute in Frankfurt. Seven more are to come in the next two years. Bruno Lima searched for them in the archives of his Brazilian homeland, and edited and published what he found: records of court proceedings, an autobiography, furious comments for the newspapers, and even satirical verses Gama had written. In total, there were 1,100 original texts and a couple thousand explanations and references – the researcher's pride is noticeable. His collection is his treasure. As soon as he opens a book, he murmurs the number of the page and footnote he wants to cite. Correctly, of course. At some point he mentions that Luiz Gama's life lasted 52 years, two months, three days, and seven hours until his death on the afternoon of August 24, 1882.

Bruno Lima leaves little doubt that he considers every day in Gama's life an exemplary day in the legal history of his country. Because his goal is to discover and rehabilitate a man who not only represented his

own case single-mindedly, but also quickly rose to become one of the most strident lawyers representing the repressed in Brazil. One who traveled the entire country; demanded human rights like the ones Brazil's constitution had established long ago (but, as Lima adds, does not guarantee to this day); dissected the wording of purchase contracts, inheritance agreements, and the wills of slaveholders; and did not stop until his clients were free. There were two million slaves in Brazil during his lifetime, around 20 percent of a population of 10 million. Lima's research proves that Luiz Gama won freedom for at least 500 of them in court. However, they could have numbered 1,000 or more. The young researcher's search is not over by any means. At the Max Planck Institute in Frankfurt, Lima has the perfect constellation to continue investigating the legacies of slavery in Brazilian law. "Slavery cuts deep, from the lives of Black people in the favelas to the trees in the Amazon forest," says Lima.

In 1870 Gama gets his big chance. Commendatore Ferreira Netto, residing in Porto, Portugal, dies. Childless. Before his death, Ferreira Netto had operated coffee plantations in the region around Santos in Brazil. His legacy poses extremely complex challenges for the local authorities: Who is entitled to the seigneuries in South America? And to the slaves, since slavery has now been abolished in their master's homeland Portugal? The judges divide up the proceedings, Gama manages to secure a mandate and delves into his work. In the end, 217 slaves win their freedom in one fell swoop. Bruno Lima has salvaged over a thousand pages about the case, which was hardly known until he did so. "It is probably the largest collective freedom suit in the history of the Americas," says Bruno Lima. Luiz Gama triumphed, despite everyone who had argued about the inheritance unanimously turning against him, even threatening him with death – it is the brilliant beginning of a career as a lawyer fighting against slavery.

A film that cuts together the life stories of Luiz Gama and Bruno Lima needs to jump and shorten time where the images of the past are not clear. Gama founded newspapers and wrote pamphlets against the evils of bondage. He wrote verses that pull the venerable lawyers around him to pieces. Bruno Lima, who tested his joy of the rhythm and wit of language as a rapper in Queens, does not shy away from comparisons. With Bertolt Brecht, for example: he says there is no doubt Luiz Gama was the better poet. Indeed, the statement may be a bit bold, but it testifies to Lima's deep respect for the lawyer and human rights activist.

Bruno Lima collected and read everything by Luiz Gama that he could find.

Rio de Janeiro, February 2024. Lima has flown to Rio for Carnival, from the cold winter in Frankfurt to the heat of the teeming urban canyons. Portela, one of the largest samba schools in the country, transformed the story of Luiza Mahin, who bought her freedom and was banished, and her son Luiz Gama into a spectacle of rhythmic stamping, singing, and dancing involving nearly 3,000 women and men in flamboyant makeup. Bruno Lima helped reconstruct the story and bring it to the street. But is that the final scene in his story? "Oh, no," the researcher makes plain. "It is just the beginning." Slavery is officially abolished in the country, which put more people into bondage than any other. But as long as history is written by those who have shaped it for hundreds of years, as long as the black descendants of slaves fear for the fate of their property and may become famous soccer players – but never president – Lima wants to do his part to make sure Luiz Gonzaga Pinto da Gama does not remain a footnote in history. With a legal biography, 11 volumes of his collected works and more than a thousand texts finally available across libraries around the world. With drums and trumpets and 3,000 dancers in tow. ←

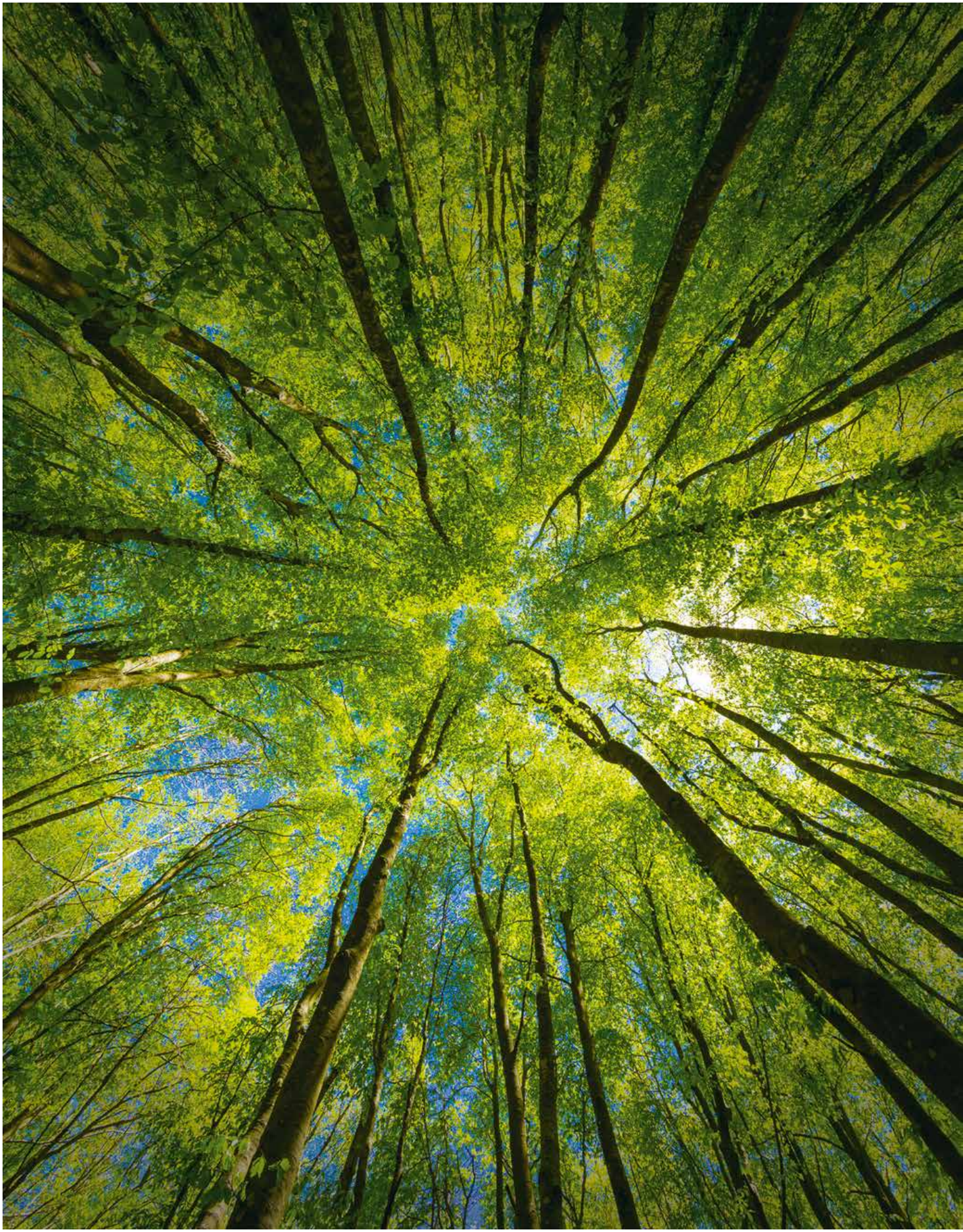

IMAGE: ADOBE STOCK/PROSLGN

DOUBLE TAKE

MAX PLANCK INSTITUTE FOR HUMAN DEVELOPMENT

Too much stress? Head for the forest! Glimpses of treetops, the spicy scent, the sounds of the forest, the soft crunch of your own footsteps – just an hour's walk in the woods has been shown to reduce activity in the amygdala (shown here in red) – a region of the brain that is particularly active during stress. By contrast, brain activity remains the same during a walk through the city. Another benefit of nature: birdsong reduces anxiety and irrational thoughts. The forest is relaxing – an insight that has been practiced in Japan for centuries as shinrin yoku – forest bathing.

IMAGE: MPI FOR HUMAN DEVELOPMENT

PIONEERING MINDS IN INTERNATIONAL LAW

Today, it seems self-evident that the primary goal of diplomacy is to secure peace among nations. Whether this succeeds depends on two factors: the skills of the political negotiators and the expertise in the background. The Max Planck Institute for Comparative Public Law and International Law has provided such expertise now for 100 years, leaving its mark on contemporary history.

TEXT: SUSANNE KIEWITZ

Today's Max Planck Institute for Comparative Public Law and International Law owes its existence to a national state of emergency. After its defeat in World War I, Germany was isolated in foreign affairs. The Versailles peace treaty, as the basis for future cooperation, had been negotiated without the Germans. The young Weimar Republic needed international legal expertise to mitigate the harsh provisions set out in the treaty.

With its severe reparation obligations, the Treaty of Versailles promised an even bigger economic disaster, as Germany also had to cede its territories on the Saar, Rhein, and Ruhr, with their productive coal mines and heavy industry, to France for many years to come. The treaty also sparked domestic unrest, as conservatives and political extremists propagated the "disgrace of Versailles" as a failure of the young democracy, which was on shaky ground. From then on, the government's strategy was to revise the Treaty of Versailles within the framework of international law.

Establishing an independent research institute for international law was intended to support these efforts, as the Federal Foreign Office lacked the comprehensive overview of the legal systems of the foreign victorious powers that was essential for productive renegotiations. On 19 December 1924, the new institute was finally founded as an independent association, thus guaranteeing its political neutrality, in accordance with the statutes of the Kaiser Wilhelm Society for the Advancement of Science. "The idea goes back to Viktor Bruns, then Professor of Constitutional and International Law at the University of Berlin," says Philipp Glahé. The historian is researching the history of the Max Planck Institute for Comparative Public Law and International Law on the occasion of its 100th anniversary, working with previously unknown sources, some of which are still stored at the Institute. Together with international law scholar Alexandra Kemmerer, Head of the Institute's Berlin Office, he has launched a multi-perspective research project to mark the centenary. Scholars from various disciplines as well as past and present Institute employees are exploring the history of the Institute and documenting their research and recollections on a blog.

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PHOTO: AKG-IMAGES

The Berlin Palace in the 1920s. After the end of the monarchy, the building housed various academic institutions, including the Kaiser Wilhelm Institute for Foreign and International Public Law.

The First World War dramatically highlighted just how interconnected the world was at the beginning of the 20th century. As a result, international agreements and structures to secure peace in the long term were of great importance; among them the League of Nations, founded in 1920. The Institute's founding Director, Viktor Bruns, also envisaged international law as an autonomous legal order that would form the basis for the coexistence of different states.

The heart of the Institute in the Berlin Palace of the now deposed royal house of Hohenzollern was its growing library, as the collection provided the basis for legal comparison, a method that Bruns introduced to his discipline as a pioneering approach. Comparing legal concepts, statutes, and the jurisprudence of various countries reveals common, general principles that can serve as the basis of agreements under international law, since they are compatible with the respective national law.

The new Institute soon provided the government with information that was important for diplomacy with former enemy states in the form of reports and expert opinions. The German strategy succeeded, at least in part, with Foreign Minister Gustav Stresemann achieving agreements with the Locarno Treaties that brought Germany back into the international community. One of Stresemann's greatest successes was Germany's admission to the League of Nations in 1926.

The Institute in the era of National Socialism

Hitler's accession to power in 1933 brought this peace process to an abrupt end. Just a few months later, Germany withdrew from the League of Nations and became a dictatorship, a dictatorship to which the Institute of International Law remained fundamentally loyal. In his contribution to the anniversary blog, science historian Rüdiger Hachtmann attests to the clear "commitment to armament and imperial goals" of key players at the Institute during the Nazi era, also analyzing this dark chapter in the Institute's history. The Nazi state discarded the previously valid idea of international law as a peace-keeping legal order of equal states and replaced it with the dogma of German ethnic superiority in order to legitimize its imperialistic expansionist aims. The Institute – still a foreign policy advisor – "was now obliged, but not forced, to support this policy," Rüdiger Hachtmann says: in 1937, Director Bruns justified Germany's withdrawal from the League of Nations. And with Carl Schmitt, whom he appointed as an academic advisor in 1933, Bruns gave pro-Nazi international law a firm place at his Institute. Schmitt, the charismatic "crown jurist of the Third Reich", provided legal foundations for the racist, imperialist policies of the war-minded "Führer state." Bruns was himself a prominent National Socialist and anti-Semite.

