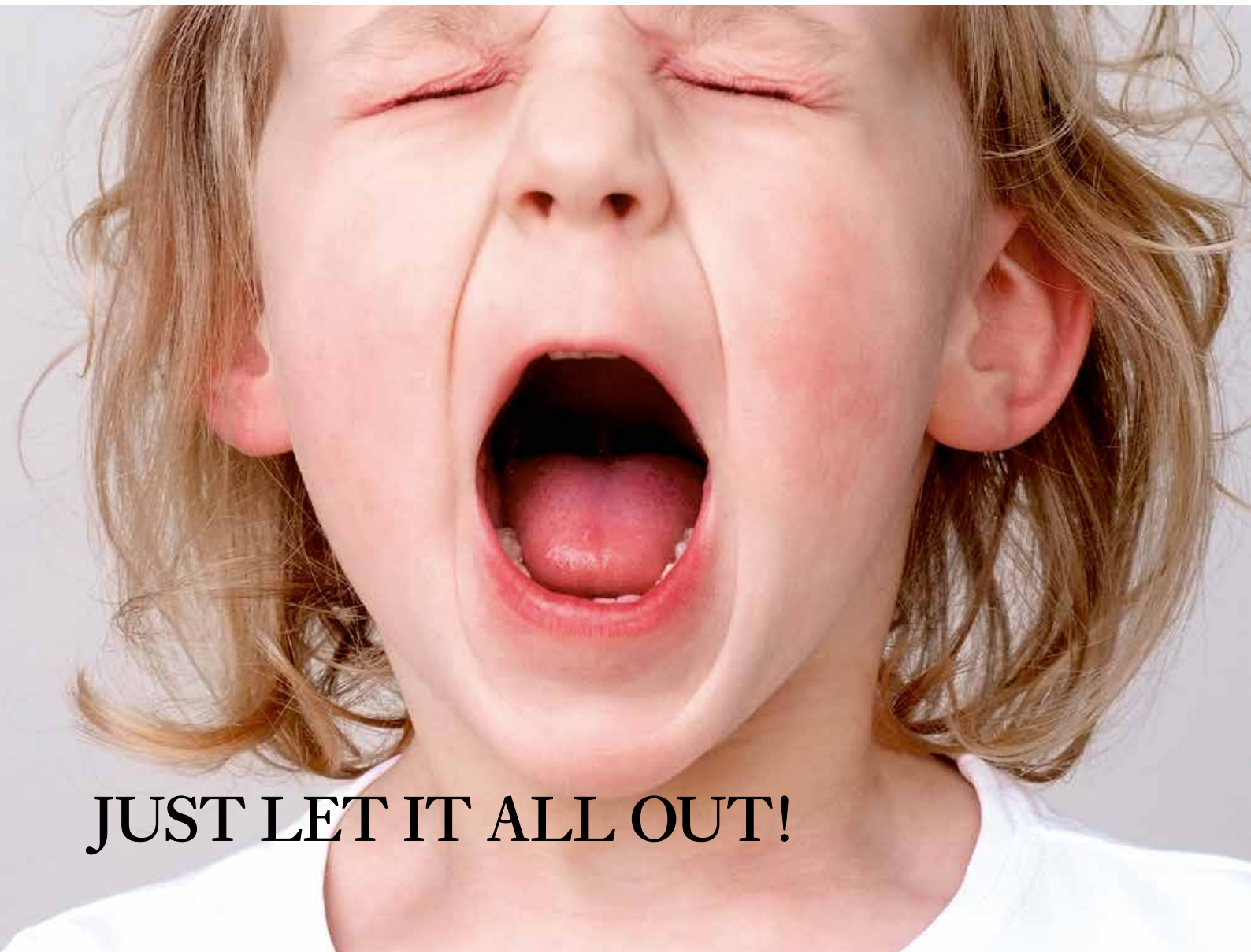
04 | 2021

MAX PLANCK *Research*

BIOMEDICINE
Booster from alpacas

ASTROPHYSICS
Cosmic detective work

CLIMATE RESEARCH
Thawing permafrost



JUST LET IT ALL OUT!

PHOTO: ADOBE STOCK

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Just get your feelings out, like this girl when she sees a plastic spider. Something that is normal behavior among children used to be unthinkable for kings and emperors in former times. Today, high-ranking politicians can allow themselves to get carried away at a soccer match on camera. And even machines are starting to feel more – at least when it comes to the robots that are being developed for therapy purposes by Max Planck researchers.

EDITORIAL

Dear Reader,

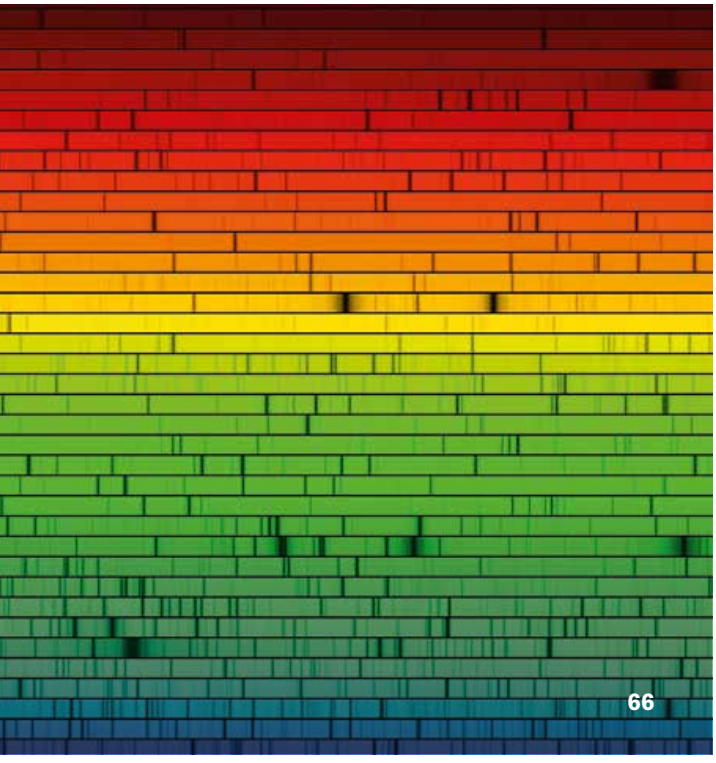
Until quite recently, emotions were considered nearly too impenetrable as a topic for scientific research, as they were deemed too subjective and not precisely quantifiable. However, it is possible to measure them on the basis of the physical reactions they produce. Among people suffering from arachnophobia, for example, the fear of spiders makes their hearts beat faster and causes them to adopt avoidance behaviors. They don't even need to be confronted with a real, live spider. Using virtual reality and a range of different sensors, researchers are now able to monitor the feelings that arise when the individual in question sees a spider, and to develop better treatment methods.

Showing emotions in public was long considered taboo. Just a few years ago, it would have been unimaginable for Angela Merkel, the head of a government, to express her joy for everyone to see at the Soccer World Cup in Brazil in 2014 – not to mention Donald Trump's eruptive outbursts. While the ideal of the calm, level-headed monarch still dominated at the end of the 18th century, as time went on, those in power increasingly tended towards making their feelings publicly known in order to secure affection and goodwill among the populace.

Meanwhile, others have yet to learn a sense of feeling: in order for robots to someday help us look after people in need of care, they will have to be able to sense how they touch a person. Unlike language and image recognition, however, the development of a sense of touch in artificial systems is still in its infancy. To make sure that being hugged by a robot engenders positive feelings, researchers are now developing new types of tactile sensors.

Our sense of touch plays a key role in determining our actions. It is a powerful tool that can help or harm us, and it conveys a feeling of closeness. On that note, we hope you have pleasant feelings while reading this edition of the magazine!

Your editorial team



PHOTOS: PICTURE ALLIANCE / ASSOCIATED PRESS / CHARLES DHARAPAK (ABOVE LEFT); AXEL GRIESCH (ABOVE RIGHT); N.A.SHARP, NOAO/NSO/KITT PEAK FTS/AURA/NSF (BELOW LEFT); SPL–AGENTUR FOCUS (BELOW RIGHT)

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People who express their feelings in public engender empathy among others.

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The physicist Hanieh Fattahi is working to protect the climate.

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Global warming is causing permafrost soil to thaw.

CONTENT

WATER TANK FOR PARTICLE SHOWERS

It may look like a construction site, but it's actually the test facility for a very special kind of observatory. Quite fittingly, the constellation of Orion – with its three characteristic stars forming the belt – can be seen in the sky above, providing a symbolic reference to the cosmos. The tank erected for these tests on the grounds of the Max Planck Institute for Nuclear Physics measures 11 meters across and six meters high, contains 550 metric tons of water – and is used to simulate a lake. But what does all of this have to do with astrophysics?

In the middle of the Chilean Andes, researchers are planning a facility known as the Southern Wide-field Gamma-ray Observatory (SWGO). One day, this facility will operate around the clock to observe high-energy radiation from the depths of the universe and measure it using an indirect method. The technique takes advantage of a phenomenon in which cosmic gamma photons produce veritable showers of particles in the atmosphere, which can be detected from the blue light they subsequently produce in water. One concept for the observatory envisages using a natural lake, from which water could be extracted, then purified on-site and used to fill balloons. These balloons would then be fitted with internal detectors and suspended in the lake.

The scientists want to use the tank in Heidelberg to test whether this idea actually works. The scaffolding allows them to literally submerge test balloons inside the tank. As part of this experiment, they are testing various balloon materials with regard to both their stability and their optical properties. In addition, a water-circulation and -filtration plant can set the artificial lake in gentle motion – creating the perfect simulation for a new window into outer space.

https://youtu.be/3ceq75YzE8E

ON LOCATION

PHOTO: MPI FOR NUCLEAR PHYSICS

PHOTO: GCO

On the winning side: *MaxPlanckResearch* has won the German Design Award for 2022.

AN HONOR FOR OUR MAGAZINE

MaxPlanckResearch has been awarded one of the world's most prestigious design prizes for its design and visual appearance. The magazine received the German Design Award 2022 in the category "Excellent Communications Design – Editorial". The award was given in recognition of the magazine's redesign two years ago. Its visual concept and approach to content convinced the German Design Award jury just as much as the journal's editorial work, which focuses on translating the specialized terminology used in each branch of science into more simply formulated language that can be understood by readers with no expertise in the subject. The German Design Award is awarded by the German Design Council to honor innovative design in the fields of architecture, communication, and product design. The entries are judged by an international jury of leading experts active in all branches of design. **www.mpg.de/17883198**

AWARD-WINNING ✶

DIETER OESTERHELT

The Emeritus Director of the Max Planck Institute of Biochemistry has received the Albert Lasker Basic Medical Research Award 2021 jointly with Peter Hegemann from Humboldt University and the American scientist Karl Deisseroth from Stanford University. The three scientists were honored for their discovery of light-sensitive proteins in the membrane of single-celled organisms and for their use of these proteins in optogenetics.

PHOTO: MPG/FILSER

ALESSANDRA BUONANNO

This year's Balzan Prize has been awarded to Alessandra Buonanno, Director of the Max Planck Institute for Gravitational Physics, and Thibault Damour from the French Institut des Hautes Études Scientifiques. The jury paid tribute to the leading role played by the two scientists in the prediction of gravitational wave signals. Their work also provides extremely accurate confirmation of the general theory of relativity.

PHOTO: SVEN DOERING

IN BRIEF

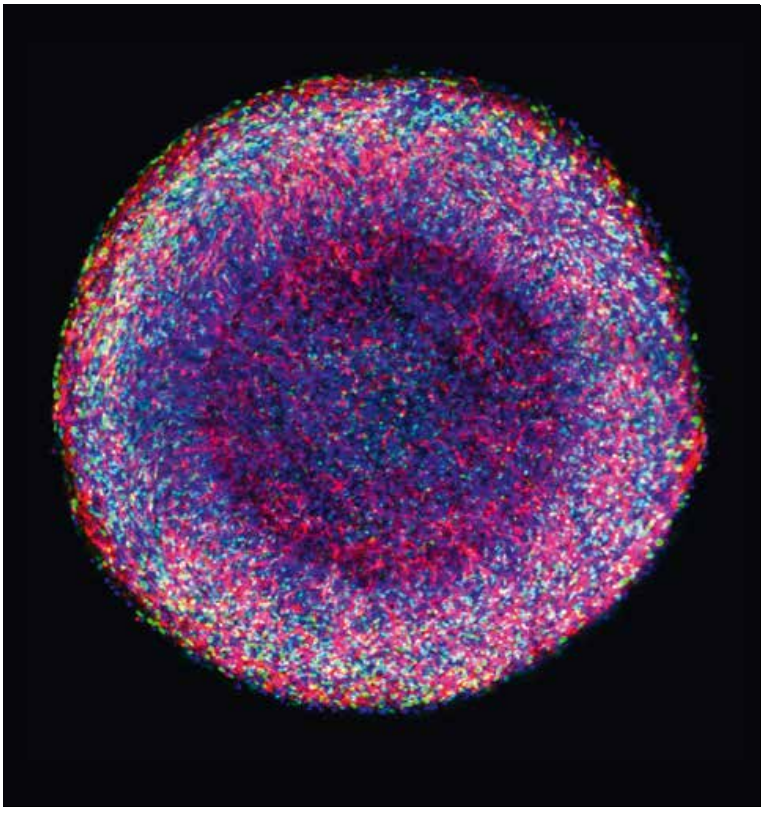

IMAGE: MPI FOR MOLECULAR BIOMEDICINE/HENRIK RENNER, JAN BRUDER

A 25-day-old midbrain organoid (blue: cell nuclei; red: nerve cells; green: progenitor cells).

PETRI DISHES REPLACE ANIMAL EXPERIMENTS

In order to elucidate the functioning of the brain and develop drugs against neurological disorders such as Alzheimer's disease, Parkinson's disease or depression, researchers have to study the brains of laboratory animals. They could in fact study nerve cells grown the traditional way in two-dimensional cultures, which thrive in a nutrient solution and form a lawn of interconnected nerve cells. However, these flat expanses of cultured cells only roughly approximate to the actual conditions in the human brain. Brain organoids from Muenster are quite different. They are grown from special neural progenitor cells that spontaneously form pieces of tissue and can create networks in all three spatial directions. They were developed by Jan Bruder and Henrik Renner at the Max Planck Institute for Molecular Biomedicine in Muenster. The two scientists have also designed an automated production process that allows them to generate and analyze large numbers of organoids using standardized processes. Researchers can use these miniature tissues to carry out basic research into the mechanisms of neurological diseases. The organoids can also be used to test potential new drug substances. If the substances are found to be ineffective or toxic, this eliminates the need for further testing on animals. The German Federal Ministry of Food and Agriculture awarded the Animal Welfare Research Prize for 2021 to the two inventors in recognition of their work.

www.mpg.de/17946077

NEW ADMINISTRATIVE HEAD

Simone Schwanitz is to become the new Secretary General of the Max Planck Society. She was previously in charge of the "Department of Research, Technology Transfer, Digitization and the European Union" at Baden-Wuerttemberg's Ministry of Science, Research and the Arts. In this position, she was also a member of Boards of Trustees of several Max Planck Institutes. The 53-year-old political science graduate has acquired knowledge and practical experience in personnel, budget, construction and legal matters through her many years of work in Ministry operations. "This will help her not only when managing the Administrative Headquarters but also when interacting with the Institutes, governing bodies and other committees, the Ministries, and the Joint Science Conference of the federal administration and the federal states," emphasizes Max Planck President Martin Stratmann. Simone Schwanitz will take office on February 1, 2022. Her predecessor Ruediger Willems will step down in March 2022.

www.mpg.de/18416593

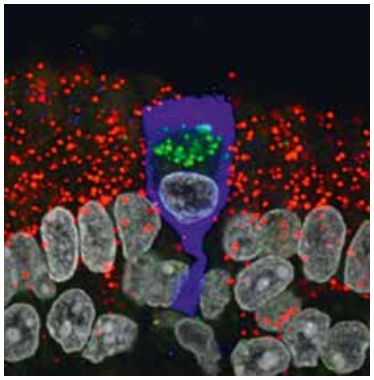

IMAGE: MAX PLANCK RESEARCH UNIT FOR NEUROGENETICS/MONA KHAN

A lone infected supporting cell is surrounded by non-infected cells in the olfactory mucosa of a COVID-19 patient who died four days after the infection was diagnosed. The infected cell has the characteristic shape of a wine glass.

CORONAVIRUS IN THE NOSE

COVID-19 can cause a temporary or even long-term loss of smell. This suggests that SARS-CoV-2 may infect the sensory cells in the olfactory mucosa and even travel along the olfactory nerve into the brain. However, researchers at the Max Planck Research Unit for Neurogenetics in Frankfurt have not found any traces of the virus in the sensory cells of deceased COVID-19 patients. Neither do the nerve cells in the brain's olfactory bulb appear to have been infected. This means there is as yet no evidence that SARS-CoV-2 can infect nerve cells. Instead, the virus mainly targets the supporting cells in the olfactory mucosa. The loss of smell presumably occurs when these supporting cells are infected, since they then become unable to supply the olfactory cells with sufficient nutrients. The supporting cells are located on the surface of the nasal mucosa, where the immune system is unable to afford them adequate protection. This means that even vaccinated or recovered patients can lose their sense of smell after being infected with SARS-CoV-2.

www.mpg.de/17907472

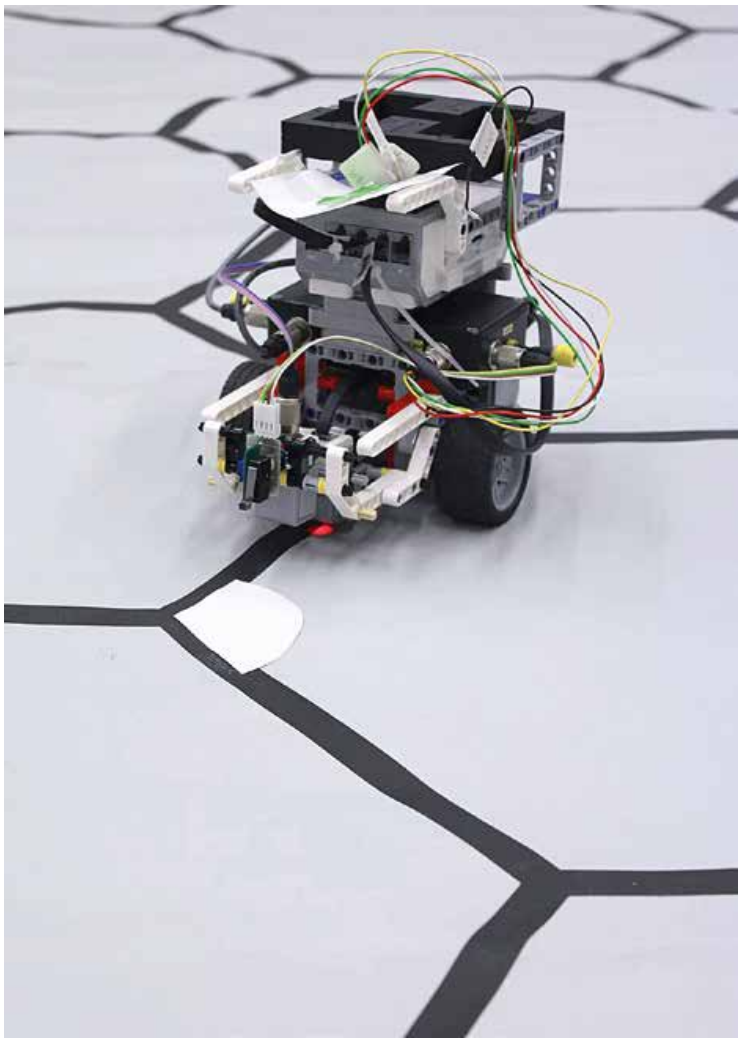

PHOTO: MPI FOR POLYMER RESEARCH

Lego with a memory: a toy robot learns to navigate a maze with the help of an organic neuromorphic circuit.

ROBOT WITH ARTIFICIAL SYNAPSES

Circuits that function like nerve cells could open up even more new computer technology applications. They could utilize energy with roughly the same efficiency as natural neurons, directly convert sensory information such as image data from a camera into control signals for a motor, and ultimately even facilitate communication between nerve cells and microelectronic components. An international team led by researchers from the Max Planck Institute for Polymer Research has now succeeded in advancing one step further in the development of neuromorphic electronics. The researchers have developed a neuromorphic circuit containing a transistor which processes information with the help of ions – just like nerve cells do – instead of the electrons used by traditional microelectronic components. This circuit can permanently memorize what it has learned, since it contains a synthetic synapse which changes during the learning process in the manner of a biological synapse. The team built the neuromorphic circuit into a robot, which then learned to find its way through a maze with the help of markings. In addition to camera data, the robot used the mechanical signals it received when it mistakenly collided with the walls of the maze. As the team expected, the robot interpreted the markings more reliably after every failed attempt because the corresponding signals sent through the artificial synapse became stronger.

www.mpg.de/18023757

FEELINGS COME FROM THE HEART

People who do not feel enough fear are more likely to engage in risky behavior. However, people who are too fearful or are even susceptible to panic attacks face problems in their everyday lives. So how can fear be kept in check? The results of a study performed on mice by researchers at the Max Planck Institute of Neurobiology in Martinsried, near Munich, show that the brain uses bodily reactions to control feelings of fear, for example by slowing the heartbeat. The researchers focused on the insular cortex, a region of the brain that – also in humans – reacts to stimuli that could signal danger, such as unexpected noises. This region also receives signals from the heart via the vagus nerve. The results suggest that the insular cortex keeps fear levels within a certain median range. If it is activated, the most fearful mice lose some of their fear. In contrast, activating the cortex makes braver animals more cautious. However, the insular cortex can only perform this function with feedback from the body, since the insular cortex is not activated if there is no communication between the heart and the brain. Intensely fearful animals remain fearful, carefree ones remain carefree. This means that physical reactions are more than just the result of feelings; instead, the brain uses them to control the body in a kind of feedback loop. ***www.mpg.de/17860303***

TELL ME WHAT YOU PLAY ...

Humans all over the world play games, but not all the games they play are the same. Previous studies suggested that people in hierarchical societies often play competitive games, while the games most commonly played in egalitarian societies tend to be more cooperative. However, these correlations have so far only been investigated in a small number of cultures. Researchers from the Max Planck Institute for Evolutionary Anthropology in Leipzig have now joined forces with colleagues in Jena, Gera and Australia to analyze historical data about this topic. The key question was whether the games typically played in a society allow conclusions to be drawn about how cooperative it is. The results showed that societies that frequently became embroiled in conflict with other societies played cooperative games more frequently than competitive ones. On the other hand, cultures in which there were frequent conflicts within the community were more likely to play competitive games. No reliable associations were found between the type of game and the hierarchical structures within the societies. ***www.mpg.de/17889012***

COVID-19 REDUCES LIFE EXPECTANCY

Over the last few decades, most western industrialized nations have grown used to seeing the average life expectancy of their populations consistently increase by a few weeks every year. The COVID-19 pandemic has now halted this development. This conclusion is the outcome of a study by the Max Planck Institute for Demographic Research and the Universities of Oxford and Cambridge. The team used complete sets of reliable data to calculate life expectancy in 37 middle and high-income countries. In 31 of the countries investigated, life expectancy decreased among both men and women. Russia was most strongly affected, with men's life expectancy declining by 2.33 years and women's by 2.14 years. In second place was the U.S., where men's average life expectancy fell by 2.27 years and women's by 1.61 years. Life expectancy indicates how long people would live on average if their circumstances during the year being investigated were to remain constant for the rest of their lives.

