04 | 2020

MAX PLANCK
Research

CELLULAR BIOLOGY
DNA origami

IRON RESEARCH
Energy revolution in the blast furnace

GRAVITATIONAL PHYSICS
A big fish is making big waves

ONE WAY OR ANOTHER

PHOTO: SCIENCE PHOTO LIBRARY/FRANS LANTING, MINT IMAGES

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Not all eggs are the same: birds' eggs have an incredible range of different sizes, colors, patterns and shapes. Everyone knows that no one egg is the same as another, and that diversity plays a key role in nature. However, this makes attempts to find out why this is so, and to explain the small (and large!) differences all the more exciting. This field of research combines disciplines such as biology, anthropology and astronomy.

EDITORIAL

Dear reader,

Most people would probably say that one egg is just like another. However, only eggs from industrially farmed, hybrid chickens show that degree of similarity. Nature is characterized by diversity – a wealth of variety that astonishes, fascinates, and sometimes even confuses us. In our standardized world, we are surrounded by millions of identical objects. Understanding diversity, recognizing its value, and looking beyond differences to see what things have in common is anything but trivial.

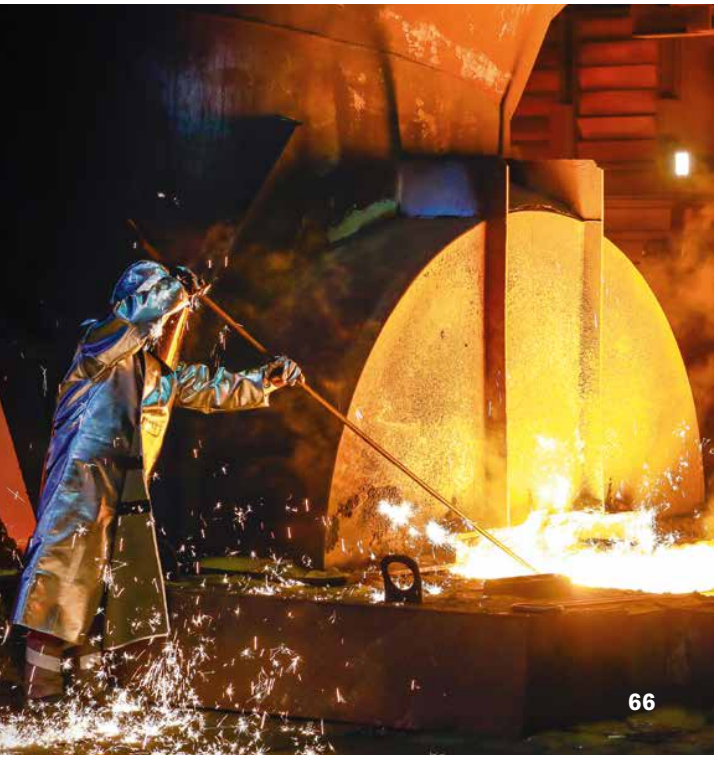
Diversity has challenged scientists since time immemorial, as the "Focus" section in this issue shows. One classic example is the biological identification of species. If you try to identify plants just from the appearance of their leaves, for example, you can easily make a mistake. Even closely related plants can have very different leaves in some cases. Genetic analysis is now helping to uncover the secret of leaf shapes.

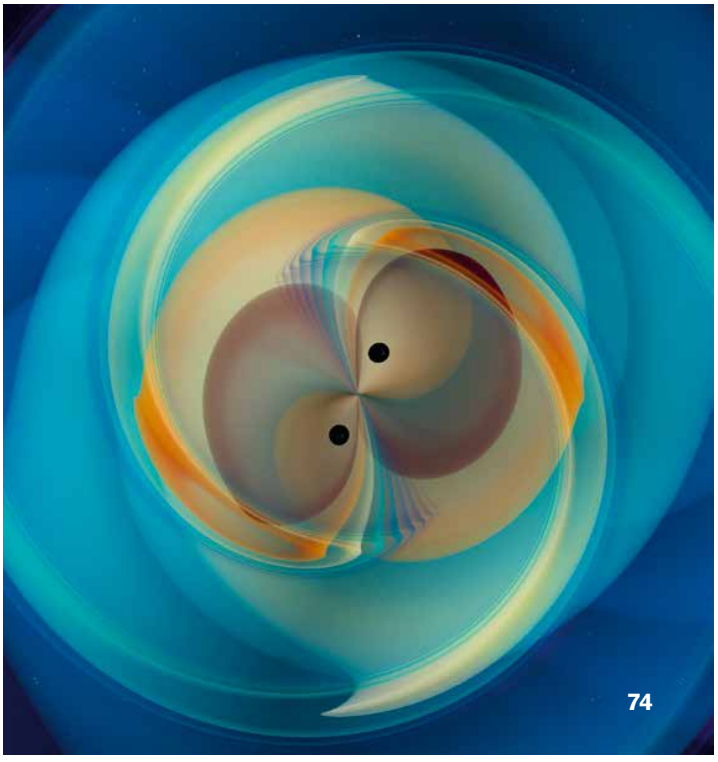
And diversity is not just unique to nature; humans too have developed a variety of cultures that impact our perception and actions in different ways. However, until recently, psychological research has paid very little attention to this phenomenon. Comparative cultural studies are now attempting to document diversity and identify uniquely human traits that transcend all peculiarities.