Germany's invasion of the Sudetenland in 1938 left no doubt that Hitler wanted to realize his imperialist fantasies of great power. The attack on Poland in September 1939 led to the break-up of the peaceful European order and to World War II. The Kaiser Wilhelm Institute for Comparative and International Public Law was now placed under the High Command of the Wehrmacht, as it was closely associated with the Foreign Office. As the war waged on, however, there emerged resistance within the system, which was organized around Claus Schenk Graf von Stauffenberg, starting in 1943. His brother Berthold had been a senior researcher at the Institute for Comparative and International Public Law since 1929 and was sentenced to death by the Nazi judiciary along with other members of the resistance after the failed attempt to assassinate Hitler on July 20, 1944.

By this time, the war had also reached the Institute with Allied air raids, and its rooms on the Berlin Palace went up in flames in the spring of 1945. However, as large parts of the precious library could be saved; there was a solid foundation for post-war reconstruction under Carl Bilfinger. Following the sudden death of Viktor Bruns, Bilfinger had already been coordinating the Institute from Heidelberg since 1944, where it was re-established in 1949 under the aegis of the newly founded Max Planck Society.

Peace in the Cold War – The Institute after 1949

In the newly established Federal Republic of Germany, research at the Institute also focused on practical, politically relevant issues. This was largely due to Hermann Mosler, who succeeded the Nazi-involved Bilfinger as director in 1954. Mosler had headed the Federal Foreign Office's legal department from 1951 to 1954. Through him, the Max Planck Institute for Comparative Public Law and International Law was closely connected to the Adenauer government for the next few years. Mosler also derived key research topics for the Institute from his work in ministerial bureaucracy. "The application-oriented international law research at the Max Planck Institute for Comparative Public Law and International Law also served to systematize international law as a legal framework for relations between states. The aim was to understand international law as a legal system – and accordingly, to approach it dogmatically," says legal historian Felix Lange, who has conducted extensive research into the history of the Institute and written a biography of Hermann Mosler, describing this specific, practice-oriented form of basic research into international law. As numerous graduates from the Institute went into the civil service, it also had an impact on legal practice and politics.

PHOTO: PICTURE ALLIANCE / SVEN SIMON

Willy Brandt kneeling at the monument commemorating the Warsaw Ghetto Uprising. Jochen Frowein of the Max Planck Institute for Comparative Public Law and International Law was among those accompanying the Federal Chancellor during this visit in 1970.

The first political goal of the Adenauer government – a few years after the end of the world war with more than 60 million dead – was to establish a stable and peaceful order. However, it was also necessary to regain trust that had been lost and to make the Federal Republic an equal partner among nations. As had been the case after the First World War, international law played a key role in this process. Hermann Mosler was convinced that cooperation with the Western powers based on international treaties would provide a safety mechanism preventing national or fascist unilateral action and thus avoid conflicts within Europe. "International law also played an important role in consolidating the young Federal Republic's foreign policy," says Felix Lange. "Hermann Mosler supported Adenauer's policy of integration into the West with his legal expertise because he shared his ideas on European politics." This included a clear orientation towards the West instead of the search for a middle ground between the power blocs in East and West.

The new European treaties between Western states were of particular interest for the Institute's research work. In 1950, French Foreign Minister Robert Schuman proposed the founding of the European Coal and Steel Community (ECSC). Hermann Mosler participated in the negotiations on the structure of this alliance as one of the legal experts in the German delegation. The founding of the ECSC in 1951 created the first European economic alliance and was also the prelude to the history of the European Union.

European integration created so many new tasks for international law that soon European law emerged as a new area of legal expertise. The supranational associations of European states

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were new legal entities intertwined with both national constitutional law and international law. Hermann Mosler also played an active role in the development of the international legal order by becoming the first German judge at the International Court of Justice in The Hague in 1976. He would not be the only one of the Institute's directors to go on to serve as an international judge.

In 1969, the social-liberal coalition took over from Adenauer's conservative Christian government after it had been in power for 20 years. A new era for German foreign policy began under Federal Chancellor Willy Brandt. "Change through rapprochement" was Brandt's motto as he sought a co-operative relationship between the Federal Republic and the countries in the Eastern bloc and promoted a peaceful Europe in the midst of the Cold War. Already in the summer of 1970, the Treaty of Moscow was signed with the Soviet Union, followed by further treaties with Poland and finally the GDR. The partners undertook to resolve conflicts without violence and declared the existing borders inviolable. This pragmatically compensated for the lack of a formal peace treaty between Germany and its former wartime adversaries with the innovative power of international law. In the Basic Treaty with the GDR, both countries agreed to set up permanent representations as a basis for the establishment of diplomatic relations.

The Basic Treaty was a turning point for the Federal Republic's intra-German policy, as it rendered the Hallstein doctrine obsolete. With this doctrine, the Federal Republic had not only rejected the GDR's claim to state sover-

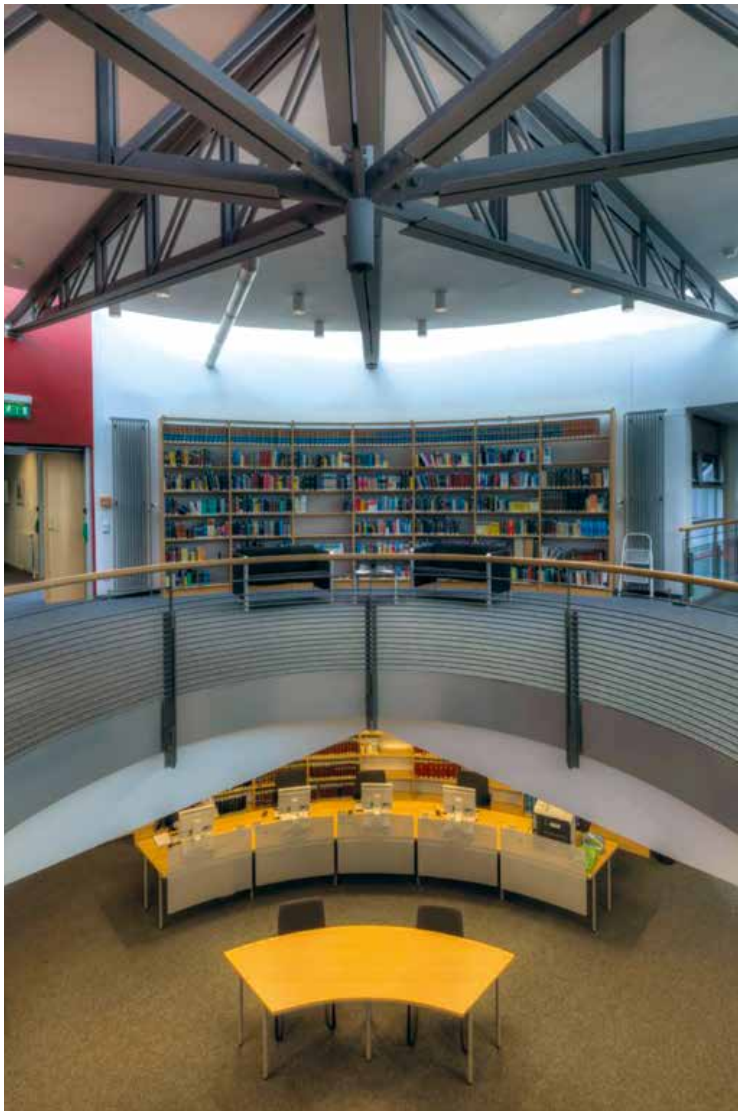

PHOTO: MPI FOR COMPARATIVE PUBLIC LAW AND INTERNATIONAL LAW

The library at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg also features collections from the Institute's early years and provides insights into the history and development of international law (here shown before it was rebuilt).

eignty, but also boycotted its recognition by non-communist countries. Willy Brandt therefore had to ensure that the Basic Treaty with the GDR was properly negotiated – not least in order to secure approval from the opposition in the Bundestag. Although many at the Institute were critical of the new social-liberal path, the Federal Chancellor also received strong support from Heidelberg: Jochen Frowein, who had worked on his habilitation (an extended postdoctoral qualification period which is required for a full university professorship) in comparative law in the mid-1960s, identified a constellation in the legal practice of the Commonwealth that could be applied comparatively to the relationship between the FRG and the GDR. This opened up new scope for legal arrangements. Frowein later concluded that a state could "establish and develop a variety of legal relationships with non-recognized states even below the threshold of full recognition."

In 1967, Frowein became a member of a small working group of the German Council on Foreign Relations which dealt with the political and legal problems arising from a recognition of the GDR. In 1968, the group presented a report that significantly influenced the actions of the Brandt government. On behalf of the Federal Chancellery, Frowein drafted a legal opinion on possible relations with the GDR and traveled with Willy Brandt's delegation to Moscow and Warsaw for the 1970 negotiations. Brandt's empathetic and respectful demeanor, which found its iconic image in his kneeling at the memorial to the victims of the Warsaw Ghetto Uprising, ushered in a political thaw for several years, which in the long term paved the way for the opening of the Iron Curtain. In 1981, Jochen Frowein became a Director at the Institute, which in the meantime had transitioned to management by a board of directors. The opening to the East also affected the work of the Institute, which intensified its academic exchanges with Eastern Europe. The topics discussed in the Institute's colloquia document increasing global interconnectedness, which raised practical questions in constitutional law. These included, for example, the domestic legal status of non-Germans, whose share of the total German population was growing. The Institute drafted an expert opinion on this matter for the Federal Ministry of the Interior. European policy issues, such as the organizational structures of the European Communities, also remained in focus.

The Institute in times of transition

The trend towards globalization since the 1980s is also reflected by the fact that Rüdiger Wolfrum, who became Director at the Institute in 1993, addressed issues in international law regarding state-free spaces. The deep sea, the Arctic, and even outer space harbor mineral and biological resources, the use of which is fraught with conflict if there are no underlying agreements in international law. Wolfrum paved the way for global environmental international law which, in light of climate change, is now one of the Institute's most progressive fields of work with high political relevance for the global community.

From 1996 to 2017, Rüdiger Wolfrum applied the international legal expertise gained from his research as a judge at the International Tribunal for the Law of the Sea. He was also president of the court from 2005 to 2008. While president, he followed the example set by his predecessors in high judicial offices: Helmut Steinberger had served as judge at the Federal Constitutional Court and the Court of Arbitration of the OSCE, and Rudolf Bernhardt served as judge at the European Court of Human Rights. With its academic contribution to the development of law, the Institute has also frequently supported global peace efforts. The break-up of the Soviet Union after the end of the Cold War and the war in Yugoslavia raised numerous questions for international research at the Max Planck Institute for Comparative Public Law and International Law, which also fed into its legal consulting. In 1995, Director Helmut Steinberger participated in the Dayton peace talks as an advisor to the Bosnian delegation on constitutional and international legal matters.

One hundred years after its founding, the Institute is making practical use of its research on democracy and the rule of law in dialogue with practitioners and academics from many parts of the world. Director Anne Peters was a member of the Venice Commission of the Council of Europe, which provides advice on constitutional law to states on their path to democratic structures. Director Armin von Bogdandy is researching and advising on the current restoration of the rule of law in Poland. The idea of international law as the legal order of a peaceful world community, which also understands itself as a community of values united by its recognition of a common international legal order, remains fundamental.

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FURTHER READING

MPIL100. The MPIL's blog is celebrating its 100th anniversary. Edited by Armin von Bogdandy, Philipp Glahé, Alexandra Kemmerer, and Anne Peters.

https://mpil100.de/

Rechtswissenschaft in der Max-Planck-Gesellschaft 1948–2002. Edited by Thomas Duve, Jasper Kunstreich, Stefan Vogenauer. V & R 2023. (open access, in German)

LISA LISTENS TO SPACE

TEXT: AENEAS ROOCH

The largest astronomical observatory is so large that it won't fit on Earth. It's called Lisa, and it will be able to detect when a 2.5-million-kilometer segment of space shrinks by even one atomic diameter. Researchers at the Max Planck Institute for Gravitational Physics in Hanover and Potsdam helped develop the gravitational-wave detector. By observing cosmic waves, they hope to gain an insight into strange processes deep in outer space.