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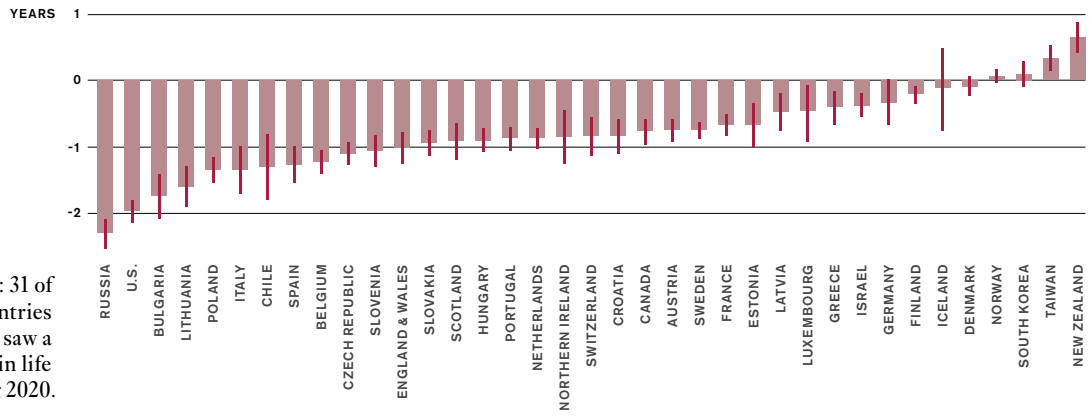


Negative balance: 31 of the 37 countries investigated saw a decrease in life expectancy during 2020.

GRAPHIC: GCO BASED ON DATA FROM THE MPI FOR DEMOGRAPHIC RESEARCH

HOW WELL MASKS PROTECT US

Even three meters' distance is not enough. If an unvaccinated person who is not wearing a mask stands within the so-called moist breath zone of a person infected with COVID-19, the risk of them becoming infected with the COVID-19 virus increases rapidly within just a few minutes. However, masks provide highly effective protection against virus transmission. When both people are wearing well-fitting medical face masks, the risk of becoming infected within twenty minutes falls to no more than ten percent. With properly fitting FFP2 or KN95 masks, the risk actually falls to less than 0.1 percent, and even poorly fitting FFP2 masks limit the risk to no more than 4 percent. These upper limits for the risk of infection were calculated in an extensive study conducted by a team from the Max Planck Institute for Dynamics and Self-Organization in Goettingen. The team investigated how well various masks protect the wearer from infection by the delta variant of COVID-19 when worn in different ways. They calculated the risk of infection extremely conservatively and are therefore certain that masks provide even better protection in real-life conditions. They also believe that masks reduce the risk of transmitting the omicron variant even more effectively than they do the delta variant, even though only a half to one-third of the virion load is required for a person to become infected with omicron. The researchers resolved this apparent contradiction by looking at the respective viral load and the size of the resulting particles found in the upper and lower airways: in the lower airways, the omicron viral load is significantly lower than that of delta. In the upper airways, the viral loads of both variants are comparably high. However, large, virus-laden particles are produced in this area – especially when talking, singing and shouting – and masks, including medical masks, can filter them particularly effectively from the wearer's breath. ***www.mpg.de/17916867***

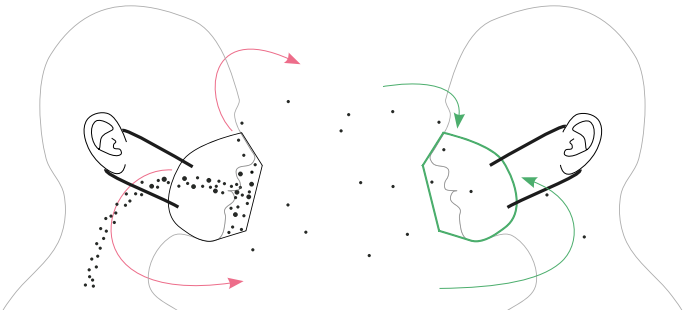
PHOTO: JAMES ST CLAIR

New Caledonian crow with a hooked tool.

CROWS VALUE TOOLS

The care with which we humans handle our property often depends on its value. The sticks that some crows use to forage for food do not have a price tag, but the birds still know their value. This was the inference drawn from a study of New Caledonian crows conducted by researchers from the University of St. Andrews and the Max Planck Institute of Animal Behavior in Konstanz. The birds use a rare species of plant to painstakingly craft hooked tools that allow them to extract their prey ten times faster than the non-hooked tools that are easier to make. The German-British team has now found that crows take more care to safeguard these valuable tools when they are not in use than they do the more basic tools. Once they have extracted their prey from cracks and crevices using a stick, they have to put their tool down in order to eat. They then hold it securely under their feet or place it temporarily in a nearby hole. They do this in an attempt to avoid accidentally dropping the stick and to prevent it from being stolen by other crows. ***www.mpg.de/18061418***

Masks that do not fit tightly at the edges allow air to enter and exit, especially at the nostrils but also at the cheeks. However, even poorly-fitting masks significantly reduce the risk of infection.



GRAPHIC: GCO BASED ON DATA FROM BIRTE THIEDE/MPI FOR DYNAMICS AND SELF-ORGANIZATION

PHOTO: JASPER WASSENBURG, MAX PLANCK INSTITUTE FOR CHEMISTRY

Stony witnesses: the chemical signature in the bands that accumulate as a stalagmite grows (the photo shows a stalactite from Morocco) provides precise information about historical climate change.

WEAK GULF STREAM REDUCES MONSOON RAINFALL

If the ice sheet covering Greenland were to thaw, this could have dire consequences for tropical water supplies. It would cause large quantities of fresh water to flow into the North Atlantic, thus slowing the Atlantic Meridional Overturning Circulation (AMOC) to which the Gulf Stream belongs. The monsoon rainfall so vital to East Asia and India would then probably decrease. This conclusion was drawn by an international team led by researchers from the Max Planck Institute for Chemistry, who performed a study that shows how the weakening of the Gulf Stream has affected monsoon rainfall in the past. For this purpose, the team analyzed the chemical signature in stalagmite deposits taken from a stalactite cave in southern China to obtain information about the amount and duration of precipitation during the monsoon season. The researchers combined these data with results obtained by other groups, which state that the AMOC weakened at the end of the penultimate glacial period due to the increased volume of meltwater flowing into the North Atlantic. Hence, the team was able to prove that monsoon rainfall decreased dramatically during this period.

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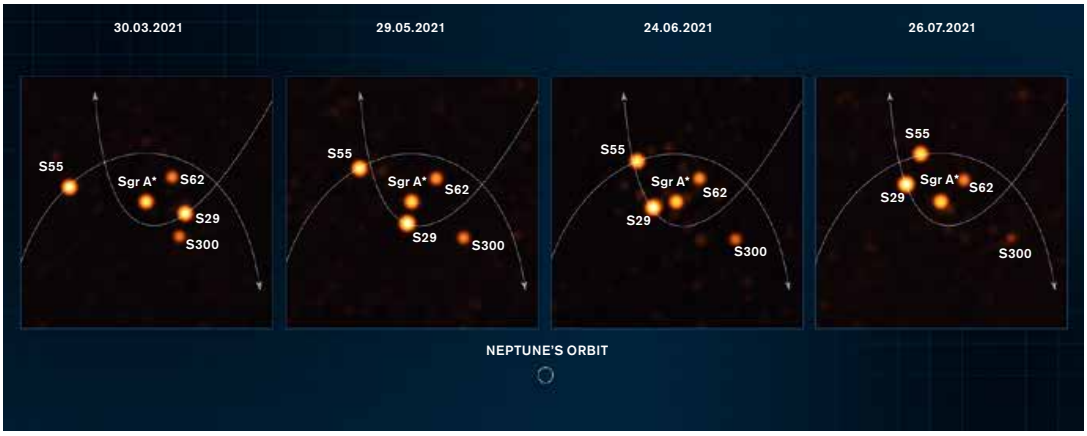

IMAGE: ESO/GRAVITY COLLABORATION

Stars circling the black hole: photographed between March and July 2021, these images show stars orbiting very close to the giant monster lurking at the heart of the Milky Way.

ZOOMING INTO THE GALACTIC CENTER

The heart of our Milky Way holds a surprise or two – not least because it is the home of a giant black hole. A team led by the Max Planck Institute for Extraterrestrial Physics has now taken a look deep inside this galactic center. Under the direction of Reinhard Genzel, the researchers concentrated on measuring the orbits of stars close to the gravity trap. These included the record-breaking star S29, which at the end of May 2021 approached the black hole at the breathtaking speed of 8,740 kilometers per second and passed it at a distance of 13 billion kilometers – just 90 times the distance between the Sun and the Earth. No other star has yet been observed passing that close or traveling that fast around the black hole. The group also found that these and other stars exactly followed the orbits predicted by the general theory of relativity for objects moving around a black hole with a mass 4.3 million times that of the Sun. With an accuracy of about 0.25 percent, this is the most precise estimate of the black hole's mass to date.

www.mpg.de/18035817

PARROTS PRACTICE SELF-CONTROL

At the beginning of the 1970s, researchers performed a so-called "marshmallow experiment" to find out how long children can wait for a reward if it grows larger over time. A number of animal species, including chimpanzees, capuchin monkeys, dogs, squid, and crows, also have this ability to control their impulses. A research team from the Max Planck Institute for Ornithology in Seewiesen has now compared the self-control of four different parrot species at the Loro Parque – Animal Embassy in Spain. The scientists tested how long the parrots resisted immediately eating a sunflower seed when the alternative was to wait somewhat longer for a walnut. On average, African grey parrots were able to wait longer for their favorite food than macaws. The best performance was achieved by a grey parrot called Sensei, who managed to wait more than twice as long as the most patient macaw. One explanation of these differences could be that bird species that have to invest more time in searching for food or that live in more complex social settings learn to exhibit more self-control.

www.mpg.de/17804523

COMMON ROOTS

The family of Transeurasian languages includes members as diverse as Japanese, Korean, Tungusic, Mongolian and Turkish. However, their origins and dispersion have long been a mystery. An interdisciplinary study with Martine Robbeets, Research Group Leader at the Max Planck Institute for the Science of Human History, as the lead author has now found genetic, archaeological and linguistic evidence that the spread of this family of languages correlated with the spread of agriculture. The data indicate that the origins of the Transeurasian languages go back to the early days of millet farming along the western Liao River in northeastern China. Proso millet (*Panicum miliaceum*) was already being cultivated in that region nine thousand years ago. From there, the family of languages initially spread to neighboring regions. In the late Neolithic, Bronze and Iron ages, the millet farmers gradually mixed with populations on the Yellow River, in Western Eurasia and in Japan. They also brought along their knowledge of pasture farming and cultivating rice and other food crops.

www.shh.mpg.de/2071364

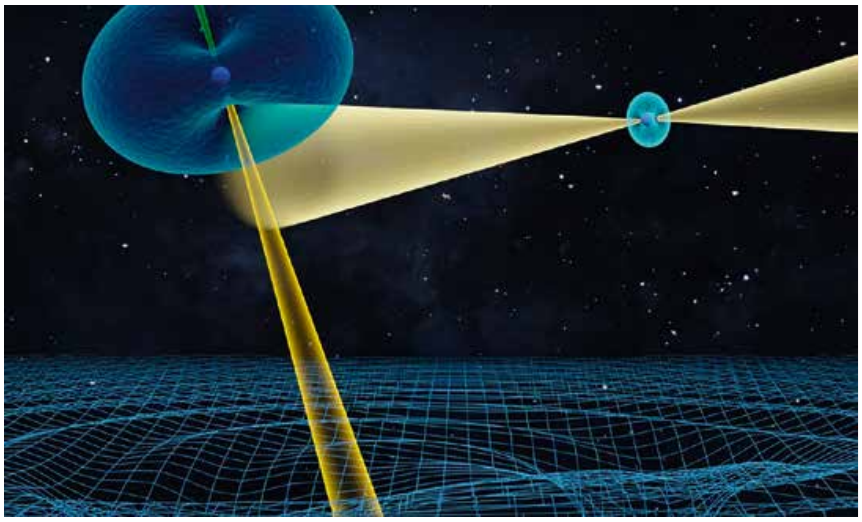

IMAGE: MICHAEL KRAMER / MPIFR

Cosmic test: the image is an artistic representation of the double pulsar system PSR J0737-3039 A/B, in which two active pulsars orbit each other in just 147 minutes. The orbital motion of these extremely high-density neutron stars causes a series of relativistic effects that have been precisely measured over a period of sixteen years.

EINSTEIN IS PROVEN RIGHT ONCE AGAIN

More than a hundred years after Albert Einstein published his theory of gravity, scientists all over the world are still trying to find possible flaws in his general theory of relativity. The observation of any deviation from the predictions of this theory would open a new window onto the science of physics and expand our current theoretical understanding of the universe. A team of researchers from ten countries has spent sixteen years attempting to prove or disprove Einstein's general theory of relativity using some of the toughest tests yet developed. For this, the group led by Michael Kramer from the Max Planck Institute for Radio Astronomy investigated a unique pair of stars with extreme properties; known as pulsars, they form a binary star system in which each orbits the other. Measurements were taken using seven radio telescopes located all over the world. These revealed new relativistic effects that had been expected but were now being observed for the first time. And the observations matched Einstein's theoretical predictions by more than 99.99 percent.

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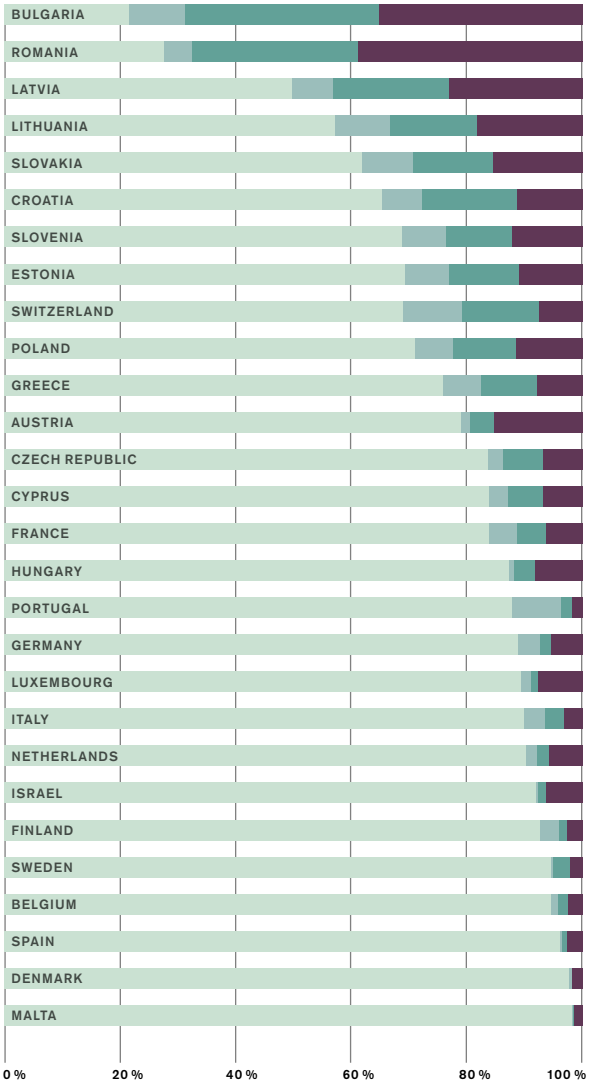

GRAPHIC: GCO ACCORDING TO SHARE-ERIC

Visible differences: a survey of the 50-plus age group showed that people in the Eastern European and Baltic countries were significantly less willing to be vaccinated than those in the other European countries and Israel.

WHO ARE THE UNVACCINATED?

A team of researchers from the Max Planck Institute for Social Law and Social Policy has performed a study to find out which demographic, socio-economic and health factors play a role in making the decision for or against the COVID-19 vaccine. For this, they used the Survey on Health, Aging and Retirement in Europe, which regularly collects data from the 50+ age group in 27 European countries and Israel. One significant finding was that vaccine hesitancy and refusal to be vaccinated were much more pronounced in Eastern Europe than in other regions. Moreover, people in lower income brackets were vaccinated less often. Another influential factor was the level of education: 15 to 16 percent of the people who had achieved a low or intermediate level of education were undecided or refused to be vaccinated, but only around 9 percent of the people who were more highly educated responded the same way. People aged between 50 and 65 were more likely to refuse the vaccine than older respondents; this finding was consistent in almost all countries. Gender was also a factor in most countries: women were more likely to be hesitant than men. There was also a correlation between the respondents' willingness to be vaccinated and their physical health, or whether they knew people who had fallen seriously ill with COVID-19.

www.mpg.de/17673849

THE LEGAL LEGACY OF THE COLONIAL ERA

Colonization has become a thing of the past. However, its impact can still be felt today in the form of coloniality – the way in which the world is perceived, understood and governed. One example are European legal concepts that continue to apply as a standard worldwide. Our author demands that this Eurocentric perspective be abandoned, and makes the case for a new, pluriversal understanding of law.

TEXT: RALF MICHAELS

In September 2021, the World Bank announced that one of its most successful projects, the *Doing Business* report, had been terminated. Since 2004, a system of indicators had been used for all countries in the world to evaluate how business-friendly they were, and to rank them accordingly. Its success notwithstanding, the project was terminated after it emerged that the evaluation criteria had been modified specifically for China. The fear had been that if China was moved further down in the rankings, that could jeopardize the World Bank's funding overall. Now, the World Bank plans to develop a follow-up project in two years' time.

The *Doing Business* report was produced by economists, without the involvement of legal experts. However, at its core, it was a legal project. The factors that were monitored, and which were used as a basis to determine how business-friendly a country was, essentially belonged to the legal system. How easy is it to start a business in country X? This references not only corporate law, but also the administrative laws relating to official permits. How quickly can a tenant who is in arrears be evicted from their apartment in country Y? This question references contract laws relating to contracts and civil procedures. How easy is it to give notice to an employee in country Z? This question references individual and collective labor laws.

→

VIEW POINT

RALF MICHAELS

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Ralf Michaels studied law in Passau and Cambridge. After completing the state law examination and gaining his Master of Laws (LL.M.), he spent 17 years teaching and researching at the Duke University School of Law in the U.S. In 2019, Ralf Michaels became a Director of the Max Planck Institute for Comparative and International Private Law. He also holds a professorship at Queen Mary University of London and the University of Hamburg. His research focuses on comparative law, law and globalization and private international law and private law theory.

The *Doing Business* report was also a comparative legal study, since it compared the countries. Such comparisons between legal regulations in different countries have always been a core field of comparative law. Traditionally, the main purpose of this area of legal studies was to determine commonalities and differences between the legal orders of different countries, and to explain, evaluate and possibly also overcome them by harmonizing those countries' laws. In addition, comparative law examines what are known as "legal transplants" – the adoption of legal rules and institutions from one legal system by another. These include the continuation of English common law in Commonwealth countries after they gained independence, for example, or the reform of antitrust law in Mexico based on the U.S. model at the end of the 20th century. Legal transplants particularly lend themselves as tools for promoting economic growth in the context of development aid. The hope is that legal rules that have led to a well-functioning economy in wealthy countries will spur economic development in poorer ones. The *Doing Business* report is a prime example of this. It defines "best practices," which are then recommended for the other countries to emulate.

In fact, comparative law scholars are rather proud of all this. In their view, other legal disciplines are simply narrow-minded and nationalistic, regarding their own national law as the only relevant standard, without knowledge of other legal systems beyond their own borders. By contrast, comparative law promotes an awareness of the diverse nature of the law worldwide. One belief held in comparative law is that in light of globalization, law can only be properly understood when different systems are compared with each other. Only those who are familiar with a large number of different legal systems have access to a superior range of potential solutions. Furthermore, it is only possible to improve a legal system when it is compared with others.

RWANDA IS REGARDED AS A SUCCESS STORY: IN THE WORLD BANK REPORT, THE COUNTRY ROSE FROM 139TH PLACE TO 32ND PLACE

However, some people are critical of this approach. For a long time, comparative law focused mainly on European and North American legal systems. When it did take other legal orders into account, it regarded them as being nothing more than inferior versions of their European models, with Nigerian law as a shoddy copy of English law, Japanese law as a poor imitation of German law, and so on. Critics who accuse comparative law experts of Eurocentrism claim that there is an implicit hierarchy in place, with European countries at the top. Seemingly, such accusations do not apply to the *Doing Business* report. While at first, typical OECD countries such as the U.S., Canada, Switzerland and Singapore were ranked at the top, several developing countries soon moved up the list. Rwanda, for example, has been regarded as a success story. From 2009 to 2010, the East African country moved up from 139th to 67th

place, and in 2014, it was ranked 32nd. Georgia, which was ranked 100th for business friendliness in 2006, had reached 6th place in the global rankings by 2019. According to the World Bank, it is precisely because the ratings take neutral indicators into account that they help overcome the prejudices that disfavor non-European legal systems. This is what allegedly makes them emancipatory.

This is the precise claim that decolonial critique addresses. According to decolonial theory, (European) modernity has always been linked to coloniality, its inseparable darker side. Liberty, equality and prosperity in Europe not only went hand in hand with oppression, unequal treatment and the exploitation of the colonies and their subjects; without them, such societal progress would not have been possible. In order to legitimize the oppression and exploitation, it was necessary to assert the claim that Europeans and their way of thinking were superior – a type of historical ranking, as it were. Moreover, the standard used for this ranking was itself based on European values and ideals, which thus became universalized. Therefore, coloniality meant dual domination by Europe over the rest of the world – not just by means of military and economic superiority, but also through the power to determine knowledge and thought.

EUROPE AND THE U.S. CONTINUE TO RULE THE WORLD WHEN IT COMES TO KNOWLEDGE AND THOUGHT STRUCTURES

The colonial era is a thing of the past, and with just a few exceptions, the former European colonies have now formally become independent states. However, this does not mean that coloniality has been overcome. Europe and the U.S. continue to set the standards against which the rest of the world is measured. European values and ideas that were developed on the basis of specific European history, a form of capitalism that originated in Europe and the U.S., continue to be regarded as universal, and are imposed upon the rest of the world. Europe and the U.S. may no longer rule the world politically, but they do still dominate when it comes to knowledge and thought structures.

Decolonial theory has, to date, only rarely been applied to the law and comparative law. Yet the *Doing Business report* is a good example of what such application can look like, and what it is able to achieve. For example, it can show that although countries in the Global South may occasionally be ranked higher than those in Europe, the price for this is that these countries are required to fully accept the standards and expectations of the project, which are dominated by Europe and the U.S. In Rwanda, for example, while the changes made to the economic system to meet the requirements of the *Doing Business* report may have improved the country's ranking, they have also led to a high level of dissatisfaction. It is debatable whether the willingness of the Rwandan government to adapt

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to these standards will pay off. Is it really preferable to do business in Georgia rather than the U.S., or in Azerbaijan rather than Israel, simply because Georgia and Azerbaijan are ranked higher?

Ultimately, the *Doing Business* report may not prioritize European countries, but it does implicitly favor European law. Thus, a great deal of importance is given to formal statutory rules that regulate activity in the countries of the Global North, but which are of less importance elsewhere. When comparative law compares different countries, it fails to take non-state law into account. Local customs and mechanisms for resolving disputes which play an important role in the Global South are presumed to weaken the state's monopoly on power, instead of being viewed as alternative, perhaps even superior, norms.

THE RANKING COMPARES OFFICIALLY INDEPENDENT STATES, BUT REMAINS LARGELY COLONIAL

When the *Doing Business* report recommends rules from the Global North as models for the Global South, it assumes a technical, non-cultural understanding of law. In the first *Doing Business* report, the presumption was "one size fits all." This approach underestimated the question of whether such rules are capable of functioning at all in the Global South – and whether former colonies, which today are officially independent, wish to be subject to rules that originate from the former colonial powers.

While a project such as the *Doing Business* report may compare formally independent states, it does in fact remain largely colonial in nature. It promotes the universalization of legal rules from the Global North, not through political recolonization and the enforced implementation of such rules, but by declaring a certain legal rationale to be universally valid and making it a benchmark by means of a ranking process. Countries in the Global South are not forced to adopt this rationale. However, if they refuse to do so, they will be ranked lower down the list.

The result is not simply a hierarchy that places countries from the Global North above those from the Global South. Instead, something more perfidious emerges. Those countries that adopt the rationale of the Global North are ranked higher than those who do not, for this reason alone. This rating system purports to be scientifically neutral and purely descriptive. In reality, however, it transfers a high level of normativity to its subject of study – it normalizes the principles of the Global North.