Science has also created a system that classifies the multiplicity of form beyond our planet. In the 1920s, Edwin Hubble did pioneering work in the field of astronomy by classifying galaxies in space according to specific criteria. Today, researchers are exploring the role played by dark matter in various types of systems in the Milky Way.

We trust you will find plenty of interesting material among the many topics we cover in this issue, and hope you will enjoy reading it!

Your editorial team





PHOTOS: ADOBESTOCK (LEFT TOP); JULIA STEINIGEWEG (RIGHT TOP); PICTURE ALLIANCE/RUPERT OBERHÄUSER (LEFT BOTTOM); N. FISCHER, H. PFEIFFER, A. BUONANNO/MPI FOR GRAVITATIONAL PHYSICS, SIMULATING EXTREME SPACETIMES (SXS) COLLABORATION (RIGHT BOTTOM)

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Different leaf shapes are evidence of a clever adaptation to the environment.

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A SMART HOME
IN A SUN LIT FOREST

ON LOCATION

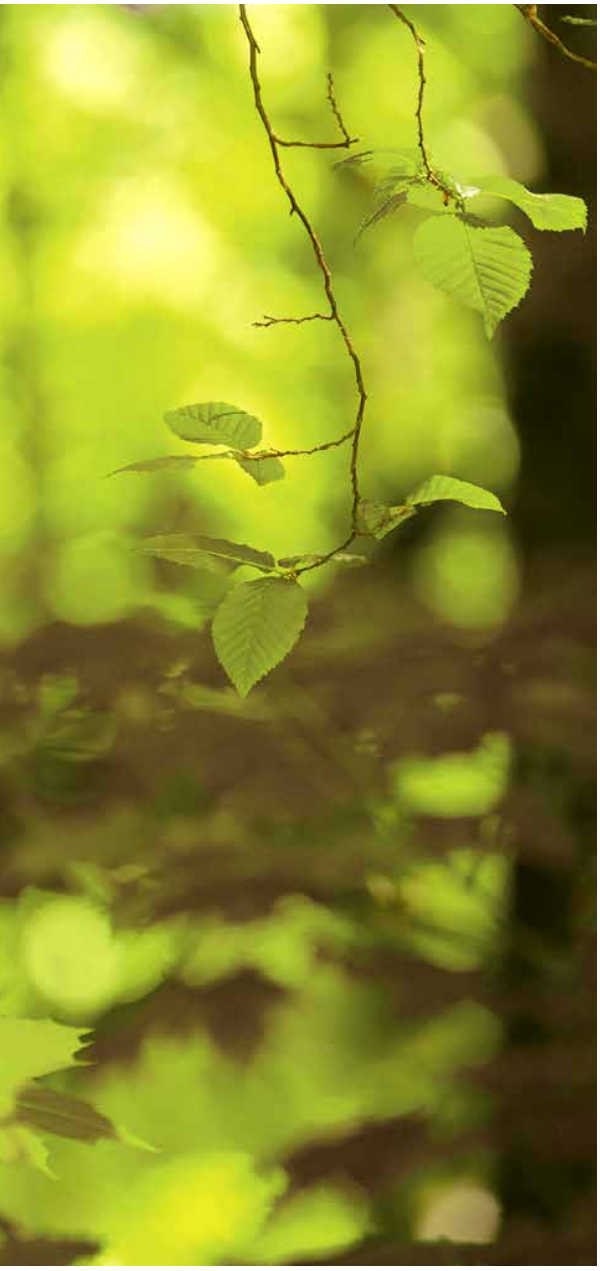
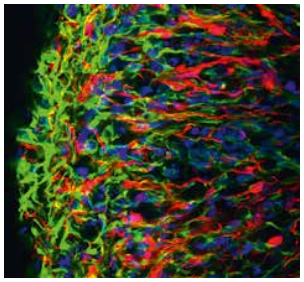


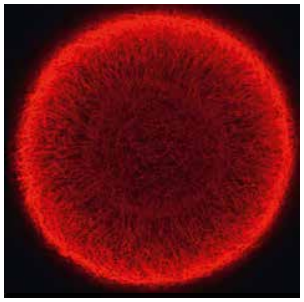
PHOTO: JULIUS KRAMER

The big double “00” is misleading. That sign on a door in the hotel corridor traditionally means “restroom”. But the inhabitants of this dwelling certainly aren’t likely to get much rest. They’re glad instead to have found such a comfortable and safe home for their new family. These blue tits have moved into a “Smart Nest Box” in Westerholz, a mixed woodland region in southern Germany. This state-of-the-art nest box was designed by the Max Planck Institute for Ornithology. The blue tit chicks have hatched and want to be fed – quite a job for their parents! With the aid of the Smart Nest Box, ornithologists can track exactly which birds enter and exit the nest and at what time. An RFID data logger system records the presence and identity of the parents, 24 hours a day, seven days a week. The birds carry tiny implanted transponders, allowing them to be individually identified. Coupled with a clock and two infrared light barriers, the system compiles an accurate activity profile for each of the breeding birds.