When someone climbs on top of a trampoline, the jumping mat bulges and bobs up and down. Our universe experiences similar distortions known as gravitational waves. They originate from unique processes in the outer reaches of the cosmos and travel through space at the speed of light, squeezing and stretching everything in their way at infinitesimal scales. We cannot see or hear them. Researchers from the Max Planck Society hope to detect particularly long waves to shed light on the shadowy past of our universe, the origin of black holes, and the nature of gravity.

Gravitational waves are invisible distortions of our world. They are difficult to conceptualize, and their existence has been controversial. In 1915, Albert Einstein proposed an idea of how space, time, and gravity are connected – his famous General Theory of Relativity. The formulas he used to describe these relationships lead to the conclusion that certain events in the universe cause compressions and expansions of space and time. Although Einstein himself assumed that these gravitational waves were too weak to be measurable, others at first considered them a theoretical curiosity that did not correspond to any real processes, even though they could be deduced from the equations. A century would pass before gravitational waves were directly measured in 2015.

One situation in which gravitational waves occur is when two black holes orbit each other in a wild, spiral dance until they finally merge. Black holes can be pictured as pressing deep indentations in an imaginary fabric in which space and time are interwoven. As the black holes orbit each other, waves travel through spacetime, dis-

IMAGE: S. OSSOKINE, A. BUONANNO (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS), SIMULATING EXTREME SPACETIMES PROJECT, W. BENGER (AIRBORNE HYDRO MAPPING GMBH)

KNOWLEDGE FROM

PHYSICS & ASTRONOMY

Like a whirlwind: Two black holes orbit each other (center of the image), emitting gravitational waves in the process. The image only shows particularly "loud" waves perpendicular to the orbit. One more revolution and the black holes will merge in a fraction of a second. The simulation shows two things: when the black holes were further apart, they emitted weaker gravitational waves (green) than shortly before their merger (orange).

torting the distances between objects – much like jumping on a trampoline causes a shockwave to spread across the entire jumping mat, making it vibrate. Although caused by gigantic masses, the distortions themselves are extremely weak, and get weaker the further away they are from the source. When two black holes with the mass of several Suns unleash gravitational waves in a distant galaxy, they compress the distance between the Earth and the Sun (around 150 million kilometers) by about a millionth of the diameter of a hair.

Extremely precise

Minuscule changes in length like these can only be observed with the help of sophisticated measuring methods, because even an incredibly delicate precision ruler would not be accurate enough. One way to measure gravitational waves is to send a laser beam through a kilometer-long tube, splitting it along the way. Half of the beam continues on its path, while the other half branches off into a perpendicular tube, with both halves reflecting off mirrors at the ends of the tubes. When a gravitational wave passes through our solar system, stretching space in one direction and compressing it along a perpendicular axis, it lengthens the path traveled by the laser beam in the first tube and shortens the path in the second. The light waves in the two tubes no longer oscillate synchronously. When they are superimposed, this discrepancy is revealed in an interference pattern. Detecting slight distortions in space with superimposed laser beams is a complex process. Even the vibrations of a truck rumbling down the next street would render the measurement useless. Nonetheless, the feat was finally accomplished in 2015 by researchers from the LIGO Scientific Collaboration, including several scientists from the Max Planck Institute for Gravitational Physics. However, many gravitational waves still reach us undetected. Just as light consists of electromagnetic waves of different wavelengths, gravitational waves form a spectrum. Laser interferometers on Earth can only detect short-period gravitational waves. Long-period gravitational waves are not yet measurable. First, they are simply too long; it would take a detector larger than the Earth, not dissimilar to giant antennas for capturing long radio waves. Second, the rumbling and crunching of the Earth's interior interferes; the operational noise of our planet drowns out the faint vibrations of space.

PHOTO: THOMAS DAMM

An eye for detail: Guido Müller is a specialist when it comes to detecting extreme events in space that are invisible to traditional telescopes.

As of early 2024, it's official: an extraordinary instrument dubbed the Laser Interferometer Space Antenna, or Lisa, will be launched into space approximately ten years from now on a mission of the European Space Agency (Esa) to measure long-period gravitational waves. Consisting of three satellites spaced roughly 2.5 million kilometers apart, Lisa will orbit the Sun in a triangular formation on an orbit similar to Earth's. To put this in perspective, the satellites will be six times farther apart from each other than the Moon is from the Earth. Each satellite will contain two small, free-floating metal cubes about the size of a package of fresh yeast and weighing around two kilograms apiece. The trio of satellites and the test masses inside them will detect the subtle tremors of space caused by gravitational waves. The gold-platinum alloy on the cubes makes them nearly immune to the effects of magnetic fields, and when solar winds hit the satellites or sunlight bombards them with radiation, the satellites will take precise countermeasures so that the only force acting on the cubes is gravity. When a long gravitational wave passes through our solar system, depending on its origin, it will compress the 2.5-million-kilometer distance by the diameter of an atom or even a bacterium. These tiny changes in length are relatively easy to measure in a lab. In space, however, and at distances like these, the job is much harder.

To take the measurements, the satellites exchange laser beams and perform a series of clever steps before reporting on the position of the cubes relative to each other. This is the only way to reveal whether a gravitational wave momentarily expands or contracts the distance between the free-floating cubes. Three laser beams exchanged in this triangle of satellites form, in a sense, three independent, two-legged laser interferometers that prick up their ears simultaneously.

Unlike with the earthbound laser interferometers, however, the laser beams cannot be superimposed on each

other, because they fan out for kilometers as they travel from one satellite to the next, and only a tiny fraction of the beam reaches the neighboring satellite through a plate-sized opening in a telescope. "We're cutting 30 centimeters out of a ten-kilometer-wide beam of light," explains Guido Müller, who is now leading the development of the interferometry for LISA as Director at the Max Planck Institute for Gravitational Physics in Hanover. "It's incredibly challenging to do laser interferometry with this weak laser light." Once all interferometer signals have been measured with extreme precision and disturbances and fluctuations have been filtered out, they are precisely offset and superimposed in post processing. "But this has little to do with classical interferometry, where two light waves are superimposed and a pattern is revealed," says Müller. "This is interferometry to the tenth power." And it takes time to develop such a delicate method of measurement. The idea for it came from Karsten Danzmann, himself a Director at the Max Planck Institute for Gravitational Physics in Hanover more than 30 years ago.

The instrument is being built by Nasa, Esa, and several Esa member states. The Max Planck Institute for Gravitational Physics has taken responsibility for the interferometric detection system and is supporting the mission and Esa on many system design topics. "On paper everything is easy," says Müller. "But the challenge is to make sure it works later on, in space." The technology tests in Hanover are therefore designed to be more difficult than live operation is expected to be out in space, where earth tremors and severe temperature fluctuations are not an issue. The Lisa Pathfinder mission, which preceded this one, has already shown that the technology can detect slight changes in length "but as of yet, not over this enormous distance of 2.5 million kilometers," says Müller. "So, we have a huge responsibility. But unless we've overlooked something really stupid, we'll get it right."

Long-period gravitational waves, which Lisa is designed to detect for the first time, originate in part from intense processes in the depths of space. One example is extremely massive black holes, millions of times the mass of our Sun, which orbit each other before merging. Even as single objects, black holes are among the most spectacular phenomena in the universe. They contain an enormous mass compressed into such a tiny space that their gravitational pull traps and swallows everything that gets too close – even light. Some black holes form when stars with masses many times that of the Sun collapse at the end of their lives, squeezing an enormous mass into a tiny space. As extreme as this may be, these stellar black holes are trivial compared to the truly massive black holes that sit at the center of many galaxies and contain millions or even billions of solar masses. How these giant black holes formed, what role they play in the evolution of galaxies, and how they managed to accumulate so much mass is still unknown.

PHOTO: SVEN DÖRING

Exciting mathematics: Alessandra Buonanno's calculations reveal what astrophysicists need to look for in the data salad.

Researchers at the Max Planck Institute for Gravitational Physics in Potsdam hope to distill answers from extraordinarily long gravitational waves. Such waves travel for millions of years before reaching Earth. As a result, they offer researchers a window onto

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SUMMARY

Albert Einstein's General Theory of Relativity predicts the existence of gravitational waves, which occur when, for example, black holes orbit each other closely or merge.

Gravitational waves from neutron stars or black holes with the mass of heavy stars have relatively short periods and were detected on Earth for the first time in 2015.

Starting in 2035, a trio of satellites called Lisa will measure gravitational waves with longer periods, such as those from massive black holes orbiting each other, in order to explore a previously inaccessible part of the universe.

Researchers hope Lisa will provide a better understanding of how galaxies develop, while also opening a new observational window onto dark matter and dark energy.

an earlier, turbulent stage of the universe. Many billions of years ago, galaxies and their central black holes were increasingly on collision courses, their gravity making them orbit each other. Merging black holes is only one explanation for how black holes in the centers of galaxies become so massive. Some of these massive phenomena grow by about one solar mass per year, when gas flows around them in a disk and falls in. On a cosmological timescale, that can really add up. As a result, long gravitational waves not only provide access to unexplored regions of the universe, but also help us gain a better understanding of how galaxies evolve. What's more, the data will allow researchers to take an inventory of black holes, finding out how many of which type and which mass there are and where they are located.

Lisa will also send other signals to the network, such as when a supermassive black hole swallows an asymmetric partner whose mass is a millionth of its own – for instance, a black hole with the mass of a star or a neutron star. When the mass ratio of an inspiral is this extreme, the merger is prolonged. The light object orbits millions of times on an irregular elliptical and constantly changing orbit around the black hole. Although the gravitational signals emitted by this dance are highly complex, researchers hope to use them to understand how spacetime is structured around black holes

Humanity's largest measuring apparatus is going to consist of three satellites that are six times further apart than the Earth and the Moon. The Lisa trio will orbit the Sun and will constantly exchange laser beams (shown in red). When there's a rumble in deep space, say, when two black holes with millions of solar masses merge, a gravitational wave is created. When the wave hits the satellites, it shakes them by a millionth of a hair's breadth. This is measurable.

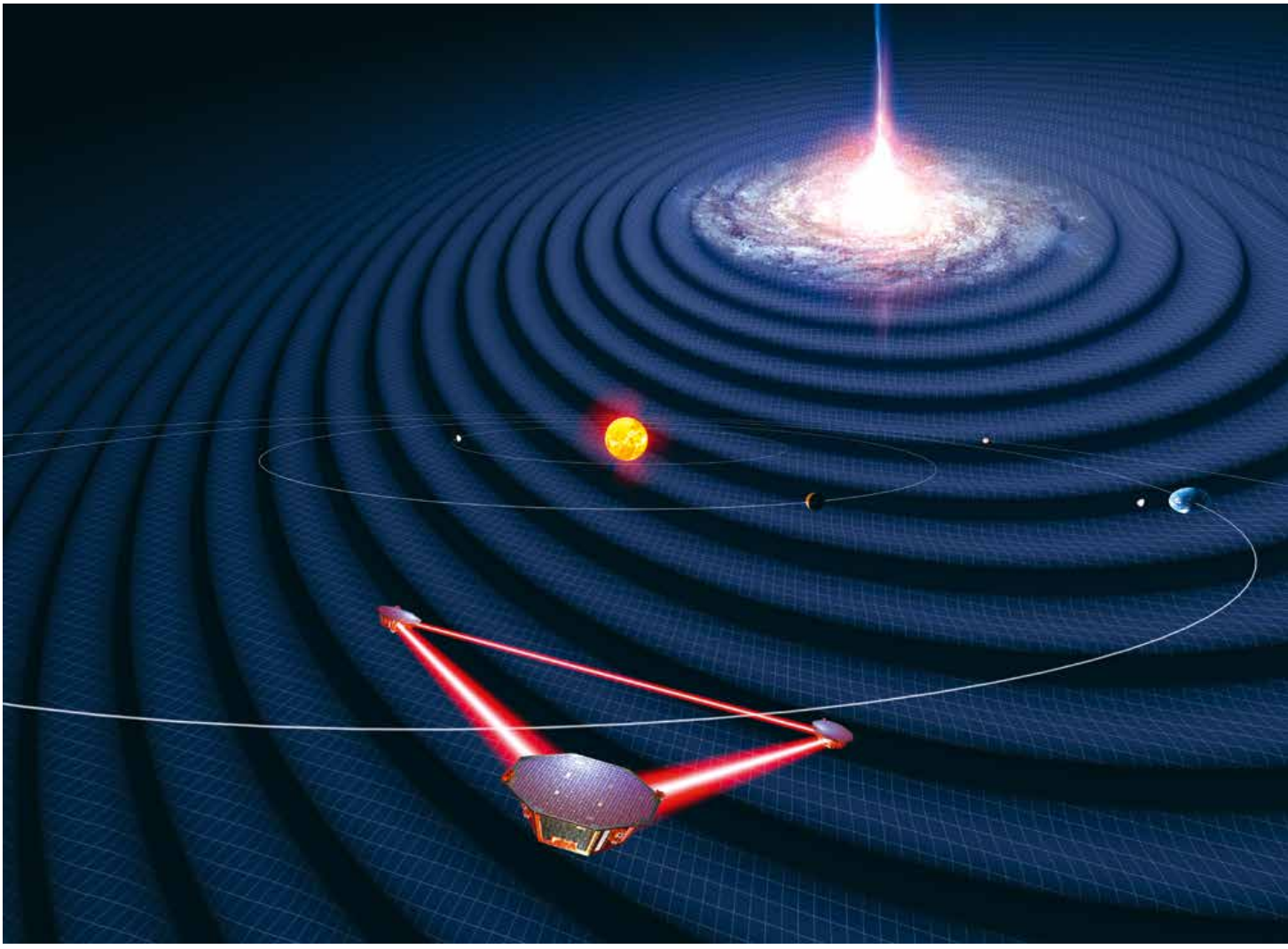

IMAGE: UNIVERSITY OF FLORIDA/SIMON BARKE (CC BY 4.0)