What might decolonial comparative law that resisted such an approach look like? The universality of western values and laws can be countered by the concept of pluriversality – in other words, the notion of a world within which many worlds are possible. In a pluriverse, European based law would have its place, but merely as one of many systems, without the claim

to general validity that it currently enjoys. Such an approach is therefore not anti-European, but it is anti-colonial and therefore also anti-universalist.

After decoupling from European universalism, options suddenly become available that seemed implausible within the European paradigm. A pluriversal attitude towards the law in the world would also make it possible, for example, to revive indigenous approaches such as ubuntu in South Africa or buen vivir in South America. Often, approaches such as these do not focus foremost on the rights of the individual, as does European and U.S. law; rather, they emphasize harmony with the community and with nature.

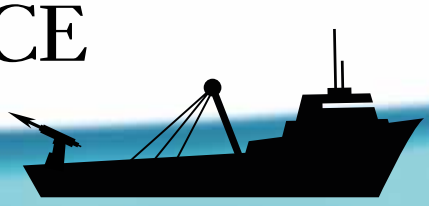
Here, pluriversality does not mean that these principles supersede European individualism. After all, that would simply entail replacing one universalism with another. However, pluriversality does mean that European and non-European perceptions and concepts are regarded as being of equal value. This by no means advocates a moral or legal relativism, in which every legal system is regarded as being equally legitimate. The mere fact that many legal systems in the Global South are shaped by coloniality already makes such an approach inappropriate. A situation could be avoided in which only European standards are applied to legal orders throughout the world.

EUROPE'S UNIVERSALISM HAS BLINDED US TO ALL KINDS OF POSSIBILITIES

Further analysis is required to determine what this would mean in detail for a new way of thinking about law. However, there is no doubt that a project such as the *Doing Business* report, even in its reformed version, is incompatible with a pluriversal world. After all, it is not acceptable to measure all legal systems against a single standard from the Global North that is biased specifically toward its legal systems and values. It is indefensible that a ranking of this type should be allowed to perpetuate hierarchies and entrench them even further. It is also inconceivable that legal systems should be prevented from development by being forced into participating in a global competition. Instead of universalist perspectives, there is hope that a truly pluralist understanding of the law in global society is emerging, in which alternative legal models are possible and sustainable laws do not founder in the face of aggressive competition.

Does that sound like a utopian dream? Perhaps. But that's surely also because European universalism has blinded us to all kinds of other possibilities. And we are blind because ultimately, comparative law has remained firmly entrenched in the European paradigm. The hope of those who promote decolonial comparative law is that those laws and rights which until now have seemed unattainable can be made possible. Without being ranked.

THE OCEANS ARE LOSING THEIR BALANCE



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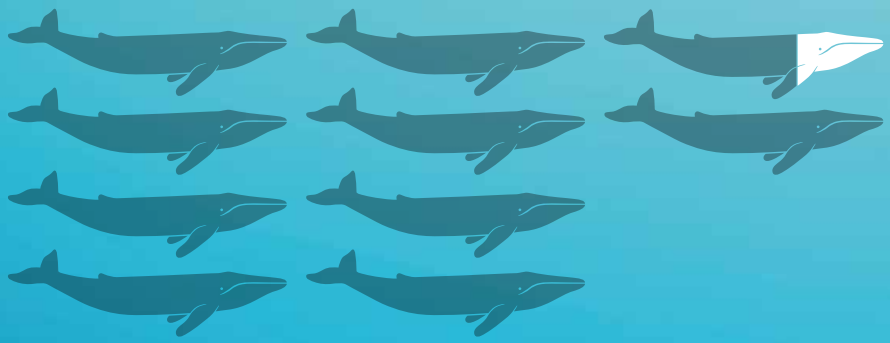
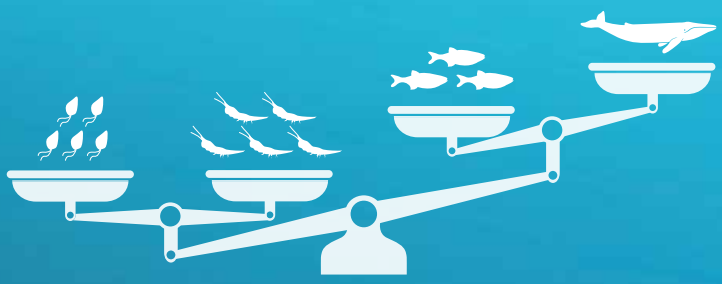


In 1850, the oceans were home to some 340,000 blue whales. Today, this figure has fallen to just 10,000 – a reduction of 97 percent.

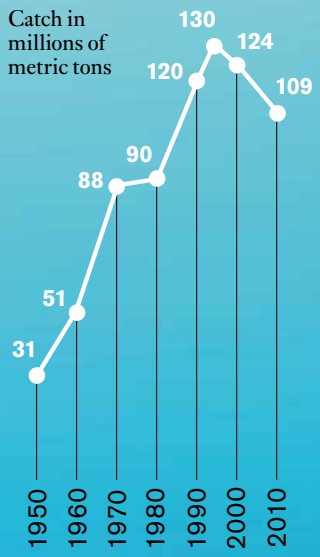
Before the onset of industrial fishing and whaling, life in the oceans was balanced. Each weight class of organism accounted for approximately the same biomass – a billion metric tons. This was because the smaller, lighter organisms were correspondingly more numerous. For example, when the industrial exploitation of the seas began in 1850, the mass of all fish in the oceans weighing between 10 and 100 kilograms was the same as the combined mass of marine plankton weighing between ten and 100 millionths of a gram. This equilibrium no longer exists today.

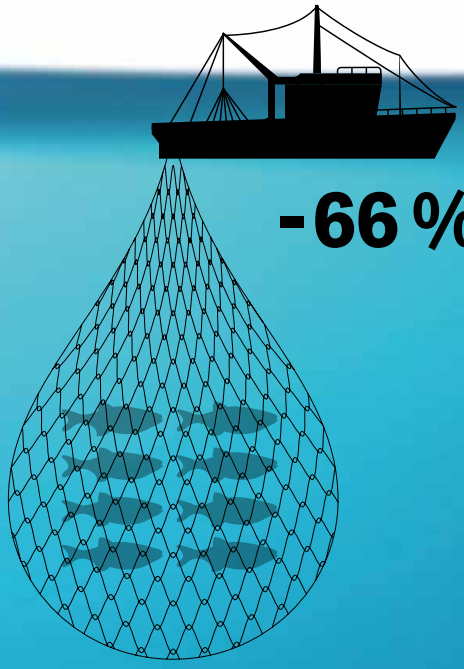
GRAPHIC: GCO, ILLUSTRATION: VALERIA DUMLER, ICONS: ISTOCK

TODAY

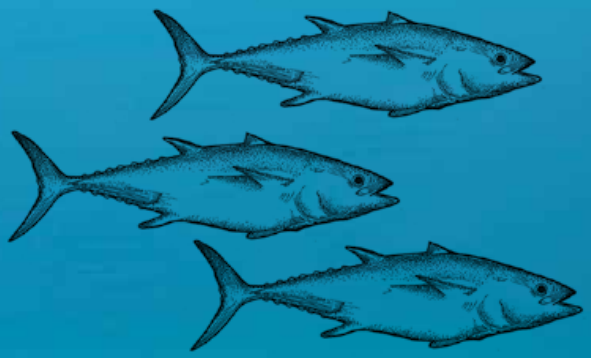


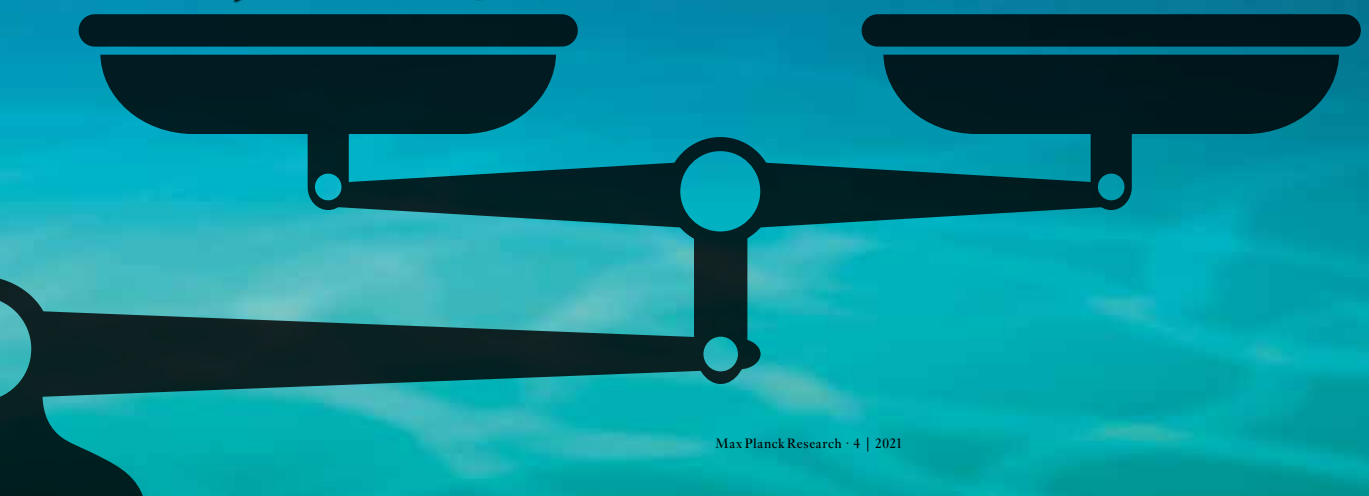
IN 1850





The seas are getting emptier: since 1850, there has been a 66 percent reduction in the mass of commercially exploitable fish (> 10 grams, 0 – 200 meters' depth). The fishing industry reached its peak in 1996 with an annual catch of 130 million metric tons of fish. Since then, catches have been decreasing steadily despite ever increasing efforts by the industry.





FOCUS

JUST LET IT ALL OUT!

PHOTO: PICTURE ALLIANCE / ASSOCIATED PRESS / CHARLES DHARAPAK

Statesmanlike: as the first black U.S. President, Barack Obama consciously adopted the style of his predecessors.

EMOTIONS, SPOT ON

TEXT: MECHTHILD ZIMMERMANN

According to traditional dogma, political decisions should be rational and sensible. Under no circumstances should they be emotional. Reality, however, has always looked somewhat different. The impact that feelings had and continue to have on political events and the rise and fall of leaders is the primary field of interest for Ute Frevert and her team at the Max Planck Institute for Human Development in Berlin. Intriguingly, their insights on the past shed light on current events.

Contrarian conduct: the first president of the United States, George Washington (to the left in the famous Lansdowne portrait), perpetuated the aristocratic tradition. The 45th president, Donald Trump, consciously broke with political conventions in order to mobilize voters who had until then felt excluded by the political elite.

IMAGE: GILBERT STUART/NATIONAL PORTRAIT GALLERY

After sixteen years as Chancellor, Angela Merkel will surely be remembered for one thing: her prosaic, rational style. Only very rarely did she allow herself to openly show her feelings. And yet in retrospect, it is precisely the times when she showed emotion that stand out. These include her elation when the German soccer team won the World Cup in 2014, her decision to open the borders to Syrian refugees during the refugee crisis of 2015, her urgent appeal to limit interpersonal contact in the corona crisis in order to protect people who were particularly at risk, and the fact that she was clearly moved when she hugged President Emmanuel Macron during a farewell visit to France. Why are these emotions so important? Is it not it enough to know what political goals the Chancellor is pursuing? Why do we care whether or not something makes her happy, or what moves her? One might argue that it is because we as humans are social beings, and are therefore interested in what other people feel. We are also not simply rational benefit maximizers, as ideal economic theory would have us believe. Quite the contrary, in fact: feelings play a part whenever people interact with each other – including in politics. It was Angela Merkel's combination of fact-based politics, a restrained demeanor without posturing and those rare but genuine emotional moments that won her the respect and trust of the population.

Win goodwill and secure power

To better understand the role that feelings play in politics, it is crucial to take a look at the past. For a long time, historical research has paid too little attention to the impact of emotions. It is in large part thanks to Ute Frevert, Director at the Max Planck Institute for Hu-

PHOTO: REUTERS/DOMINICK REUTER

man Development in Berlin, that this has changed in recent years. As Frevert, a historian, explains: "If you want to know why it is that people form societies, develop and pursue shared goals, why they separate off from each other again and go in different directions, or become enemies and cause harm to each other, you have to pay sufficient attention to feelings and the way in which they shape events." The research coming out of the center she leads shows that many aspects of historiography appear in a new light when emotions such as fear, anger and hatred, as well as hope, trust and empathy, are taken into account. It becomes possible to explain how the relationship between the people and those who govern them in the past has developed and changed.

Ute Frevert has examined the developments following the French Revolution. The momentous upheaval that took place in Paris in 1789 led to fundamental changes throughout Europe. The common people had entered the political stage by force. The deposition and execution of the French king and his wife caused consternation among the European monarchs, who feared for their safety and their continued right to rule. This is where what Ute Frevert defines as "the politics of feelings" comes into play: those in power take active steps to win over their subjects through emotions. "The politics of feelings was one way of securing power," Frevert says. "As the sociologist Max Weber put it, power requires 'compliance'; in other words, the consent of those who are subject to rule. This compliance can be brought about by the use of force. However, it works better when people submit voluntarily. To achieve this, the ruler needs to convince them, or better still, to engender feelings of trust, affection and perhaps even love."

Kings needed to court their citizens

One way was to demonstrate benign feelings toward the people by, for instance, public greetings, public announcements or personal appearances. Frevert has found numerous pieces of evidence. A letter written in 1789 by Luise, queen of Prussia, to her brother states: "I will do all I can to win and earn the love of my subjects, not through force but through civility, a courteous nature, gratitude [...]." For the aristocratic ladies and gentlemen, putting on a show of loving their people was by no means always enjoyable. Another of Luise's letters, written in 1794 to her husband, when she was still crown princess, mentioned an invitation to the heirs to the throne to have coffee and cake at the Potsdam marksman's guild: "Just think what delightful entertainment awaits us today," she writes sardonically. "What else are we to do? We are obliged, regardless of whether or not we wish it, to go through with it and perhaps be driven to madness, just to have the honor of paying court to our subjects." The rulers felt obliged to woo their own people.

This anecdote reveals another aspect of the politics of feelings that Ute Frevert emphasizes in her research: "Citizens are not simply passive recipients of emotional signals, and do not necessarily react with goodwill to the messages being sent from above. Rather, they have expectations, preferences, and perhaps even demands. And that's the risk that rulers bear: a ruler who makes an effort to win over the hearts of their subjects may fail in the process. Moreover, they send the message that they are in need of their subjects' love. In this way, they relinquish a portion of their power." This dilemma grew increasingly acute during the course of

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the 19th century when democratization and the participation of ordinary citizens in politics gained traction (although at that time, women were frequently still excluded). For this reason, the connection between the ruling dynasty and ordinary people needed to be fostered and kept alive. This was done by, for instance, organizing festivities to celebrate the king's birthday, which were extremely popular in the towns and local communities. Still, at that time, there was no such thing as "the people". During this period, the society of feudal estates, with its fixed division into the nobility, the clergy, the commoners and peasants, was in the process of being dissolved, making way for a civil class-based society. In this society, different groups, parties and social movements formed whose interests, in some cases, diverged widely. This was probably one of the reasons for the concept of nationalism spreading so rapidly and successfully during this period. It was a unifying force, but at the same time, it also changed the role of the ruling elites. The kings, queens and emperors became national identification figures and the highest representatives of the nation, and the expectations of their citizens increased accordingly.

Autographed cards from the emperor

Ute Frevert has revealed that during this period, there was a growing desire among the populace to get close to the king or emperor, to see them and perhaps even shake their hands. As numerous requests for autographs sent to Wilhelm II show, signed photographs of the German Kaiser were extremely popular at the turn of the 19th to the 20th century. Men such as the members of the Rhenish veterans associations formed a cordon to honor the Kaiser whenever he was traveling through their region. However, they were also motivated by a desire to be seen by him, as one contemporary source describes: "[...] a look from his dear eye was thought to be beneficial, they wanted to feel that his eye was still there for them." The disappointment and sense of outrage was all the greater, therefore, when in 1906, the car bearing Wilhelm II simply sped past the men waiting for him in the Rhineland.

Even so, as Frevert shows, the love and devotion of ordinary people were not automatically directed towards the Kaiser – or at least, not towards him alone. Some good indications of this include pictures of politicians that were hung in German living rooms. "You would find portraits of Otto von Bismarck and Queen Luise, but not necessarily of the Kaiser himself," Frevert explains. "There were also Social Democrats who displayed images of their heroes from the labor movement, such as Ferdinand Lassalle or August Bebel, next to a picture of the monarch." Some of the first democratically elected rulers enjoyed a similar degree of admiration as their aristocratic predecessors, for instance the first president of the United States of America, George Washington. Kerstin Maria Pahl, a researcher in Ute Frevert's team, has examined Washington and his times more closely. "At that time, Washington was a very controversial figure," she explains. "There were disputes over how much power the central government should hold, and how much should be divested to the individual states – something that is partly responsible for the political discord in the U.S. today." Even so, says Pahl, painted or printed copies of George Washington's portrait were broadly popular

IMAGE: FRIEDRICH GEORG WEITSCH

PHOTO: PICTURE ALLIANCE / DPA / MARCUS BRANDT

Reservation and euphoria: during the 2000s, it was common for high-ranking politicians to freely express their delight at soccer matches – as seen here with German Federal Chancellor Merkel and President Gauck at the 2014 World Cup in Brazil. For Queen Luise and Friedrich Wilhelm II of Prussia at the end of the 18th century, such wild displays of emotion would have been unthinkable.

during his time in office. "They were put up in private homes, inns and public buildings, and people collected them in albums. At that time, there was a close emotional bond with the new state, as is reflected in many contemporary reports from the founding years of the U.S. These powerful feelings were also directed towards the president."

Outbursts of anger versus level heads

Kerstin Maria Pahl, who holds a PhD in history of art and visual culture, researches, among others, feelings as embodied by rulers in their portraits. The Lansdowne Portrait, one of the most famous paintings of George Washington, shows the American president in the tradition of European kings, displaying an expression of decisive boldness, while also exuding calm and level-headedness. The picture reveals much about the contemporary ideals of how a head of state should behave and what feelings he should express. "One of the most important standards at that time can be very aptly summarized as 'composure'. Composure is an expression of calmness of spirit, beneath which there is deep emotionality, even a passion that is, however, externalized to a very moderate degree only." Washington's composed demeanor was emulated by many at the time, including many of his successors.

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The 45th U.S. president ostentatiously broke with this tradition. During his time in office, Donald Trump became notorious for his outbursts of anger and hotheaded rhetoric, as well as his more general (arguably) impulsive behavior. In Kerstin Maria Pahl's view, this was intentional. In order to understand the break with tradition and the reasons for its success it is necessary to see that, within each society and its institutions, there exist a large number of unwritten rules. They determine which feelings individuals are allowed to display in any given context, as well as the manner in which they are permitted to be expressed. Someone giving a speech in parliament will show their emotions differently than they would at home with their family, and in yet another way when they are visiting a retirement home. These conventions are constantly in flux. Pahl cites politics and soccer as an example. At the end of the 1990s, soccer had a grubby, lower-class image. It was not until the World Cup championship took place in Germany in 2006 that intellectuals began talking about soccer in public. Since then, high-ranking politicians have also been able to freely express their elation in the stadium, as did Chancellor Merkel and Federal President Gauck in 2014 at the Soccer World Cup in Brazil. Incidentally, this was one of the very few occasions in which the two were seen together in any one place. This usually only happened at events held in the German parliament to commemorate the victims of National Socialism.

SUMMARY

After the French Revolution, monarchs began to demonstrate positive feelings to their subjects in order to win recognition and secure their power.

Today, politicians are also subject to expectations as to which emotions they are allowed to express in public in order to appear "statesmanlike". When he was U.S. president, Donald Trump consciously broke this rule.

The more people participate in politics, the more diverse the feelings that come up against each other will be. Emotional management will become an important skill that politicians will need to learn.

Feeling conventions can change either gradually or through conscious disruption. "Sometimes, there is a tipping point. Old rules suddenly look rigid, even mummified," Pahl adds. "When someone turns up, consciously announcing: 'I don't care any more how things used to be done; I'm going to do them my own way', it can be very seductive." Doing away with conventions can give the impression of being trailblazing, revolutionary and courageous – provided the time is right. Maybe it was the case that, during the U.S. presidential race in 2016, Donald Trump was simply in the right place, at the right time. With his style of behavior, he succeeded in mobilizing people who felt excluded and no longer represented by the attitudes and language of the political elite.

It is notable that in relation to his COVID pandemic policy, Trump is often described as "cold-hearted" or "unfeeling" by domestic and international media. Kerstin Maria Pahl has analyzed this characterization from a historical perspective. In her research, she shows that already during the Enlightenment in the 18th century, a lack of feeling was considered a negative attribute. Adam Smith, the Scottish moral philosopher and founder of classical national economics, best-known today for his theory of the invisible hand of the market, saw empathy as the basis for social cohesion. A lack of feeling, on the other hand, meant social exclusion because it denied that all people were similar. "Even in the past, accusing someone of being cold-hearted was often an attack, meant to discredit the other and to distance oneself from them," Pahl explains. "However, some forms of a lack of emotional expression or even indifference can have a more positive image – it can mean being unbiased, objective or simply very cool."

Thoughts and feelings are inseparable

Ultimately, expressions of feeling, and the way they are perceived and interpreted, are often ambiguous. The norms that underly them are constantly changing. One thing, however, is clear: feelings are essential to politics. They cannot be separated from rational thought or decision-making – not least, as Ute Frevert emphasizes, because thoughts and feelings are closely interconnected in our human brains.

History has shown that the more that people are able to participate in politics, the greater the number of emotions that come into play, and the more diverse they become. Frevert illustrates this point with a current example: "If you are standing in a town square – an image that Olaf Scholz was fond of using during the election campaign – and there are some people whistling from one corner and others cheering from another, then you have to respond, but without pounding your fist on the table or getting into a shouting match yourself. This emotional management gets increasingly difficult to the same degree that politics becomes a matter for the masses." In the future, politicians will probably be measured against how they deal with this situation – particularly the new Chancellor, Olaf Scholz.

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

IN THE WEB OF FEAR

TEXT: LAURA BECK

PHOTO: BIOSPHOTO / FOTOFINDER.COM

In reality, this Australian peacock spider is only five millimeters long. But even this tiny creature can trigger fear in arachnophobes. Peacock spiders have up to eight eyes; the frontal pair are especially well developed and can even see colors. The spider uses them to focus on its prey and choose the right mate.

People who run away screaming from tiny spiders are often ridiculed by their peers. But a pronounced fear of spiders is anything but funny if you're the person affected. Florian Binder, a member of Victor Spoormaker's research group at the Max Planck Institute of Psychiatry in Munich, is using virtual reality to gain a better understanding of anxiety disorders and to develop a standard therapy. The author tried it out on herself to find out how it works.

A virtual reality headset transports Florian Binder's colleague Dorothee Pöhlchen into another world. Her movements are measured by acceleration sensors attached to her body, and then a computer translates them into movements of her virtual body.

PHOTOS: STEFANIE AUMILLER FOR MPG

"In the future, anxiety sufferers could receive fully automated treatment by entering virtual reality in their own homes."

FLORIAN BINDER

You usually don't have to make a lot of excuses for being afraid of spiders. After all, almost everyone is a little bit nervous about these eight-legged creepy-crawlies. Not pleasant, maybe rather annoying – but not that bad, you might think.

But what about when this unease becomes downright panic? Like it does with me? When I'd rather sleep on the couch than walk past a spider into the bedroom? When the sight of a spider drives practically every other thought out of my head? That's when fear of spiders, also known as arachnophobia, becomes a burden. And not just that – it can even put me in danger, for example if a spider lowers itself from the sun visor of my car and I am so overcome by panic that I can only just manage to pull over to the side of the road. This phobia causes accidents every year, some of them serious. Arachnophobia can therefore become a real problem for those affected.

SUMMARY

Phobias are often treated by exposing the patient to the object or situation they are afraid of.

However, depending on the type of phobia, this can be stressful or even dangerous. But in virtual environments, the behavior and physical reactions of persons suffering from anxiety can be recorded by standardized means.

In the future, virtual reality could be another part of the treatment plan for phobia patients.

Florian Binder is a doctoral researcher in the group led by Victor Spoormaker at the Max Planck Institute of Psychiatry. Although the reactions of arachnophobes may seem excessive to outsiders, he doesn't dismiss the phobia as irrational. Instead, he asks himself whether a behavior is adaptive, i.e. whether it could be useful for survival. After all, people have good reason to be afraid of spiders. A bite from a *Phoneutria nigriventer*, for example – commonly known as a Brazilian wandering spider – is so poisonous that it can kill a human adult. When the Voluntary Fire Department in Lauterbach in the German federal state of Hesse were called out to deal with one at the beginning of 2021, they could not be blamed for not daring to catch the spider alive and finishing it off with a fire extinguisher instead.

Measuring an emotion

Anxiety disorders, which include phobias, are the most common type of psychiatric disorder – around a quarter of the population will develop an anxiety disorder at some time in their lives. The most common of these are specific phobias, i.e. the fear of a specific object or situation. Spoormaker's team aims to understand phobias better and to make their symptoms measurable. Fear of spiders is particularly suitable as a research object, since it is the most common phobia in Germany. Moreover, it is directed at a specific object. Women are affected five times as often as men.

Florian Binder is testing people with and without arachnophobia for his study. His experiment is a pioneering project: for the first time, researchers are studying the behavior and movements of phobia sufferers who are completely immersed in virtual reality. This enables Binder – who is an information scientist, mathematician and psychologist – to program environments that may be only virtual but that trigger real emotions, like fear of spiders or heights. And he can then measure these feelings. Measuring anxiety – how is this possible? The people taking part in the study wear a virtual reality headset. This enables them to see a virtual environment like that in a 3D movie theater – with the difference that they are right in the middle of the virtual world. Sensors attached to the body record their movements and transfer them into this virtual reality landscape. When wearing the headset, the test subjects see a representation of their body and can control their virtual arms and legs by moving their real limbs. These visual impressions are so strong that participants perceive the virtual environment as real.

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The test subjects' reactions then serve as a measure of what they are feeling: the virtual reality headset measures their pupil sizes and tracks their eye movements, while electrodes record their heartbeat. Their movements are logged at the same time. The researchers put all these data together and can then use them, for example, to analyze the avoidance behavior typical of anxiety sufferers. This has enabled them to obtain objective data about anxiety for the first time. In contrast, our previous knowledge of psychological distress and avoidance behaviors in phobia sufferers came from self-assessments. However, subjective statements like these are difficult to compare, since each respondent interprets the questions differently.

Confrontation as therapy

Thus the therapies available today are highly individualized and difficult to standardize. Arachnophobia is treated using exposure therapy, which involves exposing the patient to the object of their fear, initially by showing them pictures and videos of spiders, such as tarantulas. Many people with anxiety disorders deal with their fear by avoiding the trigger. However, this does not solve the sufferer's problem – on the contrary, it can make the phobia worse. Patients therefore need to learn to conquer their fear to such an extent that they can gradually approach a real spider and even touch it. However, tarantulas aren't often on hand for therapy sessions. Moreover, a lot of patients find this type of therapy extremely stressful. That's why it is only rarely used.

I find out how upsetting a confrontation with the object of my fear can be when I test the University of Basel's Phobys app in preparation for Binder's experiment. A study has shown that people feel less afraid of spiders after they have practiced with Phobys. The program uses "augmented reality" – in other words, it merges the real and virtual worlds. It enables me to project a virtual spider into my real world using my smartphone. I then have to cope with the spider's presence in situations at various "levels of difficulty". However, this type of confrontation is too much for me. As soon as the virtual spider in my cellphone is sitting on the dining room table, my pulse accelerates and my hands start to shake. And when the spider suddenly appears to jump out of my phone, I hurl it across the room in sheer fright. (The app has since modified the test; you can now choose between "mild" and "terrifying".)

This is the state I'm in when I meet Florian Binder at the Max Planck Institute. But he laughs and says, "Don't worry, you don't have to be afraid of shocks in our virtual world." He places the virtual reality headset over my face, and we are ready to start. I am standing in a tiled room. A viewing window descends in the wall opposite me, and I see the spider – far away under a glass bell. I am asked to describe how unpleasant I find the sight of it. Then I am shown a turtle. These two animals will be my companions for the next half hour. The world around me changes; I am now standing hip-deep in water. The pool I am standing in is edged with planks of wood. The spider is on my left, the turtle on my right. My task now is to catch fish and put them into a bucket. How close do I fish to the spider, and how close to the turtle? I prefer to start fishing on the right and keep a close eye on the spider on the other side.

My surroundings change again. Now I'm in a large office, where my task is to take books from a counter and put them on a bookshelf. To do this, I have to walk past a table – the spider is sitting to the left of it, the turtle to the right. I prefer to pass it on the right. But when I go back for the next book, the spider and the turtle have changed places. Although the route past the turtle is longer, I now choose to pass the table on the left. I'm now back in the first room. In front of me on a small table: the spider. After a countdown, I have to walk over – and touch it. I start walking. The spider is black and hairy and crawling around a little. I stretch out my real hand. Through my headset, I see how my virtual hand approaches the spider. At first, I can't bring myself to touch it. My fear gradually mounts. Inside, I'm cheering myself on and laughing at myself. When I finally manage to touch it, the spider recoils in shock. I did it! I am so relieved.

My excursion into the virtual world took a good half hour. Florian Binder removes my headset. It takes a moment for me to remember where I am. Afterwards, Florian Binder explains the data he has obtained from other people taking part in the study. These data largely conform to my own perceptions and behavior. When the test subjects are asked to touch the spider, they initially approach it quickly but hesitate when they are right in front of it. And just like me,

FEAR OF NEEDLES

People with a phobia of needles refuse to be vaccinated or avoid going to the doctor in case they have to give a blood sample. This avoidance behavior can cause immense damage to the patient's health and may be an underestimated reason why some people do not want to be vaccinated against COVID-19. Angelika Erhardt and her team at the Max Planck Institute of Psychiatry offer a treatment program for people who are scared of needles. It is designed to help people tolerate having blood drawn with a syringe. During the confrontation therapy, which lasts for six sessions, the participants initially learn about the causes of fear. They are then shown images of needles and later hold a syringe in their hand. At the end of the therapy, they have blood drawn with a needle and syringe. The patients are thus required to face up to their fear and break through their avoidance behaviors. The therapy is very successful: afterwards, two out of every three patients find that they are less afraid of being pricked or injected with a needle.

people with arachnophobia maintain a greater distance from spiders than non-arachnophobes, even in virtual reality. They also look at the spider more often and are less likely to turn their back on it. They prefer to fish closer to the turtle than the spider, deliberately make detours around it in the virtual office, and need a longer period of time to touch it. "One test subject needed three minutes before she could bring herself to touch the spider. But she did it in the end – just like everyone else," says Binder.

Overcoming fear

Afterwards, there is a feeling of relief at having overcome the fear. This is an important experience for the brain, since it learns that positive feelings come from conquering fear and not from avoiding it. In real life, however, phobia sufferers don't ever get to this point because they invariably avoid confrontation. Virtual reality therefore enables researchers to collect objective data about the behavior of people with anxiety disorders under standardized conditions. During the next stage, Florian Binder wants to investigate whether a perceived loss of control influences the way people behave towards the spider. This postulation makes sense, since anxiety patients are generally likely to feel less in control, i.e. they believe that events around them are less dependent on their own behavior.

Insights like these could also be used to treat phobias. Patients could be given more control over the spider's behavior in the virtual world, thus making subsequent confrontations in the real world more pleasant – for example, by demonstrating in virtual reality how spiders react to people. Spoormaker's team also aims to use the software to reduce avoidance behavior. Virtual reality therapy could determine the patient's level of anxiety and adjust the tasks accordingly. Psychiatrists and psychotherapists would be able to measure the patient's progress directly and use the results to decide on the next steps in their treatment. The framework conditions could also be changed as needed: the spider, for example, could be replaced with other objects of fear. It could even be used to treat social phobias, such as claustrophobia. The patient could then stand in a virtual subway train surrounded by passengers, for instance; the number of passengers could then be increased or decreased and the direction in which they are looking changed, depending on how severe the phobia is.

"The day might come when virtual reality sets are available for self-treatment at home," Spoormaker tells me. Then arachnophobes would no longer have to touch a real spider in order to learn how to overcome their fear. And spiders would no longer stop me from going to bed.

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

A tireless training partner: Katherine J. Kuchenbecker and her team have converted Baxter, an industrial robot, into an assistant that can play games with people that involve movement, for example in a rehabilitation context.

PHOTO: AXEL GRIESCH

A ROBOT WITH A GENTLE TOUCH

TEXT: ANDREAS KNEBL

In order to support people in therapy or in everyday life in the future, machines will have to be capable of feeling and gently touching their human counterparts. Katherine J. Kuchenbecker and her team at the Max Planck Institute for Intelligent Systems in Stuttgart are currently developing the technology required for this objective and are already testing sensitive robots for initial applications.

Warm, secure, safe. That's how a hug should feel. And that's how it actually feels when HuggieBot's strong arms close around you and you're pressed against its warm, broad chest. The flagship robot from the Haptic Intelligence Department at the Max Planck Institute for Intelligent Systems in Stuttgart effortlessly embraces its human counterpart. Getting Huggie Bot to this point, however, has been a long journey for Katherine J. Kuchenbecker and her team. Teaching machines to feel, that is, translating the sense of touch into technology, is challenging, and this research field is still new. Kuchenbecker's goal is to better understand haptic interactions and thus improve the way in which humans and machines interact with each other and with the objects around them. Here, haptic interactions refer to contacts with robots that involve tactile perception. "Ultimately, I want to create interactive robotic systems that can really help people," Kuchenbecker says. She is particularly focused on haptic applications for robots that provide physical or social support to people in need.

Controlled hugging

HuggieBot enables the researchers to study such tactile human-robot interactions. Taking the hug as an example, the researchers can test which conditions a robot has to fulfill so that people enjoy physically interacting with it. While robotic nurses will have to deal with other, often more complex and intimate physical interactions, HuggieBot and its hugs are harmless. Nevertheless, a hug requires the robot to have a lot of sensitivity. As hugs are pleasant for most people, it's not difficult to recruit study participants to test the robot. Alexis E. Block, the lead researcher on the project, and Kuchenbecker have set themselves the goal of making HuggieBot's hugs feel just as reassuring, consoling, and comforting as a hug from a human. In the future, haptically intelligent robots could help close the gap between the virtual and physical worlds. After all, an increasing number of our social encounters take place in the virtual realm. Robots with a tactile sense could allow people who are physically far apart to literally get in touch with each other.

In order to develop HuggieBot, Kuchenbecker and Block first tested which physical properties a robot should have, so that people experience its hugs as natural and pleasant. They found it should be soft, warm, and about the same size as a human. It should also visually perceive the person interacting with it and haptically adapt its hug to the person's size and posture. Finally, the robot must recognize when to end the hug. Since then, the researchers have developed different versions of HuggieBot, such as HuggieBot 2.0, which they designed from scratch after first having worked with a slightly modified and reprogrammed commercial robot. HuggieBot 2.0 consists of a central frame, a torso that inflates like a beach ball, two industrial robot arms, and a computer screen as a head. It is dressed in a grey sweatshirt and a long purple skirt. When it recognizes a person in its environment with the help of the camera located above its face screen, it asks: "Can I have a hug, please?" and a friendly face appears on its screen. If the person then approaches, HuggieBot prepares for a hug and assesses the person's size. As soon as the person is within arm's reach, it closes its arms and presses them against its chest, which is soft and warm, because the robot's specially developed chest is inflated with air and equipped with a heating pad. Sensors and a control system for the arms ensure that the pressure with which HuggieBot embraces the person corresponds to a warm, tight hug. The robot also senses if the person returns the hug through a pressure sensor inside the rear chamber of the inflated chest. When the person releases this pressure or leans slightly back against HuggieBot's arms to end the hug, the robot opens its arms. Therefore, there is no unpleasant feeling of an involuntarily long hug and the interaction with the robot is perceived as being safe. Several studies with human participants have demonstrated how well HuggieBot's haptic elements and control system work. In one study, the participants each exchanged eight hugs with the robot, with different functions switched on or off. The results of the subsequent surveys clearly showed that haptic perception plays a major role: when the robot adapts to their size and reactively releases, the participants found the hugs more pleasant and rated the interaction more positively.

"I want to create interactive robotic systems that can really help people."

KATHERINE J. KUCHENBECKER

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PHOTO: AXEL GRIESCH

A machine in costume: HuggieBot 2.0 hugs people and reacts to their movements. It consists of a frame, an inflatable torso fitted with a heating pad and two industrial robot arms. Its head is a computer screen. It also wears clothes, so it more closely resembles a human being.

PHOTO: ALEXIS BLOCK

Feels good: thanks to its air-filled and heated torso, HuggieBot is soft and warm. That's something that Alexis Block, who played a key role in the robot's development, also likes about it.

SUMMARY

Researchers at the Max Planck Institute for Intelligent Systems are investigating the requirements robots would have to fulfill for people to experience their touch as pleasant and helpful in therapeutic or social interactions. HuggieBot, a robot that hugs people, is one of the systems the researchers use to do this.

In addition to HuggieBot, the researchers are developing and optimizing other haptic technical systems on the basis of relevant studies: Hera, for example, can be used to help teach autistic children to touch people in an appropriate manner. Max can provide training support for older adults or patients in rehabilitation.

The use of robots for therapeutic or social tasks raises ethical and data protection issues. It is not for scientists to decide the purposes for which they will ultimately be used.

In addition to HuggieBot, Kuchenbecker's team is working on numerous projects that require a sense of touch. For example, her team members are researching technical ways to perceive and transmit touch and are working on a teleoperated construction robot, as well as on a robotic hand that grasps objects and classifies them based on their tactile properties. The team is furthermore developing other robots that are based on commercial platforms, but feature additional haptic capabilities to assist humans: Hera , which is designed to support therapy for children with autism, and Max, which is intended to exercise with older adults or patients undergoing rehabilitation. The wide-ranging research in Kuchenbecker's Department has its reasons: from her days as a varsity volleyball player at Stanford University, Kuchenbecker has internalized that success is a team effort that benefits from diverse skillsets and perspectives. That's where she gets both her motivational leadership style and her willingness to allow researchers in her Department to pursue their own ideas. The success of this approach can also be measured by the fact that many of Kuchenbecker's team members go on to land coveted fellowships or academic positions.

The focus of Kuchenbecker's research is also influenced by her family background. As the daughter of a surgeon and a psychologist, she chose to study mechanical engineering to bring technology and human care together. In her doctoral thesis at Stanford University, for example, Kuchenbecker looked at how teleoperated surgical robots could be improved by adding haptic feedback to their previously purely visual controls. Since then, she has developed much broader research questions: how can tactile information be technically translated and reproduced? And how can this additional sensory information help improve the interplay between humans and technology?

Until now, there has been a significant imbalance in engineering for the human senses. While humans have long been able to record and reproduce audio-visual information, and with ever increasing finesse, comparable technology for our sense of touch is missing. For haptic stimuli, there is still no equivalent to a camera or a microphone, nor to a screen or a loudspeaker. Consequently, computers and even smartphones with touch screens are still unable to allow us to physically feel digital objects. Similarly, most machines, and thus robots, are clumsy when it comes to touching objects or people. This is because, apart from cameras and simple force sensors, there is as yet no commercial piece of technology available to robots that allows them to gather information about their physical interactions. Thus, it is difficult for a robot to determine whether an object is hard and smooth or soft and rough, for example. In the same way, it is virtually impossible for a conventional robot to determine whether and, more importantly, how a human is touching it. Yet it is precisely this physical interaction between humans and robots that is crucial for many applications.

Supporting therapy

For that reason, the Hera project brings together several research strands from the Haptic Intelligence Department. Hera stands for Haptic Empathetic Robot Animal; Rachael Bevill Burns, the doctoral student leading the project, is developing it as an educational tool for children with autism. These children often have problems dealing with social touch. Usually, humans use social touch to request attention, communicate a need, or express a feeling. But many children with autism either reject touch or, at the other extreme, seek touch but have no sense for which contact is appropriate. Thus, they may touch another person too forcefully, too frequently, or in the wrong places. Currently, children with autism commonly learn how to safely handle touch from an occupational therapist. Burns and Kuchenbecker believe that haptically intelligent robots like Hera can expand the current possibilities for therapy and care. Recently, the team interviewed numerous experienced therapists and caregivers to learn what contribution such robots could make and what characteristics they should have.

Based on the results of those interviews, the Max Planck researchers are now developing Hera, which is based on the small humanoid robot Nao. For its role as a therapy robot animal, they dressed it in a koala costume. Underneath its furry exterior, Hera will wear tactile sensors all over its body to record the physical interaction between the child and the robot. As confirmed by the experienced therapists, this application requires sensors that are soft and can reliably detect both gentle and firm touches all over the robot's many curved surfaces. However, such sensors are not commercially available. Kuchenbecker's team has therefore been developing fabric-based sensor modules that fulfill these requirements. A single module consists of several lay-

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ers of fabric with high and low electrical conductivity. When the sensor module is touched, the layers are pressed together and the electrical resistance between the two outer layers drops. Depending on how often, by how much, and at what frequency the resistance drops, an algorithm classifies the touches as, for example, poking, tickling, hitting, or squeezing. "While commercial robots often feature force sensors only in the wrists, Hera will be able to sense and respond to touches all over its body thanks to our fabric-based sensors," says Kuchenbecker. This good sense of touch will allow Hera to determine whether the child's social touches are appropriate, for example, whether the child is gripping the robot too hard or touching it in a location most people would consider inappropriate, such as the face. The robot will respond to such a transgression just as defensively or disapprovingly as a human or an animal would, but it would also signal its approval if the child learns to touch it in a more appropriate manner. Burns and Kuchenbecker envision that a therapist could use a robot like Hera to help children safely learn how to touch others.

Another interactive robot system could also be used as a training aid, this time for older people or for patients in rehabilitation, e.g. following an operation or a stroke. Max, the Motivational Assistive eXercise coach, tirelessly plays lightweight exercise games with its human partner. It is based on Baxter, a robot modeled after a human upper-body that was, originally designed for the manufacturing industry. One game requires repeatedly patting the robot's hands to wake it up. Other games require the human players to remember a long pattern of hand claps, stretch their arms out wide, or hold yoga-like poses as demonstrated by Max. Unlike HuggieBot and Hera, Max has no custom hardware, so its haptic perception is limited to the accelerometers that are built into its two grippers. Kuchenbecker's previous doctoral student, Naomi Fitter, had the idea of covering those grippers with soft boxing pads, and she programmed the robot to be highly sensitive to the contacts that occur during hand-clapping games. Even this simple form of tactile sensing positively impressed both younger and older adults who came into the laboratory to test Max as part of a study. One of the things they were asked to do was to evaluate the games in which they touched the robot and those in which they only trained with it at a distance. The researchers discovered that the participants found the games that involved touching much more entertaining.

The robots from Kuchenbecker's lab are examples of the progress that has been made in the field of haptics

The robots with a sense of touch from Kuchenbecker's lab are a good example of the progress that haptics has made and the possibilities that this technology offers for the interaction between humans and machines. When it comes to the digitalization of social and

PHOTO: WOLFRAM SCHEIBLE

A furry assistant: Rachael Burns and Katherine Kuchenbecker are developing the robotic system Hera based on the commercially available robot Nao. They equip it with touch sensors all over its body and put it in a koala bear costume. They are programming it to help teach autistic children to touch people in an appropriate manner.

health-related services, however, questions of data protection and ethics arise alongside questions of technical feasibility. Hera, for example, could collect countless data about the behavior of its human partners while acting as a companion for children with autism. To whom should this data be accessible? To the parents, the therapist, the health insurance company? And will the child be informed that its new friend is sharing all this data? Similar questions also arise in the case of nursing robots. The German Ethics Council has taken a clear stance here and recommends that the use of robotics should be guided by the goals of good care and assistance. The individuality of the person needing care must be respected and, for example, special attention should be paid to self-determination and privacy. In addition, it is important that robots do not replace human care and thereby further reduce social contacts and human interactions. Rather, the robot should only be used as a supplement for the benefit of both the caregiver and the care recipient. In all of these considerations, it is also important to take the costs into account and weigh alternatives. After all, robots that treat people sensitively will be expensive – at least initially – and will be able to perform only limited tasks. For Kuchenbecker, it is nevertheless clear that such systems have the potential to help people, since they inhabit our physical world and can interact with us in highly familiar ways. Her research is currently pushing the boundaries of what is possible by developing more and more intelligent haptic systems. Everything else we will have to negotiate as a society.

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

Originally from Iran, physicist Hanieh Fattahi was attracted to Germany because it offered many more research opportunities and greater freedoms in everyday life. Of course, once she arrived, she had to come to terms with the cultural differences. Nevertheless, she has since established her own research group at the Max Planck Institute for the Science of Light in Erlangen, Germany, where extremely short laser pulses are used to study biological microscopy. And with her talent for motivating people, Hanieh Fattahi is also active in climate protection.

TEXT: KLAUS JACOB

After completing her master's degree thirteen years ago, Hanieh Fattahi left Iran to come to Germany. To give us an impression of what everyday life was like for her as a student in Iran, she reaches for a scarf. It's not a hijab, but it does the job. With a practiced hand, she wraps the fabric around her head. The face was allowed to remain uncovered, but no hair was allowed to show. This was always checked by the guardians of public morals posted at the entrance to the university. Another restriction that impeded her studies is even more incomprehensible to Germans: Fattahi was not permitted to ride a bicycle in Iran; she could only look on with envy as her male fellow students pedaled past. When she did arrive on a bicycle one time at the university, the guards chased after her in their car and forced her to dismount.

Fattahi does not recount these incidents reproachfully, but rather full of self-confidence and humor as interesting anecdotes. And in Germany, she has built her career in a profession where women are still scarce even in this country: physics. And she pursues her work with great enthusiasm – which she considers an essential personal trait. It is also important to her to be able to explain her field so that anyone can understand it. This is hardly the norm in the German scientific community. For the last two years, Hanieh Fattahi has been working as a Research Group Leader at the Max Planck Institute for the Science of Light in Erlangen, where she wields femtosecond lasers, and also lectures at the Friedrich-Alexander University of Erlangen-Nuremberg.

One of Fattahi's high school teachers played a crucial role in kindling her passion for physics. Not only could her physics instructor explain the subject matter clearly and with enthusiasm, she was also a role model as a human being. Fashion played no small part here. While the students were required to wear a uniform that was so dark blue, it was nearly black, this teacher always wore colorful clothing. Clothing is more important in Iran than in Germany, as it can also represent a veiled criticism of the system.

The fact that Hanieh Fattahi went on to university after finishing high school is in some ways thanks to her parents, who encouraged her and were able to finance her education. Her two siblings also went to university – her older brother studied, economics and management, and her younger sister majored in genetics. Both still live in Iran. However, with physics, Fattahi chose a field in which it is nearly impossible to build a career in Iran; many can't even find a job after graduation. That may be the reason why this discipline is not very highly regarded by men in Iran, who – unlike in Germany – are by no means in the majority among college students. Furthermore, the country simply has no funds with which to purchase modern research equipment. The situation is not improved by the sanctions that the U.S. has imposed. The academic career of experimental physicists usually comes to an end after a master's degree, since doctoral research in this field is nearly impossible without expensive equipment. This was also what induced Hanieh Fattahi to move to Germany in 2008.