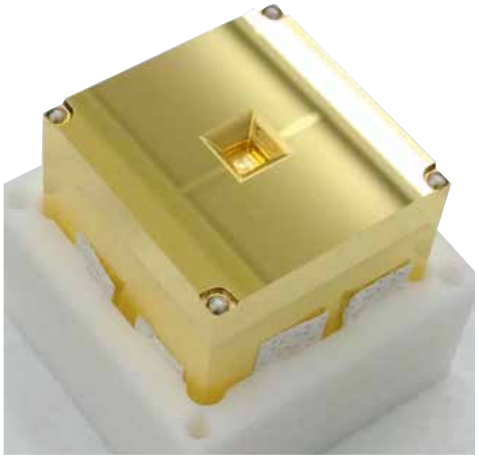

PHOTO: ESA

The sides of this gold and platinum cube measure only 4.6 centimeters. It's the heart of each Lisa satellite. When a gravitational wave shoves this cube just one atom's breadth, a clever laser system raises an alarm.

and to put Einstein's Theory of Relativity to the test.

What Lisa will record is little more than a faint jitter, but it represents the din of countless overlapping waves from various directions and completely different processes. "We don't know how many of these asymmetric partners are out there. We don't know how many pairs of two massive black holes exist. And furthermore, we don't know how many gravitational waves are generated in the depth of space contributing to the stochastic background or random noise," says Alessandra Buonanno, Director at the Max Planck Institute for Gravitational Physics in Potsdam. One major challenge, for example, is the stochastic background in our Milky Way. It is home to countless binary systems of two white dwarfs, which emit long gravitational waves, whose constant murmur drowns out the much quieter signals from the depths of space.

Buonanno and her team hope to isolate individual voices in this chaotic choir to shed light on individual processes in space. "Every source – whether it is a binary system of massive black holes or a massive black hole and a companion with a much smaller mass – produces characteristic gravitational waves. It's like a fingerprint," says Buonanno. "And with the help of theoretical calculations and supercomputers, we can see what exactly these fingerprints look like." Once the researchers are sure which signal comes from which source, they will subtract the precalculated vibration directly from the full signal. And once all the processes that cause gravitational waves are known, there should be nothing left of the babble of voices. If not, that's one more problem for astrophysics to solve. "In this way, we can check whether the General Theory of Relativity is completely accurate here, or whether we're encountering a new gravity theory or some physical phenomena that are unknown to us.

Making the invisible measurable

The whole endeavor is mathematically challenging. If the model isn't correct, the signal calculated by the Potsdam researchers might deviate from the actual gravitational waves emitted by a pair of black holes. Not only would this cause the astrophysicists to draw erroneous conclusions from the Lisa data about the pair and its behavior, but it would also produce computational artifacts when the predicted gravitational waves are subtracted from the data stream. The remaining signal could be misinterpreted as a deviation from the General Theory of Relativity. Precise pre-calculation of the vibrations captured by Lisa is therefore crucial to interpreting them correctly. Almost everything in the universe, more than 95 percent of it, emits neither light nor electromagnetic radiation and is treated as dark matter and dark energy. All we know about this invisible and mute proportion of dark matter is that it exists and is subject to gravity. Lisa could detect tiny effects in gravitational waves, which could be attributed to dark matter. The trio of satellites should also be able to take measurements independently of existing telescopes to determine how quickly the universe is expanding and how much dark energy this requires – possibly solving puzzles or posing new ones in the process. "Lisa has what it takes to revolutionize our understanding of the universe," says Buonanno. By unlocking long gravitational waves with Lisa, she and other researchers will open a new observational window onto a dark part of the universe, making the invisible visible – at least on the screens in her lab.

←

GLOSSARY

INTERFERENCE
occurs when two wave systems overlap, regardless of whether they are light, water, or sound waves. When the crests and peaks of the waves align, the intensity of the oscillation increases. When the waves are offset by half a wavelength, they cancel each other out.

LASER INTERFEROMETRY
is a method of measuring minute changes in distance. When two laser beams with identical wavelengths are superimposed, they create an interference pattern that is characteristic of the path difference of the two waves. This makes it possible to measure minuscule changes in the distance between two laser sources.

The Blue Threadfin *(Ophthalmotilapia ventralis)* is found exclusively in Lake Tanganyika, where it lives along the shore. The female first lays her eggs in a pit in the sand prepared by the male and then takes them into her mouth to incubate. When the female snaps at the egg-like spots on the male's extended ventral fins, the male releases his sperm and the eggs are fertilized. The female keeps them in her mouth until the young hatch – protecting them from predators.

PHOTO: ALEX JORDAN / MPI OF ANIMAL BEHAVIOR

ECHOES OF EVOLUTION: THE CICHLIDS OF LAKE TANGANYIKA

TEXT: CARLA AVOLIO

Lake Tanganyika in East Africa, formed ten million years ago, boasts an extraordinary diversity of species. For decades, researchers have flocked to its shores to study its unique ecosystem. Among them is Alex Jordan from the Max Planck Institute of Animal Behavior in Konstanz, who considers the lake a paradise. With the aid of modern technology, Jordan aims to analyze the behavior of the cichlids that live in Lake Tanganyika.

The Great African Lakes – Lake Tanganyika, Lake Malawi, and Lake Victoria – are some of the oldest lakes on Earth in geological terms. Over millions of years, evolution has taken advantage of this extensive time frame to create a remarkable variety of species. One family of small fish – the cichlid family – is particularly diverse. Today, Lake Tanganyika is home to over 250 species of cichlid, each occupying its own unique ecological niche.

For more than a century, scientists have been venturing to Lake Tanganyika in search of insight into the grand process of evolution. That's because Tanganyika, more than almost any lake on Earth, has been bequeathed the gift of time. A long blue jewel in the chain of African Great Lakes, Tanganyika formed when fresh water flooded the East African Rift as it began tearing the land apart, creating a lake that still stands 10 million years later.

Geologically, that time might be modest, but what evolution has done with it has been nothing short of explosive. With ample time and space, the most recent common ancestor of a cichlid fish gave rise to over 250 new species, each adapted to fit a different niche in the environment. Lake Tanganyika, along with its sister Lakes Victoria and Malawi, became known as Darwin's dream ponds – textbook examples of speciation through evolution, and a destination for those yearning to understand its story.

For those scientists, the goal has always been to unravel the complex paths evolution has taken to produce the spectacular diversity of cichlids we see today. Spending months or years in the wilds, they collected illustrations, descriptions of color and pattern, or skeletons carefully packed for later examination. Today, evolutionary behavioral ecologist Alex Jordan continues this tradition, but he is not collecting bones. He is collecting behavior.

"Lake Tanganyikan cichlids are the most behaviorally diverse of all cichlids, perhaps all fish," says the independent group leader at the Max Planck Institute of Animal Behavior in Konstanz. Species span the range from solitary hunters all the way up to permanent family groups with siblings and cousins helping to care for young. Each species also has its own behavioral variation on themes of aggression, courtship, submission, and cooperation. The ocellated shell-dweller appears to roar when confronted with a rival, while the featherfin cichlid flashes beautiful colors in a dance to deter territorial encroachers.

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PHOTO: PAUL NÜHRENBERG

Alex Jordan (front) and his team prefer to study the cichlids of Lake Tanganyika in their natural habitat. Only then can he see the full diversity of their behavior, because interactions with conspecifics and other fish species, as well as various environmental factors, have a significant impact on a fish's behavior.

For Jordan, the dazzling array of behaviors that each cichlid species displays tell an evolutionary tale just as alluring as the famous speciation that the group has undergone. But so far, what we know about the evolution of behavior lags far behind what we know about their morphology. Bringing clarity to this picture is the aim of the Jordan Lab. "Our ultimate goal is to create quantitative behavioral maps for each cichlid species, allowing us to compare entire behavioral phenomes to understand how evolution has shaped the diversity we see today."

Wilderness expedition

So twice a year, Jordan's team make the four-day journey from Konstanz to the Zambian shore of Lake Tanganyika. In the waters, they hope to sow the seeds of a new evolutionary tree – one that connects the lush branches of behavioral diversity.

This goal might seem grand, but getting there is conceptually simple. First, you have to measure the breadth of behavior an animal displays, a once impossible task that has become achievable with modern approaches to tracking and analysis of animal movement. "From a practical perspective, it's quite challenging to bring all this technology to remote locations and record animals underwater," says Jordan, "but having done that, measuring behavior isn't the hardest part."

The hard part is in the second step, which is to answer a deceptively simple question: What exactly is a behavior? Correctly interpreting the function of a behavior represents a real problem here. Take as an example the behaviors that Jordan studies. Some, such as the building of a nest to raise young, the careful tending of a courtship bower, or different methods of feeding, have clear and interpretable functions that few would disagree over. But others are far more difficult to interpret. It is these difficult cases that fascinate Jordan, for whom the most problematic behaviors are also the most interesting. "Social behaviors are some of the most complex and exciting forms," he says, "but they are by definition an interaction between animals, and an interaction that we're not part of." To map these behaviors on to an evolutionary tree and make reasonable comparisons among them, we have to know both what they are, and also what they are for. Jordan likens the problem to that faced by early taxonomists when receiving a jumble of bones in boxes sent from afar: "Without a clear picture of when, where, and why this behavior occurred, we may end up unknowingly building a Brontosaurus out of the bones of a T-Rex."

Long before he became a Max Planck group leader, Jordan was aware of this problem. "My PhD advisor would caution that behavior is a slippery thing," he remembers. And since then, Jordan has been struggling to get a firm hold. In 2019, he and colleagues from Osaka City University made quite a splash when they demonstrated that a species of fish was able to pass the "mirror test" – a behavioral assessment introduced in 1970 and widely regarded as the best indication of self-awareness in non-human animals. Up to that point, only some mammals and crows had passed the mirror test. "This was a great result because it really got people talking about consciousness in animals other than humans," says Jordan. But an uncomfortable truth gnawed at the scientist: "For me, it served most to highlight the gap in our understanding of behavior in species not our own." For Jordan, the fact that a fish passed the mirror test, without any other evidence of self-consciousness, emphasized that apparently equivalent behaviors may have vastly different causes and functions. "A fish and a chimpanzee might both pass the mirror test, but that does not mean they passed for the same reason."

SUMMARY:

In Lake Tanganyika, evolution has produced numerous different species of cichlids, which differ not only in appearance, but also in their behavior.

Researchers are studying the behavior of the fish in their natural habitat so that they can gain a better understanding of the significance of the ecological and social environments of the animals.

By using artificial intelligence, researchers aim to create an atlas of the different cichlid behaviors free from their own preconceptions. This approach will help them investigate how these behaviors have evolved over time.

A 2020 study reinforced this opinion. Interested in whether dominance played a role in social influence, doctoral researcher Mariana Rodriguez taught fish to predict the location of a food reward using light cues. She then placed these informed animals into new social groups and found that while dominant male fish learned to solve the task and were able to act as demonstrators, they were not nearly as effective in this role as subordinate males. Yet computational behavioral analyses by another student, Paul Nührenberg, illuminated an astonishing truth: dominant and subordinate males demonstrated the solution in exactly the same way – so what was the difference? "When the dominant male burst toward a food reward, all the other fish darted out of the way, apparently perceiving this as a threatening behavior," says Jordan. "Yet when the subordinate male performed the same behavior, the response was the opposite. Group members remained close to him and more quickly learned the solution themselves." For Jordan, this was further evidence that the same form of behavior can perform different, even opposite, functions depending on where, when, and how it is expressed, "and this makes evolutionary comparisons of behavior extremely challenging."