In her master's thesis, she investigated the effects of laser radiation on collagen bundles in the skin. Working with lasers was the focus of her interest even

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VISIT TO

HANIEH FATTAHI

PHOTO: AXEL GRIESCH

In sharp focus: Hanieh Fattahi and her team want to develop light microscopes that can photograph samples at high resolution without fluorescent markers and use them to observe processes in nerve cells.

then, and it has remained so to this day. The move to Germany was a real leap into the unknown, as Fattahi could not speak German when she first arrived. It was especially difficult for her to learn the language, as it has no similarities to her native language of Farsi. But still she managed, in part because English is the common language at the Max Planck Institute of Quantum Optics in Munich, where she conducted her research. Also, she was still able to converse in her native language with her husband, whom she had met at university in Iran and who came to Germany with her. Of course she also gradually learned German, if only to be able to run errands or shop for groceries. However, she still prefers to communicate in English.

Copping with the foreign culture also wasn't easy. Iran is characterized by a very complex form of etiquette known as "taarof". This basically means that no one is allowed to say directly what they really want. For example, guests must always say, "No," when asked if they would like a second helping of food – even if they are hungry. However, the host correctly interprets this doublespeak and takes the no for a yes. Fattahi explains how difficult it was for her to adapt in Germany with an anecdote: "We were visiting a friend's parents, and the mother asked if I would like more tea. I looked helplessly at my husband, because I simply didn't know how I should answer that."

She wrote her doctoral thesis in Munich on the subject of "Third-generation femtosecond laser technology." These lasers emit ultra-short pulses of light that last only 10^{-15} seconds, or one millionth of one billionth of a second. This dimension can be explained with the help of an analogy: if one second corresponded to the distance from the Earth to the Sun, a femtosecond would be roughly 0.15 millimeters long. This laser ultimately became Fattahi's ticket to an academic career. Once she had her doctorate, she was accepted into the Minerva Fast Track Program, an equal opportunity scholarship from the Max Planck Society that enables outstanding female scientists to live and work abroad and is intended to pave the way to forming one's own research group. Fattahi had initially wanted to go to continue her studies at Harvard University in the U.S. But that proved to be rather problematic. She was plagued by politics: "Donald Trump has had a big impact on my life," she says with amusement.

For it was at just that time that he came to power. Fattahi already had her visit to the U.S. planned and had worked out all the details with her advising professor at Harvard when Trump's "Muslim Ban," prohibited people from Muslim countries from entering the U.S. Due to its controversial nuclear program, Iran topped the list of sanctioned countries. Fattahi received an email from the States, informing her that her stay had been postponed. She had to wait a year and a half for a visa. Although she was permitted to briefly enter the U.S. for conferences, she could not remain for a period of months. And that decree was upheld, even though Fattahi has no connection with the Islamic religion, saying, "I don't believe in anyone." Nor did it help that she had since acquired German citizenship. In fact, Fattahi now feels herself to be part of the local society; she celebrates German holidays and cheers on German sports teams. However, she still has an Iranian passport and is therefore persona non grata in the U.S. So she went to England for a research residency at the University of Oxford instead. And when Fattahi was finally allowed to travel to the U.S., she stayed for only a few months: in 2020, she received the opportunity to establish her own working group at the Max Planck Institute for the Science of Light in Erlangen. That was a much more attractive offer. Her contract runs for five years and provides EUR 2 millions for research funding.

Fattahi is developing a camera with which she can record molecules in action. She is setting her sights primarily on biological processes.

But at first, it wasn't a smooth ride in Erlangen either: COVID-19 turned her new job into a series of hurdles. No sooner had she arrived than the lockdown brought the entire Institute to a standstill. "Nothing was working anymore, not even the telephone," she recalls. The mandatory shutdown was especially bitter for Fattahi, and not only because she was just get-

PHOTO: AXEL GRIESCH

Multicultural team: the members of Hanieh Fattahi's group come from various countries including China, South Korea, Iran and India. Their different cultural backgrounds enable each of them to approach research questions differently, which often leads to interesting discussions.

ting started. As an experimental physicist, her work relies on conducting laboratory work experiments. This is compounded by another problem: for safety reasons, two people must always be present when lasers are in use. But how is that supposed to work if only one person is allowed to be in the room at one time because of the pandemic? But there was no way Fattahi was going to sit and twiddle her thumbs. She quickly installed a camera so that a coworker could watch from outside the room and at least ensure that the necessary safety requirements were fulfilled. And she already had one employee, which was a stroke of luck: Fattahi had hired a student before she even started her own job. At a lecture at a U.S. university, she had asked if anyone would like to help her with her research in Erlangen, and Anchit Srivastava responded. So Fattahi already had a desk, a laser, and an employee. "It was difficult," she says, "but we conducted research." Fattah now has 11 employees – a colorful group of undergraduates, graduate students and postdocs from China, South Korea, Iran and India. The litmus test for Fattahi during the selection process for her team was a candidate's enthusiasm for the field. To demonstrate her relationship with her employees, Fattahi points to a toy laser lab made of Lego bricks that a former student gave her. Years ago, this German student insisted on doing his bachelor's thesis under Fattahi's tutelage, even though he was studying materials science. She finally agreed – on the condition that he learn the fundamentals of optics on his own. In fact, he successfully finished his bachelor's degree and even worked for her for a while. He is now in Bordeaux, studying for his master's degree in his new specialty. "He'll be back, that's for sure," Fattahi is convinced.

Anyone wanting to learn about her work as an experimental physicist has to don a pair of safety goggles and follow her into her laser lab. Its complex setup is slightly reminiscent of a model train set. But instead of trains, beams of light zip across the tabletop, and instead of signal towers, there are many small mir-

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rors and other optical instruments. It is not readily apparent what is being investigated here. Small wonder, because Fattahi works with structures that are invisible to the human eye. She is essentially developing a camera with which she can record molecules in action. Any photographer knows that it can be tricky to capture moving objects in a photo. The contours become blurred – unless you select a very short exposure time. But a molecule moves far, far faster than any bird in flight. This is where the femtosecond laser comes into play. Its flashes of light are short enough to take sharp images of moving molecules.

Using her special laser microscope, Hanieh Fattahi is currently focusing primarily on biological processes. The highly ambitious goal she has set for herself is nothing less than the visualization of human thought. It's about processes in the individual cells. The neurons, or nerve cells, are connected by countless synapses. These form a gigantic network in the brain, comprising roughly one hundred billion neurons and more than a trillion synapses. The signals are transmitted electrically – but only as far as the synapse. As of this point, nature switches to a chemical process: stimulated by the electrical impulse, chemical messengers known as neurotransmitters are released. These bridge the gap to the adjacent cell, where they once again generate an electrical signal. And Fattahi has trained her laser on these neurotransmitters. She wants to utilize her femtosecond laser to see how many of these molecules are required for a correct signal transfer and discover how this process works in detail. Understanding this would be a crucial breakthrough, especially for physicians, because flaws in this process can lead to diseases such as Parkinson's. Before placing human neurons under the microscope, Fattahi intends to work with animal cells. She is also starting out with a different type of synapse: a connection between a nerve cell and a muscle cell. She hopes to be able to launch her first experiment next summer.

In order to get an initial feel for the laser, Hanieh Fattahi is also currently working with biotechnologist Daniel Wehner from the Institute. His work is focused on zebrafish, a model organism favored by geneticists and developmental biologists. His team also studies nerve cells: they are investigating the incredible ability of these fish to regenerate an injured spinal cord. Spinal injuries heal again in zebrafish, when similar traumas, e.g. from accidents, leave many humans paralyzed for life. To better understand how the fish can do this and whether we could possibly learn from this how human spinal cord injuries could be healed, the researchers first use Fattahi's laser technique to precisely sever the fish's nerves – and then observe in detail how they grow back together. Sitting in on one of her working group's meetings, it becomes clear that Fattahi is still in the early stages of her project. The presentations do not cover results, but rather experimental configurations that are going to be set up. The COVID-19 pandemic is still having an impact on the meetings: people entering the Institute must wear a mask, and the employees sit far away from each

Handcrafting scientific gadgets: not least because of the restrictions imposed by the COVID-19 pandemic, Hanieh Fattahi continually had to take matters into her own hands in the lab. That is how she finally managed to generate the intense laser pulses with a duration of only five femtoseconds.

PHOTO: AXEL GRIESCH

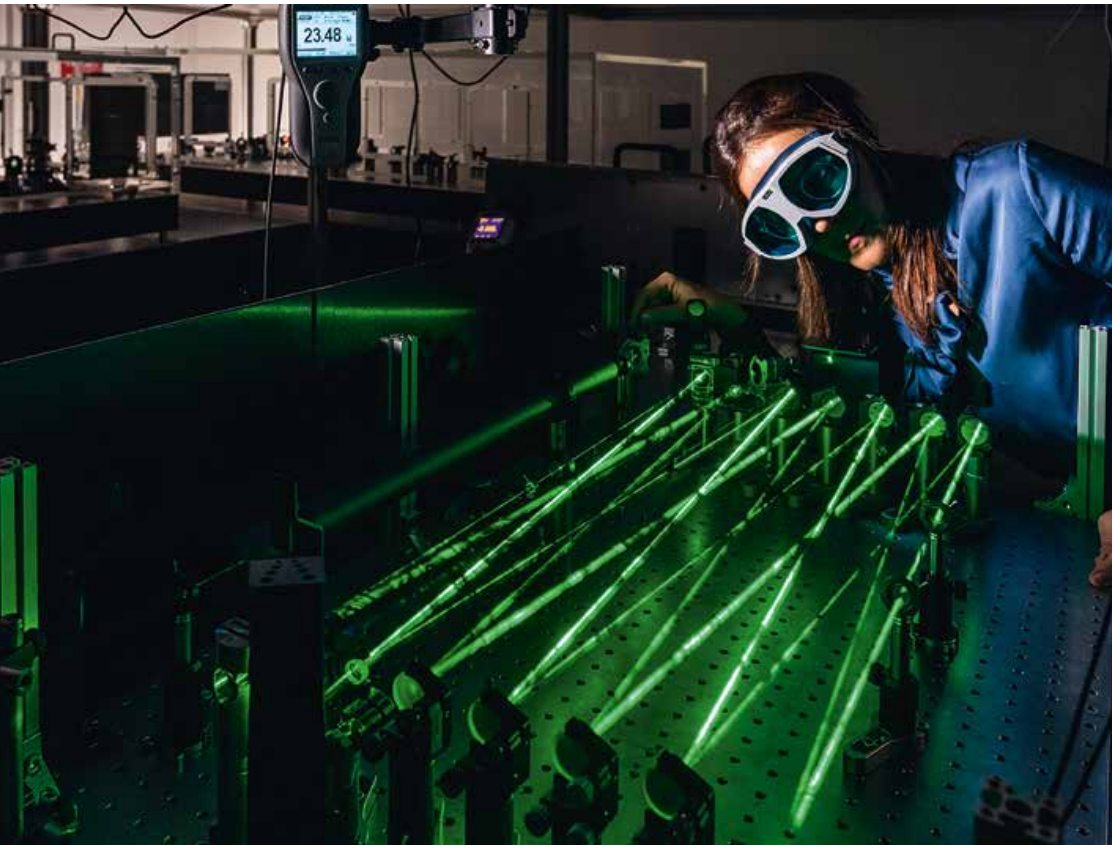

PHOTO: AXEL GRIESCH

A new instrument for climate research: Hanieh Fattahi's group developed an optical oscillator that generates intense femtosecond pulses of short-wave infrared light from green laser light. These light pulses can be used to measure greenhouse gases in the atmosphere.

other in the meeting hall. They literally lose touch with each other in the large space. Despite this, Fattahi's casual and companionable relationship with her employees is obvious. Several of them take turns stepping up to the lectern and explaining what experiments they are planning and what goals they seek to achieve. They also explain what equipment they need and how they intend to obtain it. Money also plays a role here, because Fattahi has to manage her budget. Discussions sometimes ensue about whether a component could be obtained more cheaply elsewhere. Fattahi grants her employees a great deal of freedom, but repeatedly redirects the discussion back to the experimental plans at hand.

Although the set-up phase for her group demands a lot of her time and attention, Fattahi isn't only keeping tabs on the femtosecond laser and synapses. She also wants to work actively to prevent climate change, "the most serious problem of this century," as she says. A year ago, she started the "Greenroom Book Club," to address this topic. She has the impression, she says, that the people around her are not informed enough to recognize how serious the situation is. So she sent out an email inviting everyone she knew, whether in academia or not, to participate in the book club. Since then, they have been meeting online every two weeks to discuss a book on the climate that everyone attending is supposed to have read beforehand. The club now has its own homepage and is attracting a lot of interest. But it wants to be more than just a debate club: Fattahi wants her initiative to have an influence on society. Everyone should be thinking about how they can contribute. This also applies to herself. For example, she and her team have developed an optical instrument that can be used to detect short-lived greenhouse gases such as methane, ozone and fluorocarbons. Fattahi wants to use it to help clarify the question of the sources of these gas emissions and how they are distributed within the atmosphere. Knowing this could help to more precisely determine the effects of these gases on the climate. But Hanieh Fattahi doesn't apply her talent as a laser physicist to climate protection alone. She also has a gift that has helped her build up her group even in the difficult times during the COVID-19 pandemic: the ability to motivate people to work towards a common goal.

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FROM: CLARA WEISMAN, A COMPLETE TREATISE ON ARTISTIC RETOUCHING, MODELING, ETCHING, ART AND NATURE, ART AND PHOTOGRAPHY, CHARACTER, CHIAROSCURO, COMPOSITION, STYLE AND INDIVIDUALITY, SAINT LOUIS 1903

DOUBLE TAKE

KUNSTHISTORISCHES INSTITUT IN FLORENZ – MAX PLANCK INSTITUTE

Surrounded as we are by digital images, we know how easily they can be manipulated. Photos can be corrected, adjusted, and distorted on any cellphone as desired. However, manipulating photos was already common practice at the beginning of the 20th century. This pair of images comes from a guide to retouching photos published in 1903. Back then, pencils and erasing knives were the tools of choice for smoothing wrinkles and brightening shadows in portraits. If the subject's eyes were closed, open eyes were drawn in. Photo manipulation techniques were also useful when producing scientific images. An online exhibition by the Photothek of the Kunsthistorisches Institut in Florenz offers insights.

http://photothek.khi.fi.it/documents/oau/00000311

HEARING COLORS, SEEKING GENES

TEXT: KLAUS WILHELM

Synesthesia is one of the most fascinating phenomena in psychology and the neurosciences. But only very slowly are its scientific mysteries being uncovered. Research in this field is gathering momentum, thanks to the studies being conducted by Simon Fisher from the Max Planck Institute for Psycholinguistics in the Dutch city of Nijmegen.

Even by non-scientific standards, synesthesia is baffling – at least for those who do not experience this perceptual phenomenon. Imagine you see or hear a letter, let's say the letter F, and immediately the color red lights up in your mind's eye. Or the letter Z – and the color that appears is green. Now imagine you are reading a book. You might find yourself seeing a continuous stream of colors at the same time. Other people hear certain words – and immediately experience a sweet, sour, or other kind of taste in their mouths – and so on.

Synesthesia literally means "perceiving together". It is a neuropsychological phenomenon, in which the act of perception by one sense simultaneously and involuntarily stimulates another. It is "certainly not a disorder, much less a disease," emphasizes Simon Fisher, Director at the Max Planck Institute for Psycholinguistics. It is estimated that there are 60 to 80 forms of synesthesia, which is a normal part of everyday life for around four percent of the human population. Lara Grabitz is one of them. The physics student has grapheme-visual synesthesia and sees the letters or numbers of a text in color directly on the paper or monitor. When she plays her cello, she also hears the tones in color. When she hears a year, she sees a kind of timeline in front of her with the years arranged along it. "This world feels completely normal to me," says the young woman. "I've never known anything different, I would feel quite anxious if it suddenly went away."

Simon Fisher belongs to the 96 percent of the population who have no direct, personal experience with synesthesia at first hand. He is a neuroscientist and geneticist, "a scientist with an interdisciplinary remit," as he likes to say. He is interested in "looking at the DNA of genes and understanding the biological impact of genes on behavior, language, and other traits." His team started by researching genes they'd discovered that influence specific speech disorders. At some point in his career, he met colleague Simon Baron-Cohen, Professor of Developmental Psychopathology at Cambridge University, who is known for his research on so-called autism spectrum disorders – as well as for his work on synesthesia. "I didn't know much about the field at the time," says Fisher, "but I found it incredibly exciting." Back then, next to nothing was known about the genetic background of synesthesia.

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KNOWLEDGE FROM

BIOLOGY & MEDICINE

Painting for the ears: artist Wassily Kandinsky is one of the world's most famous synesthetes. Painted in 1926, this picture with the title "*Three Sounds*" embodies his idea that colors and shapes can convey music – and vice versa.

IMAGE: WASSILY KANDINSKY / HERITAGE IMAGES / FINE ART IMAGES / AKG-IMAGES

By the time he took up the post of Director at the Max Planck Institute for Psycholinguistics, research processes were being revolutionized by high-performance technology that could rapidly analyze entire genomes from thousands of people simultaneously. Ever more precise, ever more affordable, ever more sophisticated – a giant step forward. Yet "despite all the technology, it is still an intellectual challenge to analyze these raw DNA data files and to examine how genes ultimately influence a trait," explains Fisher. "Because, even though genes provide instructions for human brain structure and behavior, we have to find out the ways in which these instructions are implemented. That's the high art of DNA analysis." And that's the domain of bioinformatics. The experts investigate whether certain traits occur simultaneously with variants of certain DNA sequences or genes. "To ascertain this, you need skill, expertise, a lot of luck, and above all a large number of DNA samples from people with synesthesia," the researcher says. This is because it is rare for a single gene to have a major effect on complex traits like synesthesia. As a rule, a combination of many gene sequences work together to make a trait more likely.

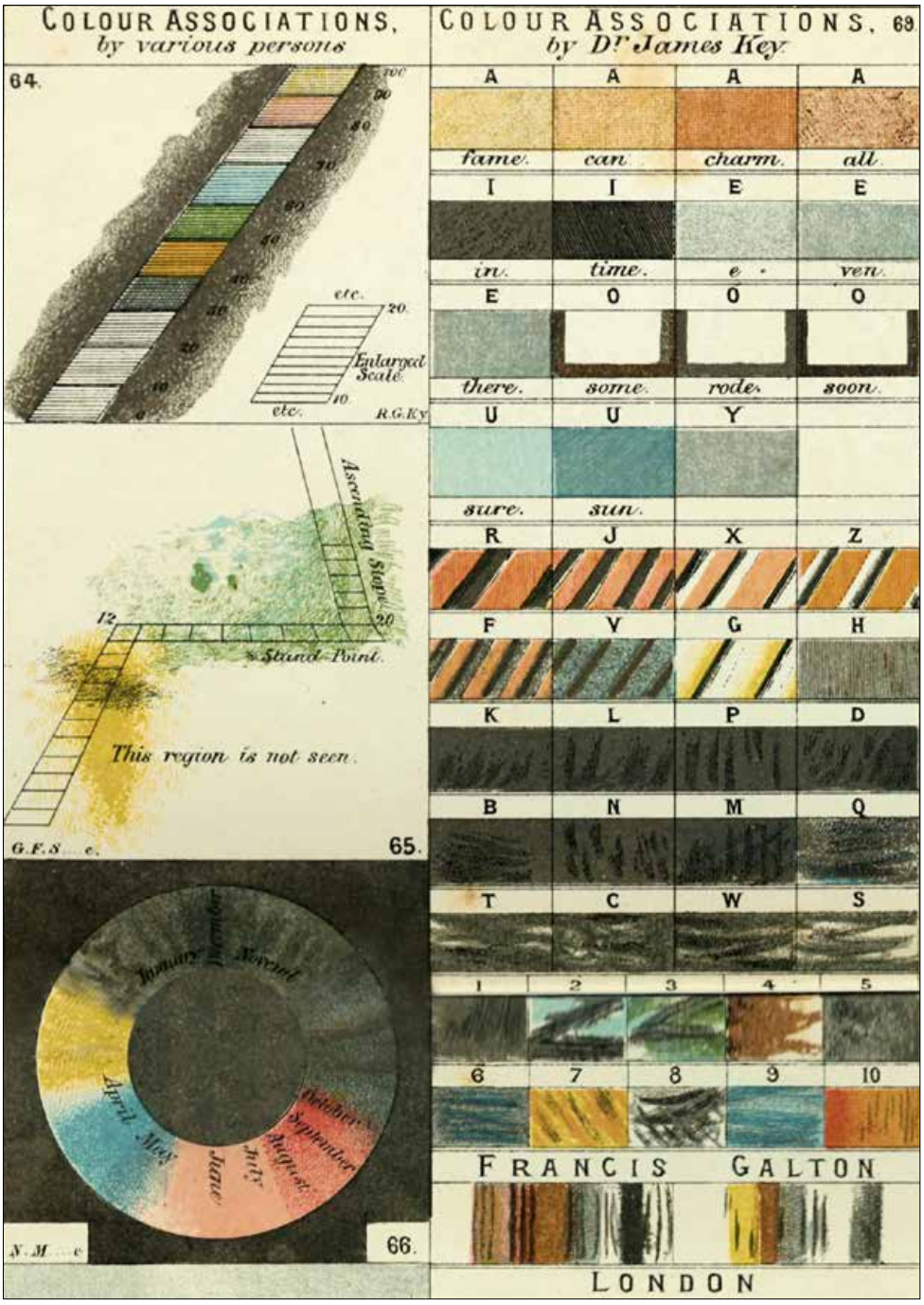

ILLUSTRATION: FRANCIS GALTON/INQUIRIES INTO HUMAN FACULTY (MACMILLAN 1883, SECOND EDITION, EVERYMAN, 1907)

Early categorization: published in 1883, Francis Galton's book about psychology contains drawings by synesthetes. Figs. 64 and 65 contain examples of how numbers are experienced in space, accompanied by their perceived colors. In Fig. 66, the months of the year are arranged in a circle and associated with colors. Fig. 69 shows colors and patterns associated with various letters and numbers.

With this in mind, researchers have already spent many years seeking people with different forms of synesthesia for their studies. They are pursuing two different lines of research: firstly, the team needs as many unrelated test subjects with grapheme-color synesthesia as possible from among the general population. They are searching for so-called "polymorphisms" in their genes. These are "normal" variants of genes that often differ by just one building-block. Although each polymorphism by itself has only a minor effect, the effects of multiple variants on various genes add up, and this is when people are more likely to develop synesthesia. However, the genomes of at least 1,000 synesthetes are required in order to make any statistically meaningful assessments. "We are almost there," says Fisher. He and his team are now approaching their first goal: to examine the genomes of these

1,000 people and identify all "suspicious" polymorphisms. If specific DNA variants are found to be more common in people with synesthesia than in those without it, these variants could be associated with the trait.

Secondly, the team in Nijmegen is searching for families in which synesthesia occurs multiple times throughout several generations. The researchers are using their high-tech methods to comb the genomes of these people for genes that could help explain the unusually high incidence of synesthesia in these families. "We can only make statistically reliable statements if we can analyze large families," Simon Fisher explains. "In similar studies on speech disorders which we conducted in the past, we investigated three generations of a family in which 15 out of 30 individuals were affected. The synesthesia families we have found so far are much smaller."

Nevertheless, the first provisional results are already available. Through the collaboration with Simon Baron-Cohen, Fisher's group got the chance to analyze the genomes of three families in which five or more members spanning at least three generations had sound-to-color synesthesia. The team, led by Amanda Tilot, identified 37 candidate genes that might potentially be linked to synesthesia. Although different genes were altered in the three families, "we noticed that some of these genes function in a similar way," explains Tilot. The researchers are interested in six of the genes in particular. These are genes that are thought to be important particular function in brain development during early childhood. They help to make sure that nerve cell extensions (known as "axons") form and link up properly – a process known as "axonogenesis," in which nerve cells form interconnections with neurons in other regions of the brain. The genes in question are particularly active in the visual and auditory centers. "There are many pathways that could lead to the enhancement of neuronal connectivity through slight variations in axonogenesis," Tilot points out – for example, through the length and positioning of nerve fibers or through unusual branching and other changes in shape. The study shows how genetic differences can influence sensory experience – possibly by altering the connectivity of neurons in the brain. "Synesthesia is therefore a clear example of neurodiversity that we should respect and appreciate," says Fisher.

"The possible role of genes involved in axonogenesis is really interesting, because it supports the hypothesis that people with synesthesia have increased connectivity between brain regions that are not usually linked." However, there are other theories that could also explain synesthesia, such as a change in the balance between neuronal excitation and inhibition (the so-called E/I balance) in the brain. "Ultimately we need a lot more data," says Fisher. This is why Fisher's team are not letting up in their efforts to find synesthetes for their studies – through their cooperation with other research groups worldwide as well as through other channels. The researchers offer the "Synesthesia Battery" on the Max Planck Institute's website and as a smartphone app, for example; this self test was originally developed by Stanford University neuroscientist David Eagleman and can determine fairly reliably whether or not a person has synesthesia, at least for some of the most thoroughly-studied types like grapheme-color. Anyone who identifies as a synesthete on the test can take part in the Fisher team's studies.

Genes and environment intertwined

Moreover, evidence exists that synesthesia-like perception can be learned. How? "Through intensive reading training using texts with colored letters," explains Fisher. "This enables people to develop an artificial form of synesthesia even if they aren't genetically predisposed to it. But it does not appear to be the same thing, because this ability disappears again." People with true synesthesia experience it automatically (i.e. involuntarily, without having to focus on it) and they experience it consistently over a period of years – this is one of the most reliable characteristics of this phenomenon. As a rule, it begins to develop in childhood. "Synesthesia is a remarkably interesting example of how genes and environmental experiences interact," says Fisher. "This genetic predisposition is present from birth." However, the colors that people with synesthesia associate with specific sounds or letters, for example, are invariably the result of environmental experiences in childhood. This has been shown by studies conducted by synesthesia expert Julia Simner from the University of Sussex, for which she observed British elementary school children over a period of several years. In conclusion, synesthesia needs a long time to develop. Amanda Tilot adds, "The classroom may play a key part in the development of synesthesia since this is where the alphabet, numbers, and the calendar are connected with the child's memory."

SUMMARY

In children, synesthetic associations are initially chaotic and fluid but become more consistent over time.

People with autism spectrum disorders report synesthetic experiences much more frequently than other people.

The development of synesthesia could be influenced by several genes that help establish connectivity between nerve cells in different parts of the brain.

In the British study, the few children at each elementary school who became grapheme-color synesthetes gradually came to associate colors with each letter of the alphabet during their early years at school. These children selected specific colors for 34 percent of the alphabet at ages six to seven, 48 percent at ages seven to eight, and 71 percent at ages ten to eleven. "Initially, the synesthetic associations are chaotic and fluid," says Fisher, "but in time they become more consistent." Many of the children and adolescents are not even aware that their perception is different from other people's.

Synesthesia can be useful

A study of 1,000 subjects recently found that men and women are equally represented among people who lead truly synesthetic lives. Simon Baron-Cohen's team also found out that synesthesia is more common among people with autism spectrum disorders – up to 20 percent of this group report synesthetic experience. Tilot explains that "the findings bring to mind the remarkable case of the British author Daniel Tammet, who has autism and a complex form of synesthesia." Tammet's synesthesia enables him to perform astonishing feats, such as memorizing and reciting the mathematical number pi to more than 20,000 decimal places. This shows that synesthesia can sometimes be useful. Grapheme-color synesthetes, for example, often say that the colors help them memorize telephone numbers or other numerical information. Studies have shown that people with synesthesia perform better in memory exercises than people without this ability, provided they are able to use their unusual perceptive experiences to boost their memory. In his book "Born on a Blue Day", Daniel Tammet describes how his sense of the uniqueness of color, shape and location of each number helps him solve complex mathematical equations at lightning speed. In general, people with synesthesia are more creative than average.

An interdisciplinary approach: Simon Fisher's work brings together knowledge in the fields of genetics and brain research in order to better understand the phenomenon of synesthesia.

PHOTO: INTERNATIONAL DYSLEXIA ASSOCIATION, IDA CONFERENCE OCT. 2018

However, there is also a flipside to the coin, as Simon Fisher explains: "The many simultaneous perceptions can occasionally be overwhelming." Sometimes, conflicts can also arise between concurrent perceptions. This can be disconcerting – for example when you are reading letters and perceive an odor of rotten eggs. "It gets difficult when systems collide, when my internal systems crash head on with the world's systems," says synesthete Lara Grabitz – for example, when the orchestra colleague with whom she shares a music stand writes numbers for fingerings on their shared sheets of music, but these mean nothing to her.

Synesthesia self-test (multi-lingual):
www.mpi.nl/page/
join-our-synaesthesia-genetics-research

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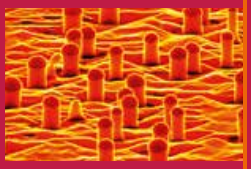

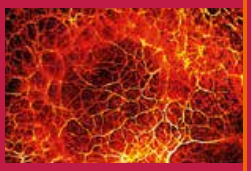

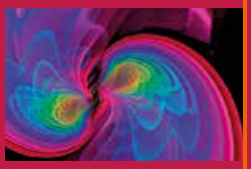

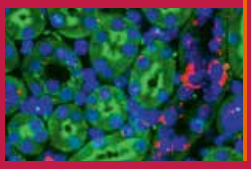

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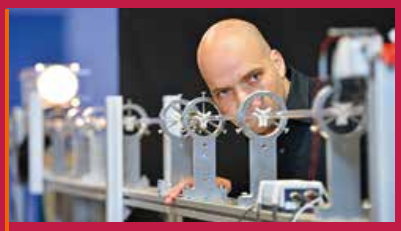

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Alpaca Britta after shearing. Alpacas originate from South America and are related to llamas. Their immune system produces antibodies with an especially simple structure. These have distinct advantages over conventional antibodies and can be developed for medical applications.

IMAGE: MPI FOR MULTIDISCIPLINARY SCIENCES/ CARMEN ROTTE

BOOSTER FROM ALPACAS

TEXT: KLAUS WILHELM

Basic research often takes a winding road and only indirectly leads to practical applications. The path of Dirk Görlich's research at the Max Planck Institute of Multidisciplinary Sciences in Goettingen began with defense proteins generated by the alpaca immune system. Görlich and his team have developed these proteins into mini-antibodies known as "nanobodies", which can block infection by SARS-CoV-2 and most of its variants. The efficacy and safety of these nanobodies will now have to be demonstrated in clinical trials.

When leaving their stable on the Fassberg hill in Goettingen, the alpacas Britta, Nora, and Xenia are met with a magnificent view of the university town at their feet. While it is admittedly not quite as breathtaking as their Andean homeland, these animals are participating in an extraordinary research project. The three alpacas are part of a herd of 22 animals at the Max Planck Institute of Multidisciplinary Sciences (until 2021 known as the Max Planck Institute of Biophysical Chemistry).

In Germany, alpacas used to be common only in petting zoos but have recently become very popular with professional and amateur breeders. Several thousand of these camelids, which are native to South America are now at home in Germany. However, Dirk Görlich and his team are less interested in the alpacas' cute appearance or their wool, but rather in a peculiarity of their immune system: when camelids get infected, their immune systems produce not only standard antibodies but also simpler versions. While standard antibodies are composed of two heavy and two light chains, the simplified antibodies comprise just two heavy chains with a smaller antigen-binding module. This may allow them to target pathogens at buried sites that are inaccessible to standard antibodies. Nanobodies (or VHH antibodies) are the smallest antigen-binding fragments of such simpler alpaca/camel antibodies.

Antibodies are proteins that can bind very selectively to specific molecules, for example, a pathogen's surface, thereby, labeling the invaders for destruction by immune cells. However, they can also directly neutralize pathogenic molecules. Scientists use antibodies to label, visualize, or block molecules to study their function. The small quantities needed for this can be readily obtained from animals, such as rabbits or goats. This is done by immunizing the animal several times with the desired antigen. The animals then respond by making antibodies against the antigen. The antibodies can then be isolated from blood samples.

Given their ability to bind to specific molecules, antibodies can also be used as drugs, for example, to treat rheumatic diseases, cancer, or and rabies. They are also being used to treat COVID-19. However, they cannot be obtained in the required quality and quantity from animal blood for such purposes. Instead, they are manufac-

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tured in genetically modified hamster cells, in a procedure that is complex, time-consuming, and expensive. This is due to the complicated structure of the antibodies with light and heavy chains that are decorated with sugar chains. Nanobodies are different – thanks to their simpler structure, they are also easier to manufacture.

Approximately seven years ago, Dirk Görlich and his team came up with the idea of using nanobodies in their projects. At the time, the researchers were struggling to elucidate the three-dimensional structure of a protein complex from the cell's transport machinery by x-ray crystallography. But they just couldn't get the complex to crystallize – until they bound a nanobody from a Belgian company to the complex. "That solved the problem right away," Görlich remembers. This inspired the plan to generate nanobodies themselves and to establish a small herd of alpacas on the Institute's grounds. In the meantime, the Goettingen researchers have become experts in nanobodies. They use nanobodies as tools in fundamental research, for example, to block specific transport pathways in cells or as high-precision probes to localize proteins in fluorescence microscopy.

SUMMARY

Compared to standard antibodies, nanobodies have a simpler structure and are easier to isolate and produce in large quantities for medical use.

The recently developed anti-SARS-CoV-2 nanobodies neutralize the virus even in minute amounts, are effective against new viral variants, and can be rapidly adapted to new SARS-CoV-2 strains.

Nanobodies could also be used for treating sepsis or snakebites.

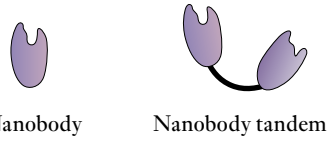
Then along came COVID-19. "It was clear that we could develop nanobodies that would stop infection with SARS-CoV-2," Görlich recounts. What followed was an emotional rollercoaster for the entire team, which pursued their project with immense dedication. "After all, there's a huge difference between producing nanobodies for basic research and developing them as drugs. In the laboratory, we use them just to bind specifically to their target structure, and a few milligrams are enough for thousands of experiments." For therapeutic purposes, however, they must not only bind to their target molecule but also neutralize it, and do so at very low concentrations to minimize side effects. In addition, very high stability is required to ensure that the nanobodies survive the production processes and years of storage without deteriorating. They also need to be produced in larger quantities – as a minimum on a kilogram scale.

The researchers vaccinated Britta, Nora, and Xenia with a crucial part of the SARS-CoV-2 spike protein: the receptor-binding domain used by the coronavirus for invading its host cells. The immune system of the alpacas responded promptly and started producing antibodies against the virus. The team then collected blood samples and isolated the blueprints for more than a billion different nanobodies. Using the so-called phage display technique, they subsequently selected from this huge library the molecules that bind most strongly to the receptor-binding domain of the virus.

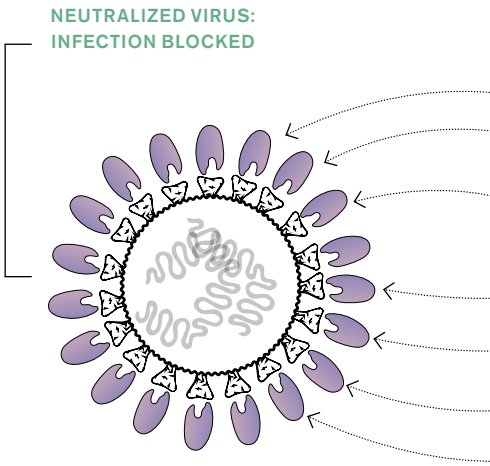
But which of these is most effective at neutralizing the virus and stopping an infection? The team of virologist Matthias Dobbelstein, Director of the Institute of Molecular Oncology at the University Medical Center Goettingen, infected cell cultures with SARS-CoV-2 in the laboratory and tested how well the different nanobodies blocked virus replication. "The lower the neutralizing concentration of the nanobody is, the lower the risk of side effects will be," Görlich explains. The most effective nanobodies could block SARS-CoV-2 infection even at concentrations of less than one millionth of a gram per liter. The researchers then engineered these nanobodies to remain stable at temperatures of up to 95 °C without aggregation. Such a high level of stability makes the nanobodies easier to manufacture, process and store, as well as safer to use.

Tandems against variants

But then variants of the virus appeared that were even more infectious than the original strain. In addition, their spike protein had changed to make it



Nanobody Nanobody tandem



harder for existing antibodies to neutralize the pathogen. Therefore, Dirk Görlich and his team fused two nanobodies that simultaneously recognize different regions of the receptor-binding domain. "These tandems bind so strongly that they can tolerate the new 'immune escape' mutations of the virus. This strategy worked perfectly with the alpha, beta, gamma, and delta variants of the virus," explains Thomas Güttler, a scientist in Görlich's team.

"By that time, we had re-immunized the alpacas with spikes from the viral variants and selected nanobodies that, already as monomers, can potently neutralize not only the original Wuhan strain but also alpha to delta," reports Metin Aksu, another scientist in the team. The now dominant omicron variants are yet another challenge since they carry 15–17 mutations in their receptor-binding domains, ≥12 more than any previous variant of concern. It now seems that two distinct nanobodies are needed to potently target all known variants. The Goettingen team has already isolated the first generation of anti-omicron nanobodies and is now optimizing a second set, which they obtained after boosting the alpacas twice with a specific omicron vaccine.

The only problem that remained was to produce these nanobodies at an industrial scale. A few milligrams of the mini-antibodies suffice for laboratory research, but kilogram amounts would be needed to make a difference in the pandemic (and the foreseeable endemic) situation. Indeed, such a goal is feasible with the help of genetically re-programmed yeast cells and industrial-scale bioreactors.

But even if your laboratory team has succeeded in developing a potential drug to combat one of the worst epidemics in recent history, that doesn't automatically pave the way to clinical trials. "I was a bit naïve" says Görlich. Initially, the intention was to start a spin-off company of the Max Planck Society to develop the nanobodies as drugs for patients and then test them on volunteers. However, it proved impossible to raise the necessary funding in a short period of time, even the major pharmaceutical

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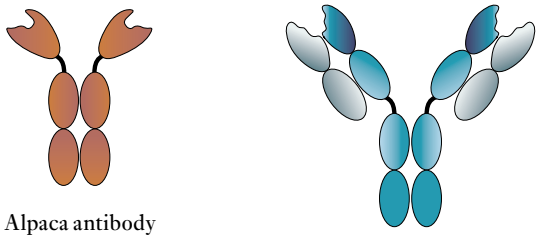
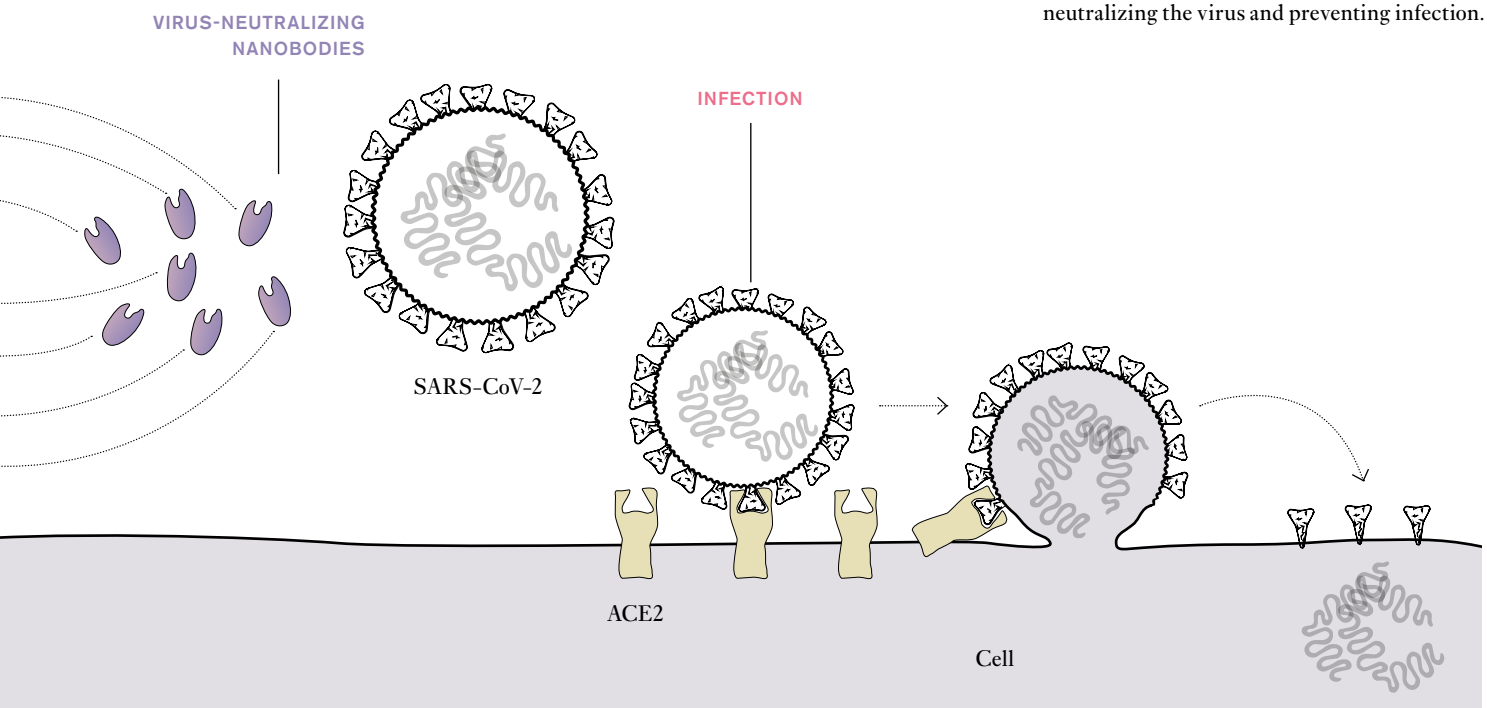


Upper: Typical antibody proteins consist of two heavy and two light chains. By contrast, the simpler antibodies of alpacas have only two heavy chains. Their antigen-binding domain can be separately produced and is then called "nanobody". Lower: The spike protein on the surface of the SARS-CoV-2 binds to the ACE2 receptors of the host cells and subsequently fuses the viral membrane with the plasma membrane, allowing entry of the viral RNA and thus infection. Nanobodies can block the spike protein, thereby neutralizing the virus and preventing infection.



GRAPHIC: GCO BASED ON AN MPG DESIGN

PHOTO: MICHAEL DANNENMANN THE MPG

In the Max Planck Institute in Goettingen the nanobodies are adapted to the spike protein of the coronavirus so that they can block different variants of the pathogen (left: Jürgen Schünemann and Kathrin Gregor, right: Waltraud Taxer (rear) and Renate Rees).

companies were very cautious. The industry's hesitancy was partly due to the fact that using nanobodies as drugs is still a very novel concept. Only one product has, as yet, made it to the market – a drug to treat a rare thrombotic disease.

Arduous path to drug development

It was only at the very last moment that the team was able to find a company willing to undertake the clinical development, an Israeli biotech venture. "The negotiations were rather tedious and complicated. We learned that the process of developing a drug follows its own set of rules," says Dirk Görlich. His team is being supported by technology transfer experts from Max Planck Innovation and the Lead Discovery Center. The Max Planck Foundation is providing financial support for the project.

Encouraged by the ultimately positive experience, the Goettingen researchers are now looking to develop nanobodies to treat sepsis. Commonly referred to as blood poisoning, such systemic bacterial infection is often fatal, and, in fact, the most common cause of death amongst hospitalized patients. Widespread antibiotic resistances adds to the problem. And even if antibiotics are effective against the bacteria, they cannot eliminate the already secreted bacterial toxins. "We are now aiming to develop nanobody cocktails that target and block the toxins of the most dangerous bacteria," says Dirk Görlich. Nanobodies could also be used for treating venomous snakebites, which cause around 100,000 fatalities per year worldwide. Until now, anti-venoms are produced by injecting snake toxins into horses and then isolating antibodies from their blood. This is a mature (>100 years old) technology but comes with severe adverse effects in patients and with hardly acceptable animal welfare problems.

Nanobodies would provide an excellent alternative strategy. From an exotic antibody of an exotic laboratory animal to novel drugs – the development of this new antibody technology would never have been possible without basic research.

←

GLOSSARY

NANOBODIES
Fragments of antibodies with a particularly simple structure, which the immune system of camelids (for instance, alpacas, dromedaries, and llamas) produce against pathogens. Unlike typical antibodies, nanobodies are composed of only a single amino acid chain. This makes them more stable and easier to manufacture. They are also more effective at recognizing hidden binding sites of other proteins. Nanobodies are therefore being considered for a broader use in medicine.

PHAGE DISPLAY
A molecular biology technique to isolate nanobodies (or other "binders") from "immune libraries". Each nanobody of a library is directly coupled to its "own" DNA-encoded blueprint. This is achieved by packing the DNA blueprints into "phages" (viruses that infect bacteria) which then express and display DNA-encoded nanobodies on their surface. Such a library is then passed over an immobilized antigen surface. Phage nanobodies with a high affinity for the antigen bind to it and are isolated, while irrelevant binders are washed away.

Irresistible at heart

In 2020, Reinhard Genzel received the Nobel Prize in Physics for his research on the black hole at the heart of the Milky Way.

We support his project GRAVITY+ at the Max Planck Institute for Extraterrestrial Physics, because with the world's largest virtual optical telescope he wants to pin down the galactic gravity trap and write a new chapter in astronomy.

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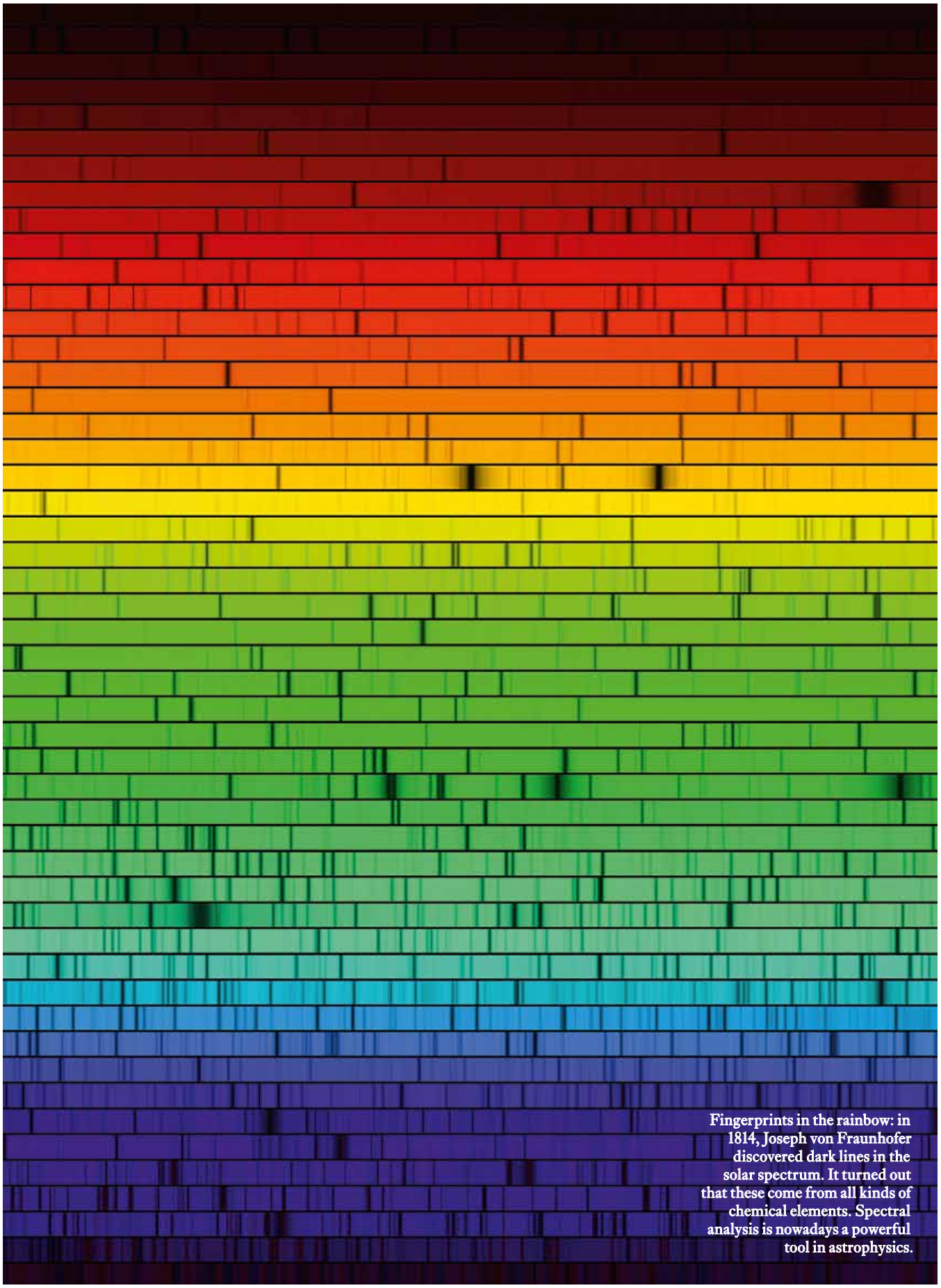

PHOTO: N.A.SHARP, NOAO/NSO/KITT PEAK FTS/AURA/NSF

Fingerprints in the rainbow: in 1814, Joseph von Fraunhofer discovered dark lines in the solar spectrum. It turned out that these come from all kinds of chemical elements. Spectral analysis is nowadays a powerful tool in astrophysics.