This becomes even more difficult the further away from humans we travel on the evolutionary tree, where the form and function of signals become increasingly alien to us. "As humans, we may have an intuitive sense of what a primate or other mammal 'means' or 'intends' when it performs a behavior, but for other animals this intuition fails us," says Jordan. The flick of a fish's fin, or a rapid change in the color of its eye, are signals that mean something for the receiver, but as humans we have little insight into what they may mean. If the goal is to compare behavior across species and evolutionary time, understanding these signals becomes critical. What is the same, what is different, and how can we as external observers make this distinction?

Distant relationship

Yet rather than being a barrier, Jordan believes the taxonomic distance might actually be the key to the problem, allowing us to take an objective perspective on behavior. "Perhaps it is the very thing we find most difficult that gives us the greatest opportunity to understand behaviors that we ourselves do not possess. To achieve this, though, we need help, some way of seeing what we don't see, and interpreting what we can't understand."

This is where the ancient lake meets the modern era. Jordan's team has developed techniques to track the movement and posture of wild fish in some of the most complex visual scenes imaginable, where fish have evolved over millions of years to blend in and camouflage with their surroundings. Aided by machine-learning approaches, the team can then track and analyze the postures, movements, and interactions of fish in their natural habitats, generating a complete description of all the behaviors an individual performs. "While this can be a very powerful step in understanding

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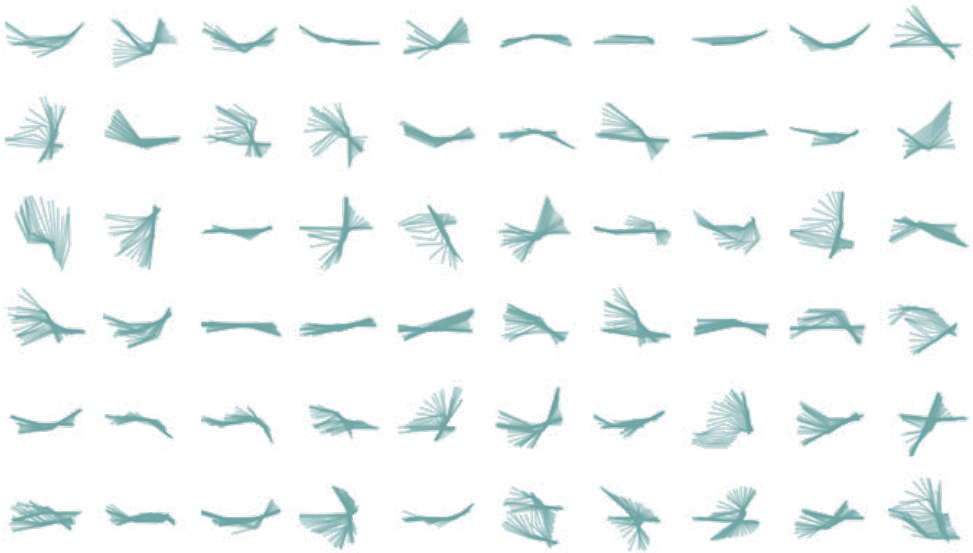

GRAPHIC: PAUL NÜHRENBERG

The individual images show the postures associated with a behavioral element that the researchers previously filmed in the lake. The aim is to digitize all the behaviors of different species and analyze the relationships between the individuals involved.

how evolution has shaped the form and expression of behavior, it is only the first step, it is still the cataloging stage," says Jordan.

Jordan explains that to understand behavior we must do more than simply describe it; we must situate it in the contexts and environments in which it is naturally expressed. He believes this method of perspective-taking can drive us forward: "The goal should not be to translate the behavior of fish, or any other animal for that matter, in human terms, but to contextualize the behavior of animals in terms of their own experience and perception," he says. "We approach this problem from many directions," says Jordan.

Real and digital fish

But to truly understand the function of behavior from the perspective of an animal requires some entirely novel approaches, and in response to this challenge, Jordan and his team are taking their science into uncharted waters. On the most recent expedition to Tanganyika, lab member Jakob Gübel carried with him a strange rectangular box with a curved glass front, capable of withstanding the immense pressures of the lake depths. Inside, safe and dry, was a tablet.

Swimming on the screen is a 3D simulation of a cichlid, which to many human observers is indistinguishable from the real thing. "But a human is not the intended audience," Jordan reminds us with a smile. "This little fish is how we change the cichlids from being study subjects to scientific collaborators." As he plays back an animation of the fish dancing and quivering its tail, Jordan explains that, depending on who is watching, this behavior could be a threat, an invitation to mate, or just a response to being stung by a jellyfish. "And the fish themselves will tell us which it is."

In this way, the behavioral maps Jordan creates for each species can be explored and analyzed to determine their function. Some areas may be novel, species-specific behaviors that do not occur anywhere else; some may be shared and understood by all species; others still may be what Jordan calls "redundant" – different forms fulfilling the same function. With this approach, they take humans out of the loop. "It is the fish who tell us the function of the behaviors," he says, "allowing us to understand how behavior has changed across species boundaries." After a decade of grappling with the slipperiest of problems, the scientist's grip may be beginning to hold.

Jordan does not claim that technological solutions will be a silver bullet in understanding animal behavior, nor that these approaches can "translate" animal behavior into human language. Rather, he says he uses these approaches to ask new questions that can reveal fundamental insights into the evolution of behavior: "And if the only ones with the answers are in a lake thousands of kilometers away, then we will be on the next boat." With more fish species on Earth than all other vertebrates combined, it seems Jordan and his team will be heading underwater for the foreseeable future, to meet their underwater collaborators where they are. ←

CLEANER WRASSE IN THE MIRROR TEST

In the test, researchers applied a colored spot under the jaw of a cleaner wrasse *(Labroides dimidiatus)*, in a location where the fish could not see it. They then placed a mirror in the fish's tank. Once the fish realized it was not seeing a rival, it began to exhibit unusual behaviors: swimming upside-down, flipping around its axis, and rubbing its jaw against the sand as if trying to remove the spot. These actions indicated that the fish understood the mirror was reflecting its own image.

PHOTO: JAKOB GÜBEL

Brave fish: Lake Tanganyika is also home to *Telmatochromis vittatus*. This eight-centimeter-long cichlid lives near the shore and uses crevices in rocks and rubble as hiding places. During the breeding season, the male defends the territory.

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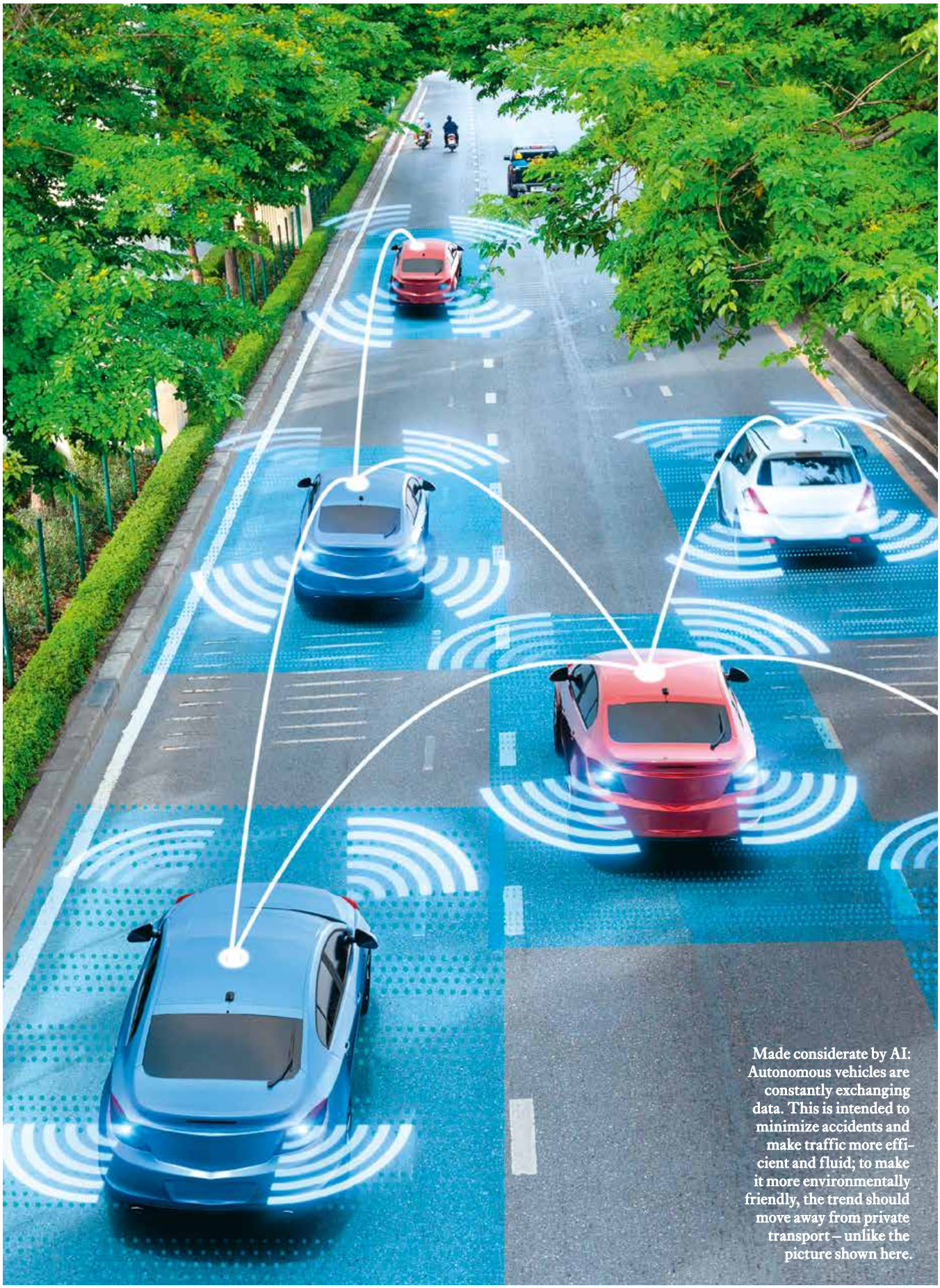

Made considerate by AI: Autonomous vehicles are constantly exchanging data. This is intended to minimize accidents and make traffic more efficient and fluid; to make it more environmentally friendly, the trend should move away from private transport – unlike the picture shown here.

IMAGE: SHUTTERSTOCK/SUWIN66

CARS WITH INTERNAL VALUES

TEXT: THOMAS BRANDSTETTER

The first self-driving cars are already on the road. Yet the technology is not yet fully developed, and certain ethical issues remain unsolved. It is also high time to think about how the new technology can promote sustainable transportation in the future.

Expectations for a mobility revolution caused by autonomous vehicles are high: fewer accidents, more sustainable transportation, and enhanced comfort are among the anticipated benefits. Autonomous vehicles are expected to improve safety and sustainability in traffic, offering convenience to those who find driving stressful and nerve-wracking. Although there are still no driverless cars on the roads in Germany, the trend seems to be continuing unabated. While an autonomous fleet from Google's sister company Waymo is undergoing practical tests in San Francisco, Hochbahn AG, the operator of Hamburg's local public transportation system, has taken up the cause. Together with the on-demand service Moia and vehicle manufacturers Holon and VW, the Hamburg-based company plans to augment its fleet of approximately 1,000 buses with a fleet of autonomously operated vehicles in the coming years.

However, there are still a few problems to be solved before robotaxis are in widespread use. The idea of an autonomously operating machine that may have to make life-or-death decisions in road traffic also raises significant ethical questions. There will likely be a need for a widespread social discussion concerning the balance between the lives of a vehicle's occupants and those of other road users. What's more, the environmental benefits of the new technology are still unclear. However, the most pressing problems right now revolve around technical shortcomings. In San Francisco, for example, there are increasing complaints about driverless cars that simply stop in the middle of the road for no apparent reason and block the path of emergency vehicles.

"When it comes to autonomous driving, it is crucial that the systems also learn to recognize complex traffic situations and then make the right decisions," says Bernt Schiele, Director at the Max Planck Institute for Informatics, whose research interests encompass computer vision. Together with his team, he has developed the AI model

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PHOTO: HOCHBAHN

Mobility for tomorrow: This all-electric on-demand shuttle leaves Hamburg's Elbphilharmonie concert hall behind during a test run in July 2021. As part of the Alike research project, a newly designed vehicle will take up to 15 people each to a destination of their choice starting in 2026 – and from 2030 onwards without a driver.