COSMIC DETECTIVE WORK

TEXT: THOMAS BÜHRKE

The chemistry of a star contains valuable information such as its history or affiliation with a particular stellar population. But accurate detection of abundances of chemical elements based on spectral fingerprints require highly sophisticated methods. Maria Bergemann from the Max Planck Institute for Astronomy in Heidelberg has set new standards here.

Nature is an elegant architect. From less than a hundred chemical elements, it has created a vastly diverse universe – from diffuse gas clouds to stars and from planets to intelligent life. The trick: atoms exert electrical forces, combine to form complex molecules, and can absorb and release energy.

The chemical composition of an object is decisive for its properties. For example, our Earth consists mainly of heavy elements such as iron, oxygen, silicon, and magnesium. On the other hand, the most abundant elements in space – hydrogen and helium – are also the lightest ones. Because of their volatility, they are relatively rare on Earth.

Stars like the Sun are hot balls of gas, and their surfaces typically reflect the chemical composition of the interstellar matter cloud from which they were born. "If we can assign each individual star in the Milky Way to a particular population in which it was born, we can reconstruct the entire history of this population, its genealogy," says Maria Bergemann, head of the Lise Meitner Group at the Max Planck Institute for Astronomy. The problem is that it is impossible to travel to the Sun – or to any other star – in order to take a sample of the gas in the stellar atmosphere. Researchers need a different method to determine the chemical composition of a star: stellar spectroscopy. These considerations are not new. But achieving this goal requires the state-of-the-art capabilities of telescope technology and the analysis of stellar spectra. For the latter, Maria Bergemann has followed in the footsteps of Joseph von Fraunhofer, Robert Bunsen, and Gustav Kirchhoff. In 1814, Fraunhofer used a glass prism to split sunlight into its rainbow colors. To his amazement, the resulting color fan contained about six hundred dark lines. Spurred on by this discovery, he also found dark lines in the spectra of very bright stars – sometimes at the same positions but with different widths and intensities compared to the lines in the solar spectrum. It is precisely these differences that provide information about the composition and nature of each star.

The decisive interpretation of the 'Fraunhofer lines' was achieved by Bunsen and Kirchhoff in 1860 in Heidelberg, where Maria Bergemann now carries out her research. During spectral experiments with gas burners, the scientists noticed that chemical elements within the spectrum produce a line at specific wavelengths. They were thus the first researchers to identify sodium in Fraunhofer's solar spectrum. Today, analysis of electromagnetic spectra is the most powerful tool in many areas of the natural sciences. This is especially true for astrophysics, as the vast majority of cosmic objects are inaccessible by any other means. The dark lines in the solar or in a stellar spectrum occur

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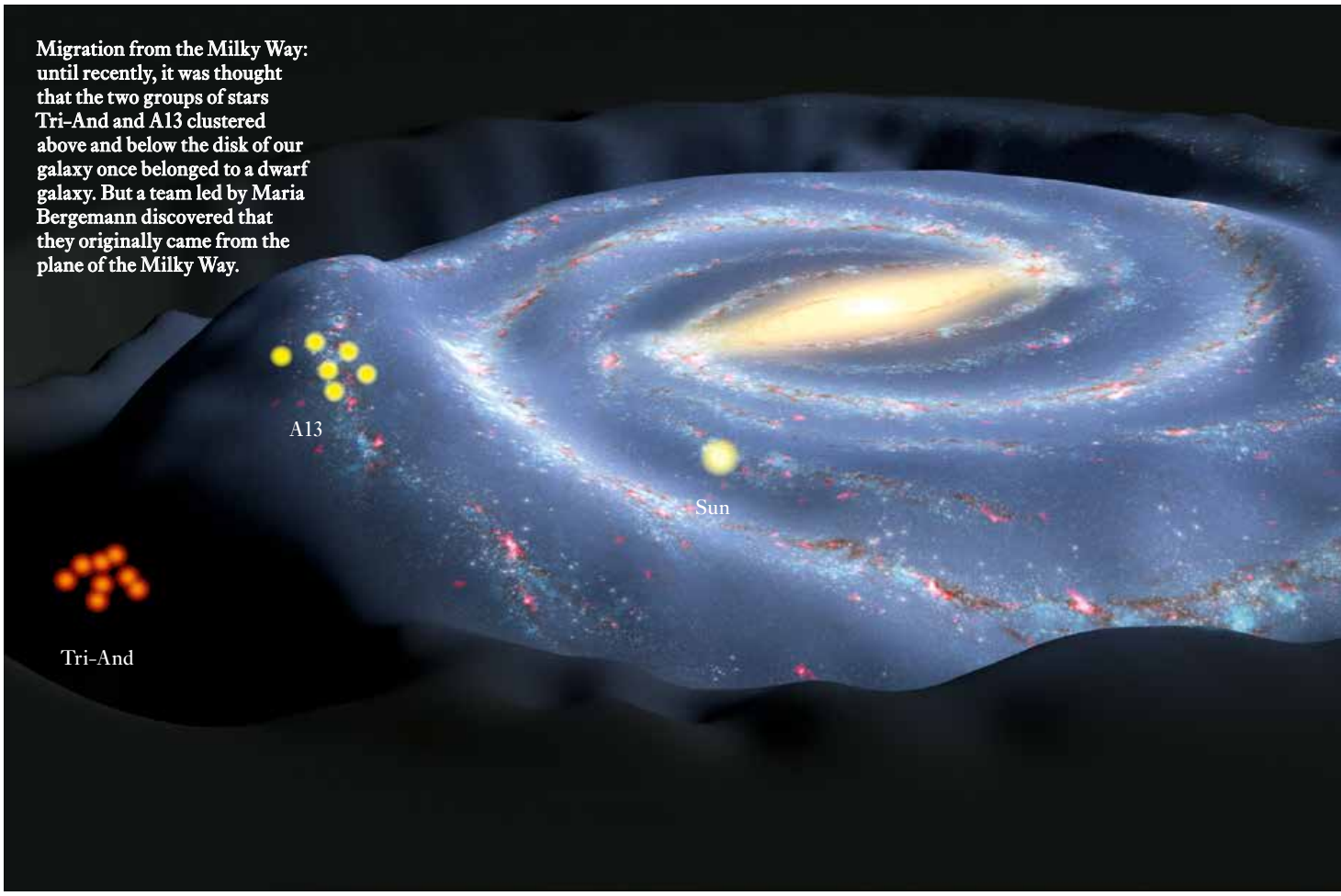

Migration from the Milky Way: until recently, it was thought that the two groups of stars Tri-And and A13 clustered above and below the disk of our galaxy once belonged to a dwarf galaxy. But a team led by Maria Bergemann discovered that they originally came from the plane of the Milky Way.

when light from the hot interior shines through the cooler outer atmosphere of the star. Atoms and simple molecules thereby absorb light at the wavelengths that are characteristic for them. A spectrum is much like a fingerprint. Several hundred thousand absorption lines are visible in the spectrum of the Sun. The critical question is: how can the element abundances be determined from the depth and width of the lines?

This requires atomic and molecular physical quantities that are measured in the laboratory. Current lists for modeling and interpreting solar spectra are based on more than one hundred million atomic and molecular lines. Many of them overlap and cannot be uniquely identified. This is one particular aspect that explains the complexity of spectral analysis.

Over the past hundred years, astrophysicists have developed theories and models in order to be able to calculate the physical parameters of stars using these spectral lines. These parameters include temperature, gas pressure, and gravitational acceleration at the surface as well as the detailed chemical composition. Such models are very complex and have to simplify reality. It was thus originally assumed that certain types of equilibria prevailed in a star. The balance of pressure and gravity leads to a hydrostatic equilibrium, while gas and radiation are in a so-called "local" thermodynamic equilibrium. "For decades, such highly simplified models were used to determine the abundances of chemical elements from spectra. But the results are sometimes wrong by a factor of five or more," says Maria Bergemann. A star is not a perfectly homogeneous sphere in which the same conditions exist at every point.

Most stars in the universe are about as heavy as the Sun or lighter. All of these star types have the same basic structure. In the outer region (which, in the case of the Sun extends to a depth of about 500,000 km), the gas is convective. Within that region – the convective envelope – masses of hot gas rise to the surface, cool down through emission of radiation, and sink back towards the interior. Water boiling in a pot shows a similar behavior. A pattern of well-defined cells emerges, and these can be observed as granules on the solar surface.

In addition to convection, various types of interactions between atoms and radiation occur in stellar atmospheres. Detailed models are therefore needed

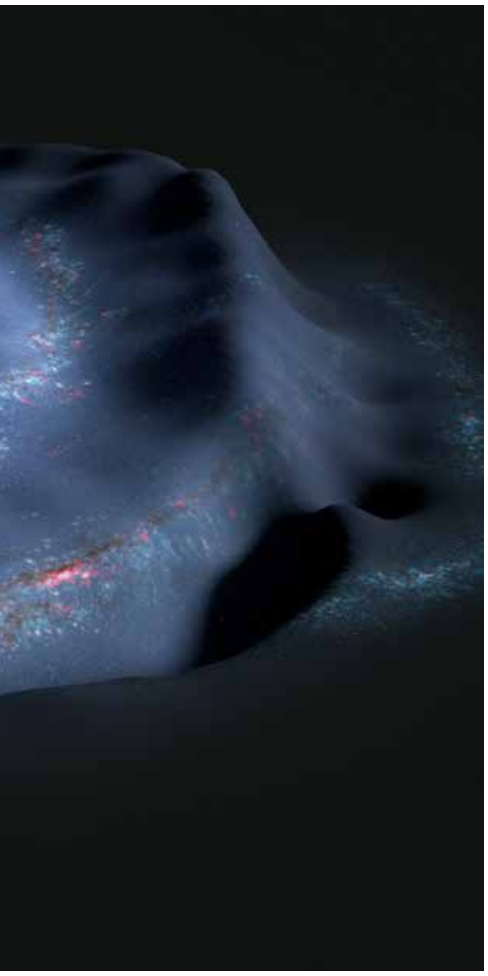

IMAGE: T. MUELLER/NASA/JPL-CALTECH

in order to calculate the chemical abundances from the measured spectral lines. For this, the paradigm of thermodynamic and hydrostatic equilibrium must be abandoned.

Models that do not rely on local thermodynamic equilibrium (non-LTE models) were developed as early as the 1970s. However, the practical application of these models in the analysis of stellar spectra became possible only about twenty years ago, with the development of powerful supercomputers. This has mainly to do with the countless excitation levels of atoms and molecules. For example, to represent the atom of a neutral iron, researchers must account for more than 600 energy levels, nearly 8,000 level radiative transitions, and 39,000 transitions caused by inelastic processes in collisions between iron and other atoms. In the beginning, the model atmospheres were one-dimensional. This was followed by a progression to two-dimensional calculations. Only recently it became possible to calculate non-LTE radiation transfer with three-dimensional convective models. However, clever and efficient algorithms are needed so that a computer can compute such models in a reasonable amount of time. Bergemann is considered a pioneer in this field.

But how do you find out which calculation gives the correct result? Here, the Sun acts as a benchmark. Each granule on its surface represents a convection cell with hot gas rising in its center and cooler gas sinking along the darker edges. However, the chemical composition does not change. Thus, if a spectrum is taken from the central region and one from the edge of the solar disk, the analysis must yield the same elemental abundances.

An analysis like this is possible only with the new, three-dimensional, non-LTE models. They correctly reproduce the shapes of the spectral lines that emerge from the hot and cooler regions. All calculations of different patches on the solar disk and different level transitions must result in the same self-consistent value. The three-dimensional non-LTE models can thus be reliably applied to other stars. "I spend about 95 percent of my time working on models," says Bergemann. She came to astronomy rather by chance. Born and raised in Kazan, Russia, she first worked in geophysics. But she soon realized that this subject just didn't interest her. "To be honest, I found it rather boring," she recalls. Her parents, who are themselves physicists, gave her the following advice: "If you want to discover some-

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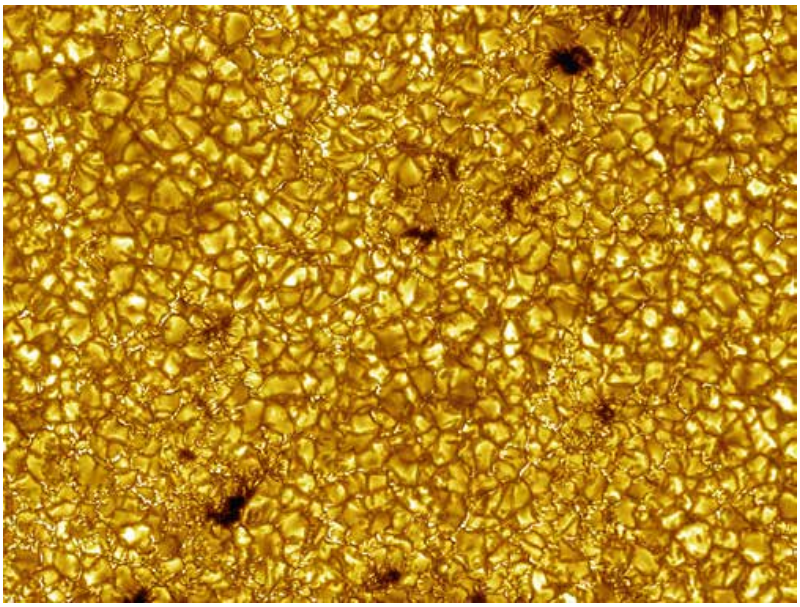

IMAGE: VASCO HENRIQUES

The Sun as a benchmark: many granules show up on the surface of our Sun. These convection cells, in which gas is constantly in motion, can be used to test models used for the spectral analysis of stars.

SUMMARY

The abundances of chemical elements in individual stars are like a fingerprint. They reveal the affiliation of a star to a stellar population.

The chemical differences of stars in the Milky Way or a distant galaxy can tell us a great deal about the formation and evolution of these stellar systems.

Calculating chemical abundances from a spectrum requires highly complex models as well as knowledge of properties of atoms and molecules, and of dynamic processes in stars.

thing fundamental, you have to go into astronomy." Intrigued, she followed this piece of advice.

She worked on stellar spectra as part of her diploma thesis at the University of Moscow. She turned down an offer of a doctoral position at Cornell University in favor of the Ludwig Maximilian University in Munich, where she received her doctorate in 2008. She then held Postdoc positions at the Max Planck Institute for Astrophysics in Garching and at the University of Cambridge before coming to the Max Planck Institute for Astronomy in Heidelberg in 2014. She now heads a Lise Meitner Group there.

Her analytical models are key to understanding vastly different astrophysical problems. It is not easy to pick out individual results from the many. But a recent event from the history of our Milky Way brought it to light. The Milky Way is a typical spiral galaxy in which most stars are associated to and move within the disk. But stars can also be found outside the disk – in the Galactic halo. Among others, there are two small groups of stars in the halo, each about 14,000 light-years above and below the plane of the Milky Way disk.

Until recently, most experts assumed that these groups – called Triangulum-Andromeda (Tri-And) and A13 – once belonged to a dwarf galaxy. But then an international team led by Bergemann obtained the spectra of these stars. The surprising result: the members of these two groups in the halo have an identical chemical composition that is indistinguishable from that of stars orbiting within the disk of the Milky Way.

The galaxy disk oscillates

"These stars most likely migrated out of the disk and are not remnants of a dwarf galaxy that collided with the Milky Way," says Bergemann about the result, which has since been confirmed by numerous other teams. Such stellar migration can be explained by an oscillation of the galactic disk, which is triggered by the tidal interaction with a massive satellite galaxy passing nearby. Computer models show that in this process, the outer disk of the Milky Way oscillated by as much as 30 degrees and so stars like those in Tri-And and A13 groups can be relocated from the midplane into the halo. The Heidelberg researcher and her team thus added another piece to the big puzzle of the evolution of the Milky Way galaxy.

Another result leads even further back into the past. In the Big Bang nucleosynthesis, the two lightest elements hydrogen and helium were created almost exclusively, with traces of lithium. The first stars fused these nuclei to heavier elements in their interiors. Via strong winds and during the explosions of massive suns as supernovae, the newly created elements entered the interstellar medium, where they were available to form the next generation of stars. These, in turn, incubated heavier elements in their interiors. Because of this cyclical process, the universe accumulated the heavy elements necessary for the formation of planets and life.

The first generation of stars probably formed sometime between 100 to 300 million years after the Big Bang. Whether any of them have survived to this day is unclear; so far, none have been proven to be that ancient. However, there are some stars in the Milky Way that contain so few heavy elements that they must have originated from one of the first generations. Bergemann's postdoctoral researcher Camilla Hansen selected two of these stars and calculated their chemical abundances. A comparison with nucleosynthesis predicted by supernova explosion models proves that these two stars belong to the second generation and consist of matter that was ejected by stars with 25 and 19 solar

Paradigm shift: does a type Ia supernova always result from the explosion of a white dwarf after it accreted enough matter from the companion to reach the critical mass(left)? Maria Bergemann's research group doesn't think so. Far more often, white dwarfs merge with one another after dancing around each other for a while (right).

masses, respectively. In this way, we can learn about the extinct first generation of stars.

Last year, Bergemann caused a bit of a stir in cosmology. She published a paper that targets one of the pillars of this science of the origin and evolution of the universe: dark energy. According to the present knowledge, dark energy is the dominant component of the universe and acts like an overpressure valve in a steam boiler. It inflates space and makes it expand at an accelerated rate. A spectacular discovery for which the American researchers Saul Perlmutter, Brian Schmidt, and Adam Riess were awarded the Nobel Prize in Physics in 2011.

The findings of the three scientists are based on their observations of a certain type of supernovae, which can be observed up to great distances and thus far into the past of the universe. It was once believed that most of these supernovae – of the so-called Type Ia – were caused by an ordinary star orbiting a white dwarf star. During this interaction, the white dwarf draws hydrogen from the outer layers of the companion and grows as a result. If it exceeds a certain mass, it explodes. Because this always occurs at the same mass, no matter how large the white dwarf was to begin with, all Type Ia supernovae are expected to be intrinsically equally bright and make excellent distance indicators. At least in theory. In reality, however, there are probably at least three other ways that a supernova Ia can form. For example, when two white dwarfs orbit each other, approach each other, and eventually collide. However, these types have distinctly different luminosities. This may affect the determination of the cosmic distance scale and the accelerated expansion calculated from that as well as the dark energy. How could we now find out which type of supernovae Ia predominates in space?

The different types of supernovae produce elements such as iron and manganese in different abundance ratios. And that's where Bergemann comes in. She and her colleagues determined the abundances of iron and manganese in 42 stars of varying ages. This allowed the team to reconstruct the history of manganese production in our galaxy. This led to an astonishing result. In order to explain the ratio of manganese to iron, three-quarters of all supernovae Ia in the Milky Way would have to be the result of merging

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IMAGE: NASA/SWIFT/AURORE SIMONNET, SONOMA STATE UNIV.

PHOTO: THOMAS HARTMANN

Against the mainstream: Maria Bergemann leads a Lise Meitner Group at the Max Planck Institute for Astronomy and has caused a number of paradigm shifts during the course of her research.

white dwarfs. This variety is therefore apparently the rule and not the exception as previously assumed. Could this have consequences for the theory of dark energy?

"I asked Adam Riess about that once," says Bergemann. "He wasn't thrilled about the idea. But he didn't elaborate on it." The new findings do not refute the concept of dark energy as a whole. However, they show that apparently some things are still unexplained in connection with this mysterious actor.

At any rate, Bergemann is looking forward to an exciting future. In 2020, she received the ERC Starting Grant worth nearly EUR 1.4 million for her "ELEMENTS" project. This will allow the industrious researcher to hire additional team members, who she needs for the 4MOST and WEAVE measurement programs. 4MOST – a project run by the European Southern Observatory (ESO) in Chile in which the Heidelberg Max Planck Institute plays a major role – will obtain high-quality spectra of more than 18 million stars in the southern sky. The WEAVE project on La Palma, in turn, will be recording millions of stellar spectra in the northern sky. Bergemann is now eagerly awaiting this treasure trove of data. But it all began with the discovery of the spectrum of the Sun more than 200 years ago.

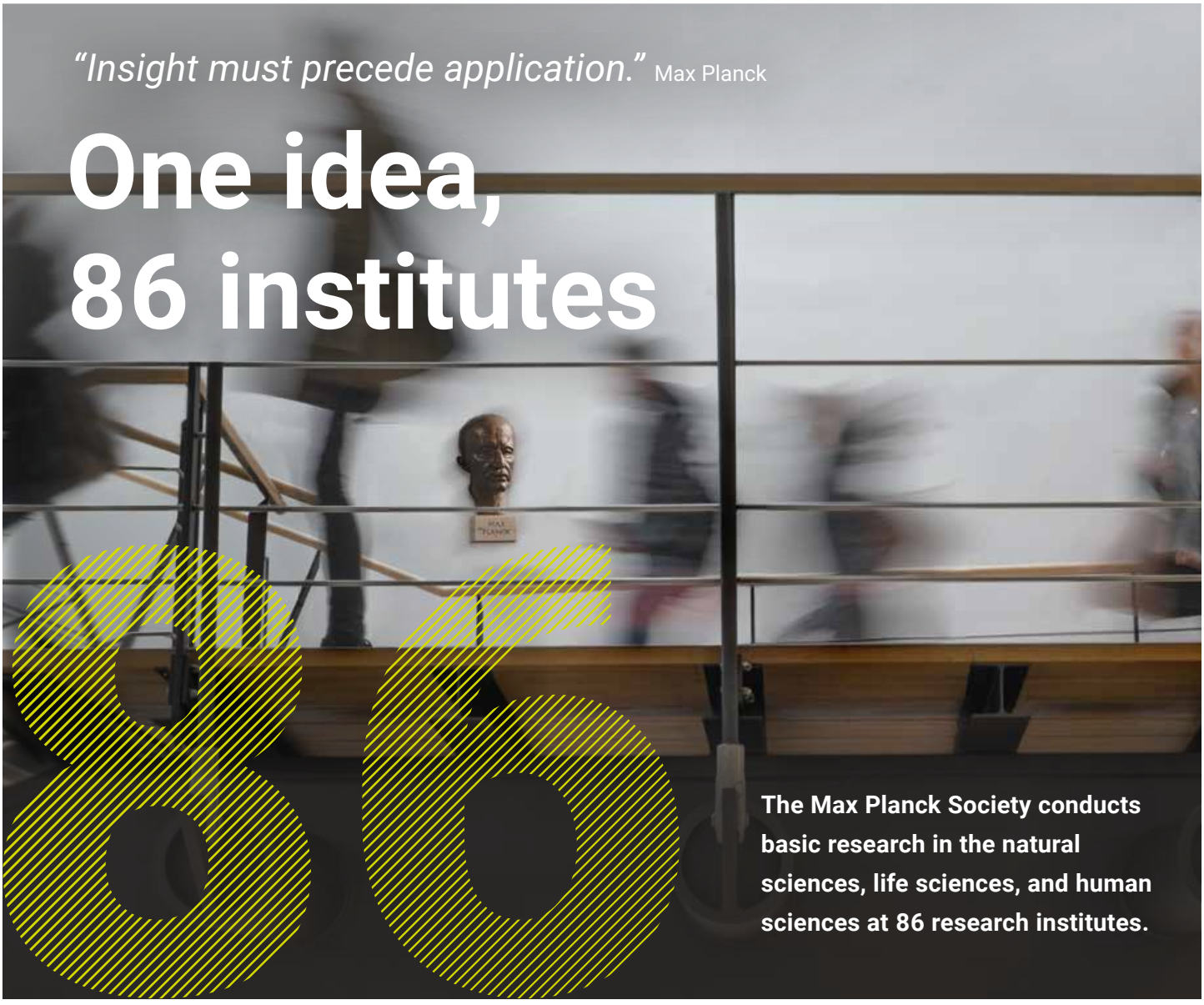
GLOSSARY

THE MILKY WAY
is a spiral galaxy with an estimated 200 to 300 billion stars. One of them is our Sun. The galaxy has the shape of a Frisbee, the edge of which arcs slightly. It measures about 100,000 light-years in diameter and is enveloped in a spherical halo.