MTR++, which can increase the efficiency of training for autonomous vehicles when it comes to assessing and responding to the behavior of other road users. The researchers have already won two first places in Waymo's Motion Prediction Challenge – a competition in which different AI systems are trained on an identical data set and their predictions are then compared. For example, if several vehicles are approaching a junction from different directions, there is a multitude of possibilities as to which one will turn in which direction and when, and exactly which path a vehicle is following. "In a situation like this, each driver has a relationship with the next and influences their behavior," says Schiele. "To train the systems, we use transformer models, which function similarly to those powering large language models."

Artificial intelligence (or more precisely: machine learning, which is what Schiele's research group uses), essentially relies on artificial neural networks. These networks, which bear similarities to biological nervous systems, optimize themselves through extensive training data until they recognize correlations and consistently produce accurate results. To achieve the recent remarkable accomplishments of ChatGPT and similar systems, this concept was expanded with the capability to efficiently correlate and relate various elements to one another. While their predecessors had to analyze sentences word by word in order to fathom the structures of human language, the transformer architecture allows the new language models to look at entire sentences as a whole. The transformer simultaneously determines the extent to which all of the words are related to one another. This allows the algorithm to learn what individual words mean in context. Invented in 2017, this method has not only revolutionized computa-

SUMMARY

The technology behind self-driving cars is not yet fully developed. Scientists like Iyad Rahwan are also researching how AI should prioritize human lives in road traffic and how trust in this technology is created.

People are more likely to trust the AI if it is clear why it makes certain decisions. In light of this, Bernt Schiele is developing neural networks that better recognize and interpret complex traffic situations.

Autonomous vehicles could make traffic safer. But they will only make it more environmentally friendly under certain conditions, such as when on-demand shuttles reduce private transportation.

tional linguistics, but has also been adopted in computer-based vision. Just as the meaning of a word depends on how it is embedded in a sentence, the behavior of road users is also determined by the overall traffic situation. In light of this, the systems analyze different traffic situations and try to understand the behavior of other vehicles. "A language model generates the next word in a sentence based on a given prompt," explains Schiele. "And based on the input of where you want to go, our system predicts the possible trajectories of all vehicles involved at an intersection."

In this case, the AI processes all information about vehicles and the road at the same time. The training is therefore much more efficient compared to previous methods, in which the individual motorists in road traffic and their relationships to each other still had to be modeled separately. "When these processes occur simultaneously, it grants the network greater flexibility in its learning. And that makes the learning process much more powerful," explains Schiele. "However, we no longer know exactly how the network has modeled the relationships."

The fact that the results of artificial neural networks cannot be fully explained is a fundamental problem. While classic computer programs allow for a line-by-line understanding of how the code operates and its outcomes, machine learning involves understanding the algorithms that train a neural network; however, the exact process by which the network, or model, arrives at its results largely remains opaque. The training data essentially provides the outcome, and the AI algorithm optimizes a highly intricate function with numerous parameters. The goal is to design the training process so skillfully that the model also performs well in practical applications.

Explainable decisions

This approach works effectively for straightforward classification tasks, where a neural network can learn to recognize what defines a bicycle, for instance, after being exposed to a sufficient variety of images of bicycles. However, occasionally something goes wrong during training and the network does not base the classification on the actual object, but on other image content that is related to it. "In one of our analyses, we discovered that sometimes the system identified bicycles only when a person was sitting on them," says Schiele. Such errors, which are based on correlations with other image content, are difficult to detect with conventional neural networks. "The result is correct, but for the wrong reason."

This is why Schiele and his team are developing special neural networks that also allow for troubleshooting. "Currently, networks are primarily trimmed for maximum performance and not for explaining their decisions," says Schiele. The Max Planck Institute's new system, on the other hand, not only delivers the result of what it thinks it recognizes in an image, but also shows exactly which pixels of the image were relevant for this decision. This allows it to explain its decisions to the user during operation. And if it highlights image content such as the person on the bicycle rather than the bicycle itself, this immediately signals a problem. The researchers also discovered another insufficiently trained network that only recognized a road

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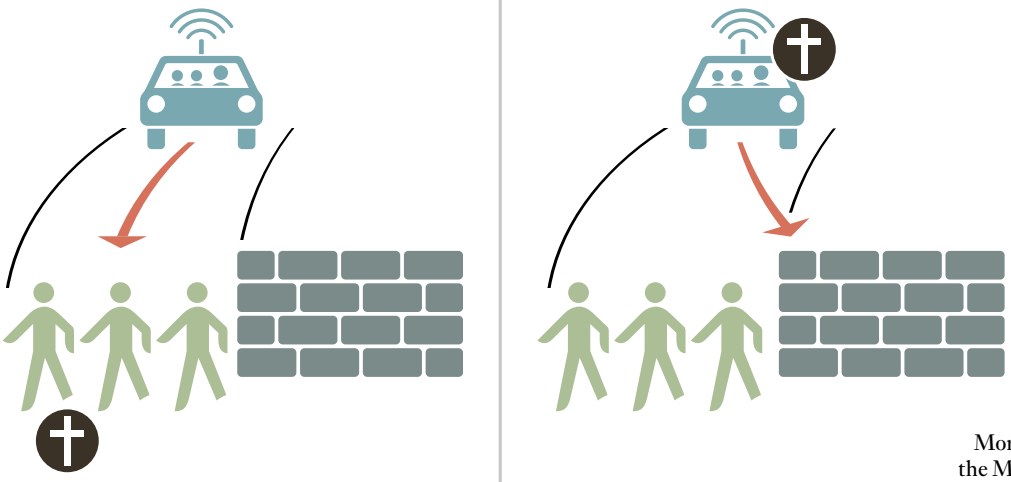


CHART: GCO ADAPTED FROM MORALMACHINE.NET

Morally unambiguous? In this example, the Moral Machine presents participants with a choice: should an AI steer a car with two children and one adult on board into a group of three adults, or is it better to drive into the wall?

as such when a car was driving on it. "When we took the car out of the picture, the network no longer saw the road," reports Bernt Schiele. Such errors can only be identified at an early stage, when networks can be interpreted. "Or at least it helps to uncover the mistake in retrospect if something went wrong, perhaps an accident has even occurred." For Iyad Rahwan, Director at the Man and Machine Research Unit at the Max Planck Institute for Human Development, this is an important prerequisite for the acceptance of autonomous vehicles. "In order to build trust in this new technology among people, it's essential that we are able to question the cars about their decisions," says the researcher, who focuses on ethical issues at the intersection of computer and behavioral sciences. "After all, it makes a difference whether a vehicle has simply not seen a cyclist, for example, or whether it has decided to take a certain risk." The former would be a purely technical problem, which, of course, needs to be resolved as quickly as possible. The latter, on the other hand, could be the result of an assessment by the AI as to whether it places the protection of its own occupants above that of other people involved.

With their platform "Moral Machine," Rahwan and his team have pushed the life-or-death decision scenarios that the AI may face in road traffic to the extreme. Anyone who is interested can take part in the online study. Using simplified, illustrative depictions of dangerous traffic situations, the researchers ask, for example, whether an autonomous vehicle that has no possibility to swerve should run over a child or two adults. Or whether the AI at the wheel should instead crash the car into a wall beforehand and thus endanger the lives of its own occupants. "Of course, such situations will only occur very, very rarely in reality," acknowledges Rahwan. "But people can't stop thinking about questions like these. And if we want them to use autonomous vehicles, we have to provide answers."

Over three million people worldwide have now taken part in Moral Machine and entered 40 million decisions into the system. If you want to evaluate a traffic scenario yourself, you can do so online. Some findings were predictable, such as the prioritization of children's lives over adults'. There was also general agreement that as few people as possible should come to harm, even if this is at the expense of the occupants. The problem with this, however, is that nobody wants to sit in such a vehicle themselves. "There is a huge tension between what people think is right and what consumers are prepared to accept," says Rahwan. This poses a societal challenge, as it's assumed that widespread adoption of autonomous vehicles would substantially reduce overall road fatalities. "It will be important to convince people to think

PHOTO: WAYMO

Waymo's autonomous vehicles have three types of sensors, each of which performs its own tasks. LiDAR laser sensors and a radar system scan the surroundings in three dimensions, whereby the radio waves from the radar can also penetrate the Hamburg fog. A 360-degree camera on the roof monitors and categorizes the surroundings visually.

not only about their own safety, but also about the common good," says Iyad Rahwan. The striking questions posed by Moral Machine may be exaggerated, but there is no question that autonomous vehicles have to make important decisions. "In reality, it will mainly be about statistical issues," says Rahwan. Programmers have to decide whether a vehicle should drive in the middle of a road in normal operation or closer to the edge. This automatically influences the likelihood of either running into oncoming traffic and causing a serious accident or perhaps instead exposing those who are cycling on the side of the road to greater danger. "Such decisions will be reflected in the accident statistics in the long term," warns Rahwan. "If we want people to accept autonomous vehicles, we must also ensure that the safety benefits they provide are distributed fairly."

Less individual traffic thanks to AI

In any case, there seems to be a consensus that autonomous vehicles would make road traffic safer as a whole. After all, the vast majority of accidents are the result of human error, caused by people driving too fast, carelessly, or even while drunk. Whether and, most importantly, in what manner autonomous driving will be adopted is a different question. "The hope among us researchers is that shared-use autonomous vehicles will gradually replace private cars," says Michael Krail, who heads the Mobility business unit at the Sustainability and Infrastructure Systems Competence Center at the Fraunhofer Institute for Systems and Innovation Research.

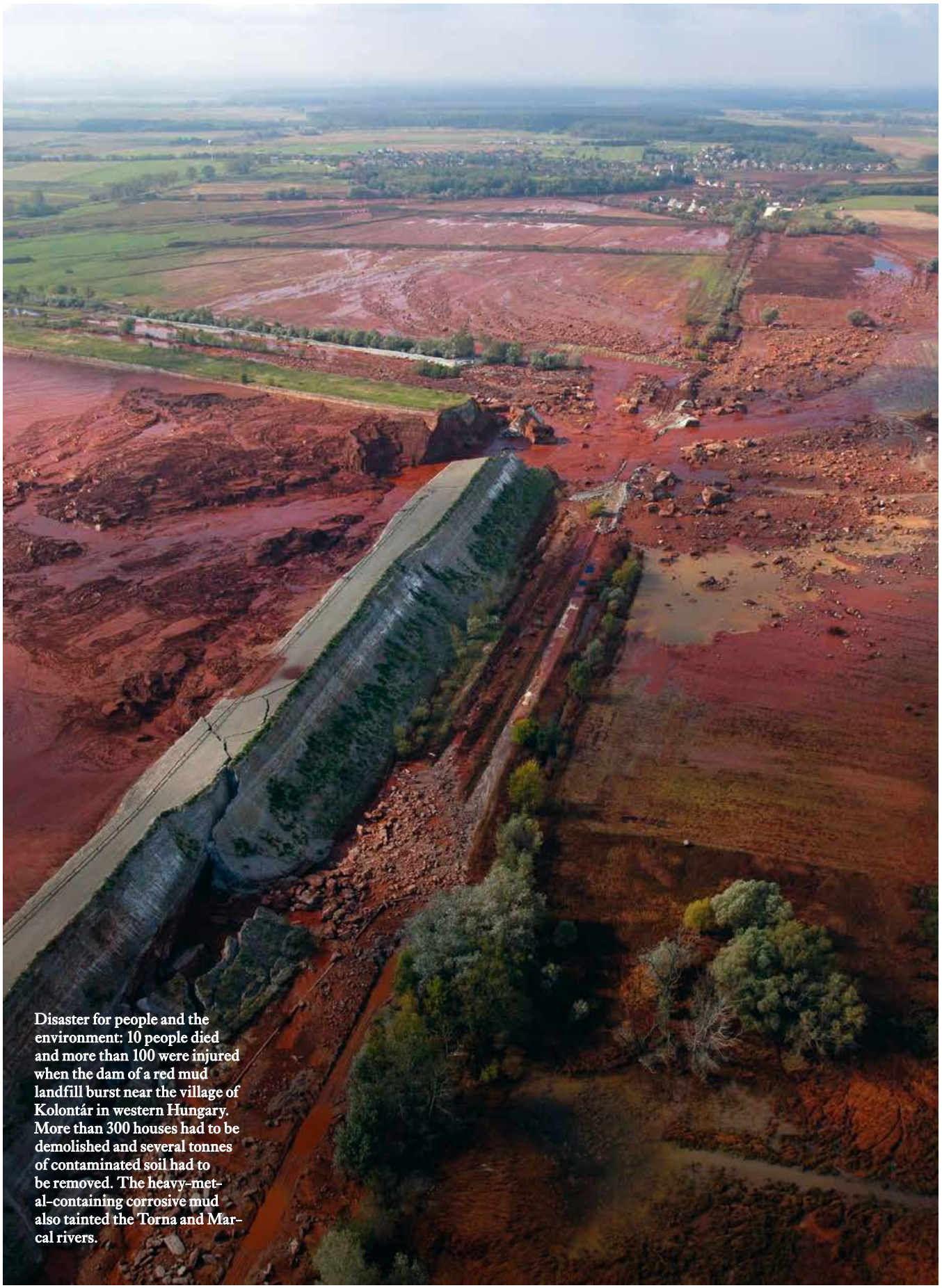
This could significantly reduce the contribution of road traffic to global warming, especially through ride pooling, where multiple requests from passengers heading in roughly the same direction are consolidated. "If one of these vehicles were to pick you up at your doorstep, it would have the same functionality as your own car," says Krail. "This could also be attractive in terms of pricing and could even compete with public transportation." After all, the most expensive thing about taxis or shuttles with a small number of passengers is the driver. The Alike project in Hamburg will initially have attendants in the vehicles, but by 2030 at the latest, the fleet of minibuses should be operating autonomously on the roads. According to the Karlsruhe Institute of Technology, this could potentially replace 250,000 cars. By then, it should be possible for all Hamburg residents to access public transportation within five minutes. According to Krail, well-coordinated combined solutions would also be an option. The taxi could take you to the train, for example, and a shuttle would be waiting at the destination station to continue the journey. This is the exact goal of the EcoBus system developed by a team from the Max Planck Institute for Dynamics and Self-Organization. The system is currently undergoing testing with various transport companies (see Max Planck Research 1/2019).

But how sustainable is a single autonomous vehicle on the road compared to a conventional car? It is assumed that the algorithms will facilitate predictive driving, thereby potentially saving fuel or electricity, depending on the type of propulsion. And ultimately, when all vehicles are autonomous and connected, this should improve traffic flow and lead to additional savings. On the other side, artificial neural networks, which rely on numerous sensors to perceive their surroundings and make driving decisions, consume a lot of energy themselves. And the computer hardware needed for current prototypes often fills the entire trunk. "At the moment, this additional electricity consumption is still a major problem," says Krail. However, the shift towards electromobility is also compelling manufacturers to rigorously manage power consumption in the future. Failure to do so could result in reduced vehicle range and diminished market appeal. "It is therefore reasonable to assume that future vehicles entering the market will require less power for code processing and data transfer," says Krail. What remains, however, is the concern about how the new technology will actually be used in the future. Even if autonomous vehicles turn out to be safer, more comfortable, and possibly even cheaper, this does not automatically lead to more sustainable mobility. In the worst-case scenario, privately used autonomous vehicles could simply replace cars one-to-one, dropping users off at their destinations. If they cannot find a parking space there, they may even drive around with no passengers until needed again. "In order to prevent such excesses, we should monitor developments very closely and create suitable conditions in good time," warns Michael Krail. After all, the new technology should be part of the solution and not become another problem. ←

GLOSSARY

MACHINE LEARNING
classifies large volumes of data, recognizes motifs in images, and makes predictions. People train a model by manually marking picture elements and indicating their meaning. How well the finished model independently recognizes image elements in unfamiliar images depends on the quality of the training.

NEURAL NETWORKS
are trained in deep learning, a sub-area of machine learning. The network processes data such as pixel values through many layers. The upper layers recognize simple features such as edges and shapes, while the lower layers recognize concepts such as "road" or "human." Advantage: the model independently recognizes complex features in unfamiliar images. Disadvantage: the more complex the network is, the more difficult it is to understand the results.



Disaster for people and the environment: 10 people died and more than 100 were injured when the dam of a red mud landfill burst near the village of Kolontár in western Hungary. More than 300 houses had to be demolished and several tonnes of contaminated soil had to be removed. The heavy-metal-containing corrosive mud also tainted the Torna and Marcal rivers.

PHOTO: PICTURE ALLIANCE / DPA / BALAZS MOHAI

GREEN STEEL FROM RED MUD

TEXT: PETER HERGERSBERG

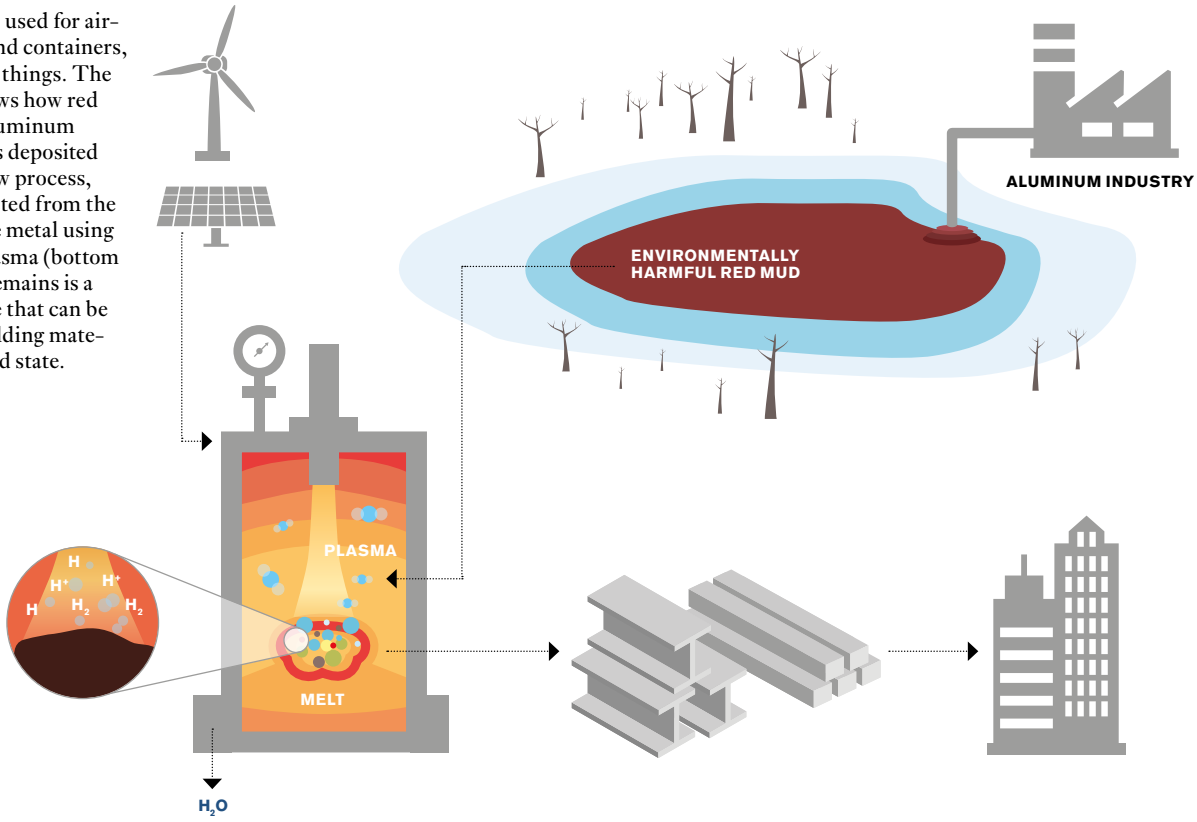
Aluminum production generates massive quantities of toxic red mud. Moreover, the steel industry is a huge contributor to climate change with its CO_2 emissions. A team from the Max Planck Institute for Sustainable Materials has discovered a way to tackle both problems with a single process – one which would also be economically viable.

The devastating flood occurred around midday, at 12:25 p.m. on October 4, 2010, the dam of a reservoir, into which the company MAL AG was disposing of toxic red mud from aluminum production, burst near the western Hungarian town of Ajka. Several hundred thousand cubic meters of heavy metal-containing, corrosive mud surged into the surrounding countryside, burring parts of the villages of Kolontár, Devecser, and Somlóvasárhely. Ten people died, well over 100 were injured, and many more lost their homes. The disaster in Hungary illustrates the dangers of red mud and its disposal, and up to 180 million tonnes of it are produced each year. At best, in many countries the waste is dried and disposed of in gigantic concrete-bound basins at great expense, if not also simply disposed of in nature. Around 4 billion tonnes have accumulated in such landfills around the world over the past decades. However, the highly alkaline red mud attacks the concrete walls of the landfills that can become structurally weak over time. Additionally, during bouts of heavy rain, the basins can overfill and thus the red mud is often washed out and spilled into the surrounding area. Furthermore, when red mud dries, it can be dispersed into the environment as airborne dust by gusts of wind.

However, red mud does not need to end up as hazardous waste, collected in large piles inside gigantic ponds. A team from the Max Planck Institute for Sustainable Materials in Düsseldorf, previously known as the Max-Planck-Institut für Eisenforschung, have tackled the topic of how to make valuable resources out of red mud by targeting its high iron oxide content, which can be as high as 60 percent. Recently, in a study published in the journal Nature, they demonstrated a method for producing green steel from red mud in a relatively simple way. The scientists melt the red mud as it comes from the landfill in an electric arc furnace – the steel and aluminum industries have used such furnaces for decades to melt down scrap metal. At the same time, the researchers reduce the iron oxide to iron using a plasma containing ten percent hydrogen. This transformation, referred to in technical terms as "plasma reduction," takes just ten minutes, in which time the liquid iron separates from the liquid oxides and can then be easily refined. The iron is so pure that it can be processed directly into steel. "Our process could solve the waste problem of aluminum production and, at the same time, improve the steel industry's carbon footprint," explains Matic Jovičevič-Klug, who played a key role in the research. Almost 700 million tonnes of steel could be ex-

→

Aluminum is used for aircraft, cars, and containers, among other things. The diagram shows how red mud from aluminum production is deposited (top). In a new process, iron is extracted from the waste as pure metal using hydrogen plasma (bottom left). What remains is a neutral oxide that can be used as a building material in its solid state.



GRAPHIC: GCO ADAPTED FROM THE MPI FOR SUSTAINABLE MATERIALS GMBH

tracted from the approximately four billion tonnes of red mud that have accumulated worldwide. This equates to a good third of global annual steel production. "If green hydrogen is used for this, the steel industry could save around 1.5 billion tonnes of CO_2," says Isnaldi Souza Filho, research group leader at the Max Planck Institute for Sustainable Materials. The steel industry is the largest contributor to greenhouse gas emissions, accounting for 8 percent of global CO_2 emissions from its smelters. If the research outcome is transferred to an industrial scale, the metal industry of the future could use a much larger proportion of the red mud material than the few million tonnes that are currently used annually in cement production or iron production.

Mitigated heavy metals

The metal oxides that remain from the reduced red mud are no longer corrosive and solidify into a glass-like material when cooled. This can be used as a filling material in the construction industry, for example. Other research groups have used coke to produce iron from red mud, a method that produces iron with high levels of impurities and large quantities of CO_2. However, if green hydrogen is used as a reducing agent instead of coke, these greenhouse gas emissions are prevented. The heavy metals in the red mud can also be mitigated to a certain extent using this process. "We detected chromium in the iron after reduction," says Matic Jovičevič-Klug. "Other heavy and precious metals are also likely to pass into the iron or into a separate area. We will investigate this in further studies. Valuable metals could then be separated and reused." Additionally, any heavy metals that remain in the metal oxides portion are strongly bonded in them and can therefore no longer be washed out with water, as can naturally happen with red mud.

However, producing iron with hydrogen directly from red mud is not just doubly beneficial for the environment, the process is also economically profitable, as the research team demon-

Widely used in the metal industry: steel and aluminum scrap is already melted down in electric arc furnaces, making it possible to recycle it.

strated in a cost analysis. With hydrogen and an electricity mix for the electric arc furnace that is partially renewable, the process is already profitable if the red mud contains 50 percent iron oxide. If the costs for the disposal of the red mud are also considered, 35 percent iron oxide content is sufficient to make the process economically viable. Using green hydrogen and electricity, a 30 to 40 percent proportion of iron oxide is needed at today's costs – factoring in the cost of landfilling the red mud – to enable the resulting iron to stay competitive on the market. "These are conservative estimates, as the cost of red mud disposal is probably underestimated," says Isnaldi Souza Filho. Using red mud as a raw material rather than landfilling it could become increasingly attractive for the aluminum and steel industries, especially given the anticipated significant rise in metal demand in the coming years. The industry predicts that the demand for aluminum and steel will increase by at least 50 percent by 2050, resulting in a correspondingly higher environmental impact. Using red mud as a raw material for CO_2-free iron could help ensure that the growth of the metal industry is more economical and sustainable. "Considering the economic aspects in our study was also important for us," says Dierk Raabe, Director at the Max Planck Institute for Sustainable Materials. "Now it's up to the industry to decide whether it will also subject red mud to plasma reduction in order to produce iron."