SPECTRAL ANALYSIS
is a method that involves splitting the light emitted by an object into a "rainbow" by optical instruments. In the case of the Sun and other stars, characteristic lines appear in their respective spectra; these indicate certain chemical elements. This allows the chemical composition of these distant celestial objects to be studied.

“Insight must precede application.” Max Planck

One idea, 86 institutes



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Sculpted by melting ice: thermokarst lakes, like the ones shown here on the Kolyma River in Siberia, can form when the permafrost thaws. Global warming is intensifying this process.

PHOTO: MARTIN HEIMANN/MPI FOR BIOGEOCHEMISTRY

THAWING PERMAFROST

TEXT: KLAUS JACOB

Over a trillion tons of carbon are sequestered in permanently frozen soils (permafrost), especially in the Arctic Circle. But this frozen ground is steadily thawing as a result of climate change. Whether or not this will lead to the release of large quantities of greenhouse gases is one of the vital unresolved questions in climate research. Mathias Göckede, who heads a research group at the Max Planck Institute for Biogeochemistry in Jena, is among those looking into this question and he has already come up with some surprising answers.

The terrain doesn't exactly look as if it could be helping to fuel global warming – there are no open-pit mines from which bucket-wheel excavators are scooping out coal, no oil industry drilling rigs, and no forests threatened by drought or slash-and-burn agriculture. Instead, the vegetation is rather sparse, only broken now and then by small groups of trees, and a scattering of smaller and larger lakes, partly connected by natural channels. Many permafrost areas display a peculiar charm all their own. Yet, as idyllic as they may seem, the lakes bear witness to a profound change, because many of them have only been created since global warming has been causing once permanently frozen soils to thaw, which could also dissolve the carbon reservoir stored within the permafrost. According to one theory espoused by climate researchers, as temperatures rise, large quantities of this element – which had previously been bound by year-round frost – could escape into the atmosphere in the form of the greenhouse gases methane and carbon dioxide, which would accelerate global warming and thus climate change. Mathias Göckede, who heads a research group at the Max Planck Institute for Biogeochemistry in Jena, is currently investigating the extent to which this fear is justified.

About a quarter of the landmass in the northern hemisphere, including almost the whole of Greenland, large parts of Siberia, northern Canada, and Alaska, is considered a permafrost zone. Experts estimate the organic carbon content of these regions at around 1,500 billion tons, which is theoretically enough to triple the concentration of greenhouse gases in the atmosphere, which means that there is a huge potential for the far north to intensify global warming. The latest report by the Intergovernmental Panel on Climate Change also confirms this. They warn that thawing permafrost is extremely likely to play a role in changing the climate over the next few centuries. Moreover, if the warming exceeds a critical value, this zone could thaw even further, and the process would become irreversible. Because of the self-reinforcing mechanism involved, the system could go beyond a tipping point.

However, it has not yet been clarified how rapidly this process would unfold and what quantities of greenhouse gases would be emitted in the process. We simply don't have the data. While weather data has been recorded for more than a century, researchers have not been concerned with permafrost soils until recently. Thus far, the available measurement series are not long enough to be able to show a reliable trend against the background of natural weather fluctuations. Winter snowfall can be heavy at times but less extreme in other years; some summers can be extremely dry and some are extremely warm, and then again others are very cold. The COVID-19 pandemic has made research even more difficult: all research trips were canceled during a period of almost two years resulting in gaps in some data series. However, Göckede and his team were fortunate: their Russian colleagues downloaded the data from their devices for them. They were also

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able to resume travel as early as September. "Many of my international colleagues were envious because most of them were not yet able to access their survey sites," says Göckede.

Even without measurements, it is evident that something is changing in the far north. Building foundations are subsiding because the thawing ground no longer supports them. Following a warm, dry summer in 2019, a house collapsed in Chersky where Göckede's research base is located, leaving the elongated building without its central section. And the fuel storage tanks of a combined heat and power plant in the industrial city of Norilsk ruptured in May 2020, resulting in an environmental disaster when more than 20,000 tons of diesel spilled out. Landslides are affecting slopes, and deep craters and lakes are forming as well. Fires ignited by lightning during the increasingly frequent thunderstorms are also rising. "Fires had been extremely rare around Chersky until a few years ago," Göckede explains. A number of wildfires have ravaged areas close to his team's study sites during the past two years, even in floodplains that were assumed to be wet. It is of little consolation that the carcasses of Ice Age animals, such as mammoths or cave bears, will emerge from the eternal ice and can then be studied as a result of climate change.

Göckede is taking detailed measurements to determine whether additional greenhouse gases are being released through the warming of the permafrost regions and, if so, how much, whereby it is obvious that both methane and carbon dioxide could be released into the atmosphere in the process. To understand this, one first has to consider the forests of the warm south: trees in temperate latitudes and the tropics absorb carbon dioxide from the air, which they then incorporate into their leaves, branches and trunks. When the leaves fall or a tree topples over, microbes decompose the organic matter thus releasing the carbon, so the overall balance in mature forests and a stable climate should be equalized. Different rules apply in permafrost zones, where the upper layer of the soil thaws in the summer and refreezes in the winter. This so-called active layer, which is not part of the permafrost, is between 40 centimeters and several meters thick. Although sparse vegetation often thrives on it, not all of its detritus decomposes, not only because of the low temperatures, but also due to waterlogging, which is common in Arctic ecosystems. Carbon has therefore accumulated over thousands of years – frozen within the soil, sometimes to a depth of several hundred meters.

If the average temperatures in the Arctic zones rise, which has been observed in recent decades, the soil can thaw to greater depths. This destabilizes the underlying permafrost layers and microbes break down the carbon contained within them, producing greenhouse gases, such as CO_2 and CH_4, in the process. The microbial community in dry ecosystems with well-oxygenated soil primarily produces carbon dioxide. In waterlogged ecosystems, by contrast, anaerobic microorganisms produce methane, which has a particularly strong greenhouse effect. The extent to which thawing permafrost will exacerbate climate change will be significantly affected by the quantity of methane released into the atmosphere.

The journey there is arduous enough

But accurately measuring the gas exchange between air and soil is truly a challenge. Göckede and his team first have to travel to their study area, which is arduous enough: after flying to Moscow, they then fly another six hours to Yakutsk, the largest city in

Climate catastrophe: in 2020, the thawing ground caused the tank farm of a combined heat and power plant in the industrial city of Norilsk to subside and rupture. Over 20,000 tons of diesel spilled out and polluted the environment.

the Siberian permafrost zone. Then they take another four-hour flight on a smaller plane to Chersky, which has a population of just 2,500 and lies about 100 kilometers from where the Kolyma River flows into the Arctic Ocean. Once they reach the "Northeast Science Station", a Russian research base, they then set off for their research sites. Their instruments are installed on two towers in an undisturbed area of the tundra in the Kolyma River's floodplain. These devices measure the concentrations of methane, carbon dioxide, and water vapor 20 times per second. Airflows are also recorded. This high frequency is necessary in order to capture the turbulent exchange processes that take place in the near-surface atmosphere. It is a powerful approach to determine the quantity of carbon being absorbed or released by the soil and vegetation. The inhomogeneity of permafrost zones presents another research problem: no two areas are alike – here a recently formed lake, there a patchy group of scraggly trees, here a floodplain, there a scarp. One would actually have to run numerous test series to get a proper understanding of this localized fragmentation. However, there is one type of terrain that is common, which is characterized by numerous wedge-shaped ice patches that crisscross the ground like a network. When heated, these ice wedges thaw out more and the ground can subside in the affected areas, transforming a previously flat, largely homogeneous tundra surface into a landscape of hollows in which water collects, interspersed with relatively dry islands. It is expected that this process of ice wedge degradation will occur frequently in the far north over the coming decades. The Max Planck researchers artificially replicated this effect by draining an area of about 200 meters in diameter with the aid of a drainage ditch to see how it changes carbon flows.

Currently almost no additional greenhouse effect

This experimental area has now been in existence for around seventeen years. Following an initial four-year experiment and a subsequent break of several years, Göckede's team has been continuously measuring and observing how the landscape on the artificial island has been changing for the past eight years. The change is clearly visible: vegetation is thriving and growing taller and, instead of just grass, bushes now grow there as well.

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PHOTO: IMAGO / ITAR-TASS

Of course, the greenhouse gas emissions are of particular interest. "We were surprised by the results," says Göckede. Because the largely dry artificial island is no longer a suitable habitat for anaerobic microbes, methane emissions decreased by roughly fifty percent compared to an undisturbed reference area, as the measurements showed. In contrast, the situation regarding carbon dioxide is rather different: the ecosystem should actually have absorbed more CO_2 as the vegetation increased. Yet, the opposite proved true overall: the vegetation actually did suck more carbon dioxide out of the air, but the ecosystem as a whole was now close to neutral regarding CO_2 exchange. This effect was due to increasing emissions from the thawing permafrost, for which the additional uptake capacity of the vegetation was unable to compensate.

Because methane is a more efficient greenhouse gas than carbon dioxide, there is currently almost no net additional greenhouse effect. Less methane, more carbon dioxide – "the net effect is amazingly balanced," Göckede explains. Nobody had expected that. So, despite the significantly altered properties of the ecosystem, the greenhouse gas balance in disturbed permafrost areas could be similar to that of undisturbed areas in the immediate surroundings on the long-term. But, whether these results can be applied to other Arctic regions remains unclear and only experiments at other sites will be able to shed light on this question.

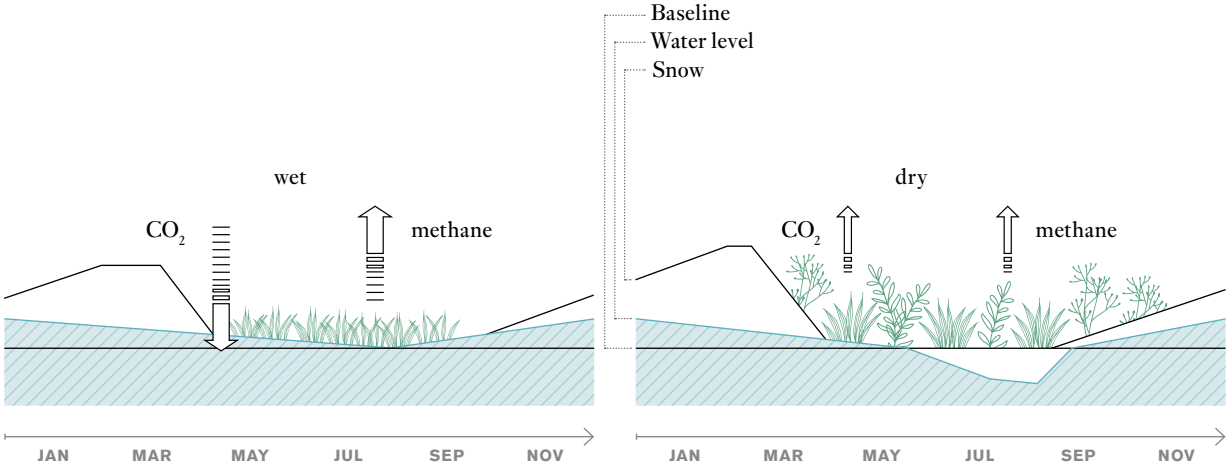
Probably more greenhouse gases in the future

Göckede is rather pessimistic about the long-term development because, as he explains, even if it continues for a few years or decades, the positive effect of enhanced vegetation growth on the carbon budget of permafrost ecosystems will not be permanent, because a point will eventually be reached after which no further growth will be possible – bushes and trees cannot grow infinitely into the sky. It is therefore likely that carbon dioxide and methane emissions will increase as a result of thawing soils.

Another thing that Göckede's team discovered is the strong influence of snowpack on permafrost. When three times as much snow fell in one winter as in an average year, the upper soil layer in some areas was more than ten degrees warmer than usual, despite the fact that the air temperature was virtually the same as in previous years. Snowy winters can significantly accelerate permafrost thaw because snow insulates the ground.

Russian researchers are taking an original approach to preserving permafrost and improving its greenhouse gas balance: they are relying on ruminants to do the work. They created the "Pleistocene Park" around 25 years ago and have since brought in entire herds of horses, musk oxen, bison, goats, sheep, and recently even camels at considerable expense. Their thinking is that the animals' excrement will fertilize the soil, thus promoting plant growth and increasing carbon uptake. The animals also scrape the snow aside or compact it in winter, which reduces the insulating effect, which could keep the permafrost frozen despite rising temperatures.

Relatively dry islands form between the newly formed lakes in the thawing permafrost (right). Compared with the original wet ecosystem (left), the water table on the islands (shaded blue area) falls in summer, allowing taller vegetation to grow there. Because of climate change, snow also accumulates earlier in the fall and thaws a bit faster in the early summer. Unlike the wet ecosystem, the dry ecosystem emits CO_2 but releases less methane, so its net greenhouse gas balance is roughly the same.



GRAPHIC: GCO BASED ON MATHIAS GÖCKEDE/MPI FOR BIOGEOCHEMISTRY

PHOTO: MARTIN HEIMANN/MPI FOR BIOGEOCHEMISTRY

Eroding permafrost cliffs: the soil on the banks of the Kolyma River slides over the still-frozen layers, carrying organic material with it, which then gets washed away by the river. Much of it decomposes, releasing carbon dioxide.

SUMMARY

If the permafrost in the Arctic Circle were to thaw as a result of global warming, large amounts of carbon dioxide and methane could be released, which would intensify climate change.

Increased plant growth enables the ecosystem to absorb more carbon dioxide. For the time being, according to measurements by a team at the Max Planck Institute for Biogeochemistry, this process is able to compensate for the increased activity of microorganisms that release carbon dioxide or methane.

In the long run, however, vegetation will reach a growth limit and will not be able to store more carbon dioxide, so emissions from microorganisms will likely predominate.

Whether this approach will prove successful is still unclear. In fact, the landscape has since undergone a significant change, with continuous vegetation now thriving where there had been only isolated clumps of tall grass in the past. "In qualitative terms, the experiment has worked," Göckede says. But as a scientist, he insists on reliable data: "What I want to see are measurement series, and they don't yet exist." He himself has been supporting the experiment for two years by taking sporadic measurements. But he points out that these have been only snapshots, which do not count as evidence. "We would need a large-scale monitoring system." Göckede also doubts that the process would even be feasible on a larger scale, because the cost of bringing in and caring for the animals is enormous. Nevertheless, he thinks it is important to test such approaches. Every success, no matter how small, could make an important contribution towards preserving the permafrost.

Naturally, the best way to preserve permafrost is effective climate protection. Humans will ultimately decide how the climate changes over the coming decades and centuries – and with it the regions in the far north. Göckede, for one, is glad that he can still experience what he calls this "fascinating landscape" in its current form. "Who knows if it'll still exist in twenty or thirty years?" He will continue to monitor the changes in the course of an EU-funded ERC project. In addition to the long-term experiments, he is planning to do more research into nonlinear processes that could fundamentally change the appearance of the Arctic. For example, he will be looking at what happens when lakes form – a process that is likely to become more common as warming increases. Because the insulating effect of an expanse of water is similar to that of a deep blanket of snow, one would expect the ground beneath it to thaw more rapidly. How exactly does this affect the greenhouse gas balance and what would happen if the lake were to drain away? Many such disruptive processes are taking place in the Arctic that remain largely unexplored, so there is still a lot for researchers to do in the far north.

PHOTO: ANDREA MÜLLER

A practiced team: many plant species belonging to the *Tococa* genus live symbiotically with ants. The small insects keep pests at bay. In return, the plant provides the ants with food and shelter.

Max Planck researchers are currently collaborating with partners in over 120 countries. In the following article they talk about their personal experiences and impressions. Andrea Müller from the Max Planck Institute for Chemical Ecology in Jena spent four months in Peru. She has been studying plants that live symbiotically with ants in the Tambopata National Reserve in the southeast of that country. Below, she shares her enthusiasm for the rainforest and how, in addition to the coronavirus, protesting coca farmers can jeopardize scientific field work.

For me, the rainforest is nature in its purest form. Nowhere else in the world is there so much life and biodiversity. It always thrills me to wake up early in the morning to the sounds of birds and monkeys, to breathe in the fresh air after a tropical downpour, and to experience the countless plants and animals. My passion for the jungle has taken me to South America once before. I went to work as an intern on a reforestation project in Ecuador. Back then, we lived in the middle of the forest, a three-hour walk from the nearest road. There was no electricity, and we got our drinking water from the river. Afterwards, I backpacked across the continent alone, traveling from south to north. It was a stroke of luck when the Max Planck Institute in Jena offered me the opportunity to conduct research in Peru.

My doctoral thesis focuses on plants within the *Tococa* genus, which live symbiotically with ants. The plants provide the insects with shelter in the form of specialized cavities. In addition to sheltered accommodation, the ants also receive food in the form of nectar. In return, the ants defend the plant against predators, such as caterpillars. I'm interested in discovering exactly how the partners live together symbiotically. Are the plants still able to successfully defend themselves using their natural chemical defense, even when no ants are present? Or do they perhaps only start specifically attracting ants when they are attacked by caterpillars? To find out, I compare plants that are colonized by ants with those from which I have removed the ants. I collect samples of volatiles and leaves to analyze their chemical constituents at the Institute in Jena.

The plants I study grow in the Tambopata National Reserve in southeastern Peru. Just getting there is an adventure: from Lima, you fly over the snow-capped Andes and the Amazon rainforest to Puerto Maldonado. From there, you continue for about three hours in a wooden boat, traveling upstream on the Río Tambopata to the lodge, passing capybaras, turtles and caimans sunbathing on sandbars along the way.

The lodge's wooden cabins are usually occupied by tourists and scientists from all over the world. However, during my last stay, the COVID-19 pandemic meant that there was no-

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LIMA, PERU

one there except me and Victor, the manager of the facility, and his family. We met regularly for meals and every now and then for a night excursion. The light of a flashlight often reveals frogs, and occasionally spiders and scorpions. They don't bother me in the least. But I'm afraid of snakes – all the more so as Peru is home to numerous venomous species.

I have sixty *Tococa* plants growing in a clearing about ten minutes from the station. The footpath to get there leads across a small river with a now weathered wooden bridge. It's always nerve-wracking to haul my aluminum boxes over the bridge to the site. They contain liquid nitrogen and expensive research equipment to obtain and preserve the scent samples. If something were to happen to the equipment, I wouldn't be able to find a replacement in Peru.

On one of my last field trips, I wasn't able to collect any volatiles because my equipment got stranded in the middle of nowhere on route. When I fly to Puerto Maldonado from Lima, I send the heavy equipment ahead in the bus. One time, the bus was unable to move for days because protesting coca farmers had set up a roadblock. The boxes didn't arrive until I was just about to leave. All I could do was send them back the same way they came.

Notwithstanding such mishaps, I've now successfully completed my experiments. It's a relief, in particular because I lost a lot of time at the beginning of the corona pandemic. During the spring of 2020, I was stranded in Lima for weeks; I wasn't allowed to set foot on the university campus because of the lockdown, nor could I get a return flight to Europe. But after six weeks I managed to catch a flight to France and traveled home from there. If all goes well, I'll be completing my doctorate within the next year. After that, I definitely want to go back to Peru again. As for the future, I hope it involves ant-plants or other adventures!

PHOTO: PRIVATE

Andrea Müller

29, studied biochemistry and chemical biology at the University of Jena. For her bachelor's and master's degrees, she conducted research at the Max Planck Institute for Chemical Ecology in Jena. She has been a doctoral researcher in Axel Mithöfer's working group there since February 2018. In Peru, Andrea Müller has studied the symbiosis between tropical plants and ants.

FIVE QUESTIONS

ON MENTAL HEALTH DURING THE COVID-19 PANDEMIC

FOR TANIA SINGER

Ms. Singer, lockdowns turn everyday life completely upside down. How did people living in Berlin experience the contact restrictions in 2020 and 2021?

TANIA SINGER There was a significant decline in mental health during the first lockdown in March 2020: more people suffered everything from anxiety, stress and loneliness to depression. Following this shock effect, people then recovered a little as restrictions were eased during the summer. However, during the second, even longer lockdown the usual resilience of Berliners once again declined steadily from month to month. They were unable to resort to coping strategies because the social contacts necessary for these to be effective were severely restricted, which resulted in a significant fatigue effect in the winter of 2020/2021.

Which groups were most affected?

Predominantly the 18 to 25-year-olds and women in general suffered a lot due to the COVID-19 pandemic. The first lockdown had already weakened their resilience, after which the downward spiral started all over again and things gradually went downhill. Resilience can often be restored through social contacts and by getting together with other people, but the two lockdowns imposed severe limitations on these options.

How did you discover this?

In the CovSocial project, we studied not only mental health and resilience, but also social cohesion, which is observable in such things as the trust we place in others in social networks and personal encounters. Our observation period extended from the first lockdown in the spring of 2020 through the easing of restrictions in June to the second, longer lockdown in the fall of 2020 and winter of 2021. We mailed invitations requesting participation in the project to a random selection of Berliners aged between 18 and 65 and also advertised it on posters in the subway.

And then the project was divided into exactly two phases, right?

Exactly! Phase one involved an online survey in which we asked 'How are you?', 'How did you experience the pandemic and the various associated contact restrictions?'. In combination with stress hormone measurements that we took, this resulted in the analysis of the respective participant's current state. In phase two, which is ongoing, we want to offer people help with dealing with the increased stress levels and loneliness by hosting online mental training courses involving short daily exercises, which are designed to actively point out potential ways out of isolation, for example, with the aid of the CovSocial app. During this phase, we will continue to measure participants' stress hormone levels and conduct surveys on such things as their levels of compassion and empathy, and on parameters for mental health. This will tell us what has changed in relation to the first phase and whether people are feeling any better after the training.

What social changes were you able to observe within the community?

Social cohesion, i.e., the sense of belonging to certain groups – actually more an economic and political construct than anything else – suffered immensely during the second lockdown. The macroscopic social fabric is beginning to fray, and solidarity with others is decreasing, which means that contact restrictions also have a significant effect on socially relevant variables. This is something that the government ought to bear in mind when considering any further lockdowns, as it is likely that every new lockdown will lead to even greater fatigue. In other words, society is becoming increasingly vulnerable and resilience is continuing to decline. If depression and loneliness are on the increase among adolescents, who are at an age at which the brain is still very malleable, then the situation is extremely serious in terms of mental illness and suicidal ideation. While it may not be as immediately evident as a COVID-19 infection, it's still a huge problem. Our goal is to identify people who are particularly vulnerable, in order to provide them with better support and assistance in their daily lives.

Interview:
Valerie Zöllner / Barbara Abrell

www.mpg.de/podcasts/pandemie-psychische-gesundheit (in German)

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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