←

SUMMARY

Aluminum production generates up to 180 million tonnes of highly corrosive, heavy metal–containing red mud every year.

Using an electric arc furnace, the iron oxide present in the mud can be reduced to very pure iron using hydrogen in an economically viable way.

This could make it possible to extract 700 million tonnes of CO_2-free steel from the approximately four billion tonnes of red mud dumped worldwide – this is the same as one third of global annual production.

PHOTO: ADOBESTOCK/DAVIT85

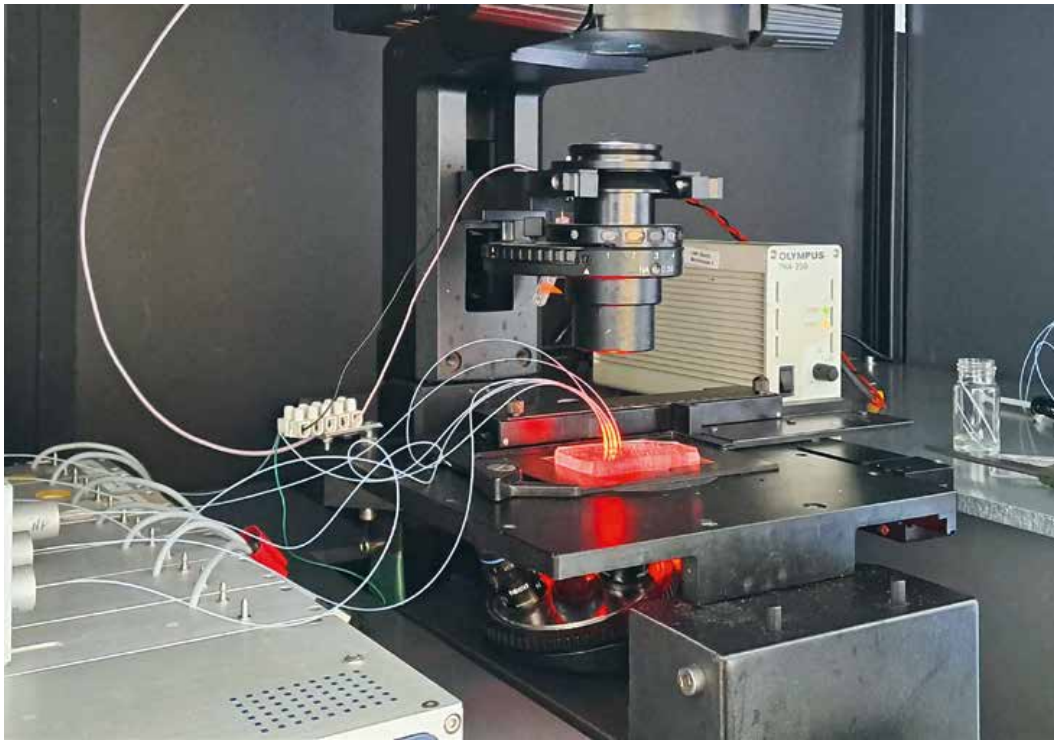


PHOTO: ELIZAVETA BOBKOVA/MPI FOR TERRESTRIAL MICROBIOLOGY

Miniature laboratory: Elizaveta Bobkova uses a device like this one to create minuscule drops and then research the biochemical reactions that take place inside the drops.

Max Planck researchers collaborate with partners in more than 120 countries. In this article, they write about their personal experiences and impressions. Elizaveta Bobkova from the Max Planck Institute for Terrestrial Microbiology in Marburg spent three months in Bordeaux as part of the German–French exchange program Salto. She mastered complicated lab technologies, served as a juror for a synthetic biology competition, and practiced her favorite sport: figure skating.

I discovered my first passion when I was four years old. My parents gave me a pair of ice skates. From that point on, I practiced jumps and pirouettes several times a week. Later, when I was a student in Heidelberg, I was a member of the figure skating club. My second passion emerged during my high school years: I became increasingly interested in the sciences and had a lot of fun participating in biology competitions.

After I graduated from high school, I enrolled in a degree course in biosciences and later focused on biophysics. One highlight for me was participating in the annual competition "International Genetically Engineered Machine" (iGEM). In that competition, teams of young scientists from around the world present their developments in the field of synthetic biology. You look through the microscope and see something you've created yourself and nobody else has ever seen before – how cool is that?

One day I attended a talk by Tobias Erb. He and his team at the Max Planck Institute for Terrestrial Microbiology in Marburg succeeded in developing an artificial metabolic pathway and coupling it to chloroplasts. That makes it possible to bind carbon dioxide and convert it into new compounds. Ideally, these kinds of synthetic reaction cycles could be used in the future to extract greenhouse gas from the atmosphere and use it to create chemical substances in an environmentally friendly manner. I was fascinated by this vision of being able to fight climate change with biotechnological techniques. That's what I wanted to research!

I introduced myself to Tobias Erb and received a position as a doctoral researcher. In my doctoral research, I am looking for a way to selectively transport molecules through synthetic membranes. My goal is to make the artificial reaction cycles even more efficient by spatially separating the subprocesses. To accomplish this, I use microfluidics – a technique that can be used to examine biochemical reactions in minute spaces. The first place I went to study this technique in depth was the laboratory run by Jean-Christophe Baret in Bordeaux.

POST FROM

BORDEAUX

Baret is an expert in this field and has been working with our research group for many years. The German–French exchange program Salto, a collaboration between the French research organization Centre national de la recherche scientifique (CNRS) and the Max Planck Society, made it possible for me to go there.

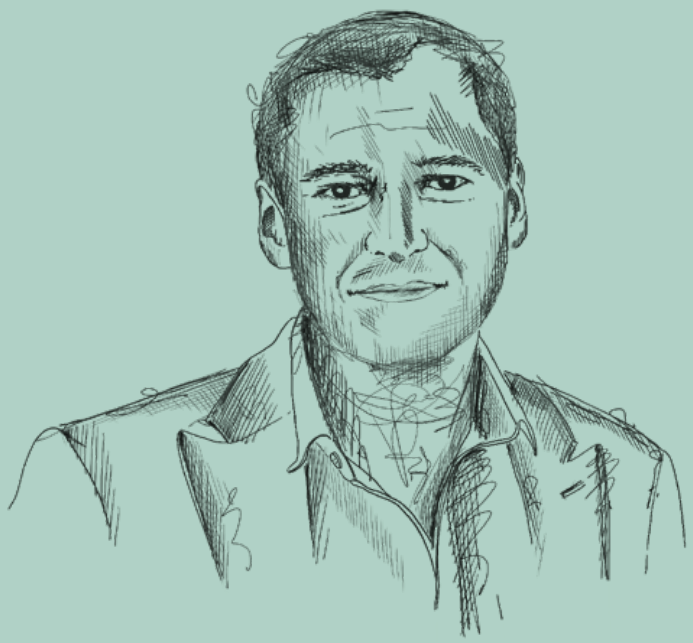
Microfluidics is an extremely versatile technology. I essentially use drops of liquid as minuscule test vessels. To create these vessels, I guide three fluids through extremely fine channels. Two of the fluids, each containing different components of the reaction, intermix. They then form a drop within the third fluid, which is immiscible with the first two and serves as a "vessel." The reaction begins as soon as the reactive components meet inside of this vessel. It's an ingenious technique, but handling the extremely small cannulas and syringe pumps takes a steady hand and some getting used to. I learned an incredible amount in Bordeaux, especially from Thomas Beneyton, the postdoctoral researcher who supervised me there.

The time I spent in France was a great success in another regard: since this year's iGEM competition was being held in Paris at the same time, I took the opportunity to make a stop in Disneyland on my way to Paris. Unlike in the past, I was a jury member and not a participant in the competition. The excellent projects and exchanges with so many creative people were inspiring and a lot of fun. And as if that weren't enough, I got to ice skate in France for the first time in ages. The nearest rink in Marburg is so far away that I have had to put my favorite sport on hold for the time being. In Bordeaux, however, it was just around the corner, so I could pursue my old passion again after work. The best thing about it was that I could still do jumps and figures!

PHOTO: PERSONAL

Elizaveta Bobkova

28 years old, she is the spokesperson for PhDnet, the Germany-wide network of Max Planck doctoral researchers, and a board member of N², a networking platform for the doctoral candidates of the Max Planck Society, Leibniz Association, and Helmholtz Association. While working on her doctorate at the Max Planck Institute for Terrestrial Microbiology, she also taught herself how to draw. Most of all, she enjoys illustrating scientific publications.



FIVE QUESTIONS

ABOUT RESEARCH IN UKRAINE

FOR ANDRIY STYERVOYEDOV

Mr. Styervoyedov, together with V. N. Karazin Kharkiv National University, you are creating the German–Ukrainian Plasma-Spin-Energy Core of Excellence, which is funded by the Federal Ministry of Education and Research. How are your colleagues in Kharkiv managing to conduct research?

ANDRIY STYERVOYEDOV: The situation around Kharkiv is not good. The Department of Physics and Technology at Karazin University is located in the northern part of the city, which is only about 25 kilometers from the Russian border. Now many windows are broken, and much has been destroyed. Alarms are frequently going off, and sometimes you hear explosions during meetings. My colleagues often have neither power nor heat. In the winter, it is not uncommon for the temperature in some of the labs to be as low as five or six degrees Celsius. But they continue working as best they can.

Stuart Parkin's department is researching spintronics, which uses electron spin as a source of information rather than their charge. What is the Plasma-Spin-Energy project about?

Spintronics can make computers faster and more energy efficient. To achieve this, we are developing devices made of very thin layers of different materials. Our partners at Karazin University have a lot of experience with plasma technology. They typically use it to create thicker layers for applications in medical technology, for example. Together, we are now developing equipment capable of significantly improving the quality of atomically engineered layers for spintronic devices, using advanced plasma technology. We are thus not only helping the group there, but also learning from their expertise.

How will the Core of Excellence help rebuild research in Ukraine after the war?

Here in Halle, we are currently filling two doctoral positions, a postdoctoral position, and an engineering position with Ukrainians who will return to Ukraine after the war. We also have a larger team of experienced scientists and engineers in Kharkiv, as well as two doctoral students and two postdoctoral researchers. The team in Ukraine is helping us develop equipment and simulate the plasma processes. The equipment is being built in Halle, but will then be transferred to Kharkiv once the war is over. Ukrainian researchers will have online access to the equipment and will be able to conduct experiments remotely. This way, it will be relatively quick and easy to get the new devices up and running in Ukraine, as the scientists and engineers there will already be trained to use them.

What does it mean for the future of Ukraine and its science if many well-educated young people leave the country because of the war?

Many young scientists had left Ukraine even before the war. The Cores of Excellence that the Federal Ministry of Education and Research is funding are intended to reduce the brain drain from Ukraine and stimulate brain circulation instead. Many of the experienced researchers and engineers who left Ukraine after February 24, 2022, want to return there. But it also depends on whether there will be interesting scientific projects and suitable positions for them after the war. The Core of Excellence project aims not only help reconstruct science in Ukraine, but also to attract investment to the country. The idea is that high-tech start-ups will be founded based on our scientific developments. This will create new jobs in Ukraine. If there are good working conditions for highly qualified people, they will return to their homeland.

How optimistic are you that you will be able to bring the new equipment to Kharkiv within the four years this project will last?

I hope the war ends as suddenly as it began. The best thing we can do is be prepared for that to happen. We also have a lot of plans for the time after the war. We want to cooperate in the long term, not just for four years. We want to commercialize our developments as well. If a German-Ukrainian spin-off company emerges from the Core of Excellence, this may bring new ideas and additional investment for research.

Interview: Peter Hergersberg

Andriy Styervoyedov completed his doctorate at V. N. Karazin Kharkiv National University and has been researching in Stuart Parkin's department at the Max Planck Institute of Microstructure Physics in Halle (Saale) since February 2015.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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- Sub-institute / branch
- Other research facilities
- Associated research facilities

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- Nijmegen

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- Rome
- Florence

USA
- Jupiter, Florida

Brazil
- Manaus

Luxembourg
- Luxembourg

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