While blue tit pairs usually jointly rear their young, both partners may engage in additional sexual interactions. In recent years, it has become clear that this is far more common in blue tits than previously thought. What is the evolutionary advantage of rearing such “illegitimate” offspring? Thanks to the Smart Nest Box, the researchers have discovered that these chicks hatch earlier and are stronger than their half-siblings. In addition, nests containing only chicks from a cuckolded partner are rare, and in some of these cases, the social partner was found to be infertile. “Extramarital” copulation may, therefore, represent a kind of insurance against infertility.

Top: midbrain organoids under the microscope. Bottom: whole organoid (red: young neurons).





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

ORGANOIDS FROM A MACHINE

Sometimes, hundreds of thousands of active substances have to be tested in time-consuming, costly experiments to identify just one therapeutic. However, the automated production of organ-like tissues, known as organoids, promises to accelerate the development of new therapeutics in the future. Organoids are generated when precursor cells derived from body cells form three-dimensional tissue aggregates in special culture conditions. These mimic the tissue's characteristic properties better than conventional cell cultures. This organoid production process was developed by a team at the Max Planck Institute for Molecular Biomedicine in Muenster, and the technology transfer company Max Planck Innovation has now licensed it to the American biotech company StemoniX. The process facilitates the automatic generation of organoids that resemble the human midbrain – the part of the brain which produces the dopamine-producing neurons that are the first to die in patients with Parkinson's disease. Researchers can use it to generate and test up to 20,000 brain organoids a day. In comparison, manual processes only allow for the generation of a couple of hundred organoids in a day; moreover, these vary considerably and are therefore unsuitable for drug testing. StemoniX aims to use these automatically generated organoids to guarantee that its partners only develop the safest, most effective active substances for treating diseases such as Parkinson's.

www.mpg.de/15969879

AWARD-WINNING ★

ASIFA AKHTAR

The Director of the Max Planck Institute of Immunobiology and Epigenetics in Freiburg is to be awarded one of the German Research Foundation's Leibniz Prizes. The award recognizes her cell biological work on the mechanisms of epigenetic gene regulation and her contribution to the scientific understanding of chromosome regulation, also known as "dosage compensation". Asifa Akhtar has also held the post of Vice President of the Max Planck Society since July 2020.

PHOTO: WOLFRAM SCHEIBLE FOR MPG

VOLKER SPRINGEL

Another Leibniz Prize is to be awarded to the Director of the Max Planck Institute for Astrophysics in Garching. Springel is being honored for his work in the field of numerical astrophysics. He has developed new methods that can help to explain, amongst other things, how the diversely structured cosmos could have emerged from an early, almost uniform universe.

PHOTO: HEIDELBERG INSTITUTE FOR THEORETICAL STUDIES (HITS)

FIRST NATURE INDEX FOR GERMANY

The scientific journal Nature has now published its own evaluation of scientific achievements in Germany for the first time. The report states that Germany is maintaining its position as one of the world's research giants. The journal cites strong, steady scientific funding and long-term investment in basic research as keys to the country's success. However, a lack of diversity and slow adaptation to contemporary research directions could challenge Germany's prolific research record going forward. The Nature Index Germany is determined by counting the number of articles published by an institution in prestigious scientific journals. In Germany, the top positions in the Nature Index are held by three non-university research facilities – the Max Planck Society, followed by the Helmholtz and Leibniz Associations – while the two universities in Munich rank fourth and fifth.

IN BRIEF

PHOTO: WABENO/ISTOCK

A long way: the fall of 2015 saw many people fleeing on foot through the Balkans to central Europe. Since then, the EU member states have been struggling to agree on a joint course of action for their asylum policy.

FACING FACTS

Five years after the "long summer of migration" in 2015, the Max Planck Society's scientific initiative "Challenges of Migration, Integration and Exclusion" has published its research report. The researchers have made eight recommendations based on their findings and summarized them in a position paper on migration policy. In this paper, they argue that given the global challenges associated with climate change, globalization and demographic shifts, it is not only regrettable but actually quite dangerous for current discussions about migration to revolve primarily around irregular migration and asylum. Migration policy should instead be guided by facts. At the national level, the researchers suggest standardizing the fragmented legal framework and increasing the involvement of local authorities. Within the European Union, it is important to overcome the impasse regarding asylum and to shape a policy that is in accord with human rights.

www.mpg.de/16169506

GREEN LIGHT FOR MUNICH QUANTUM VALLEY

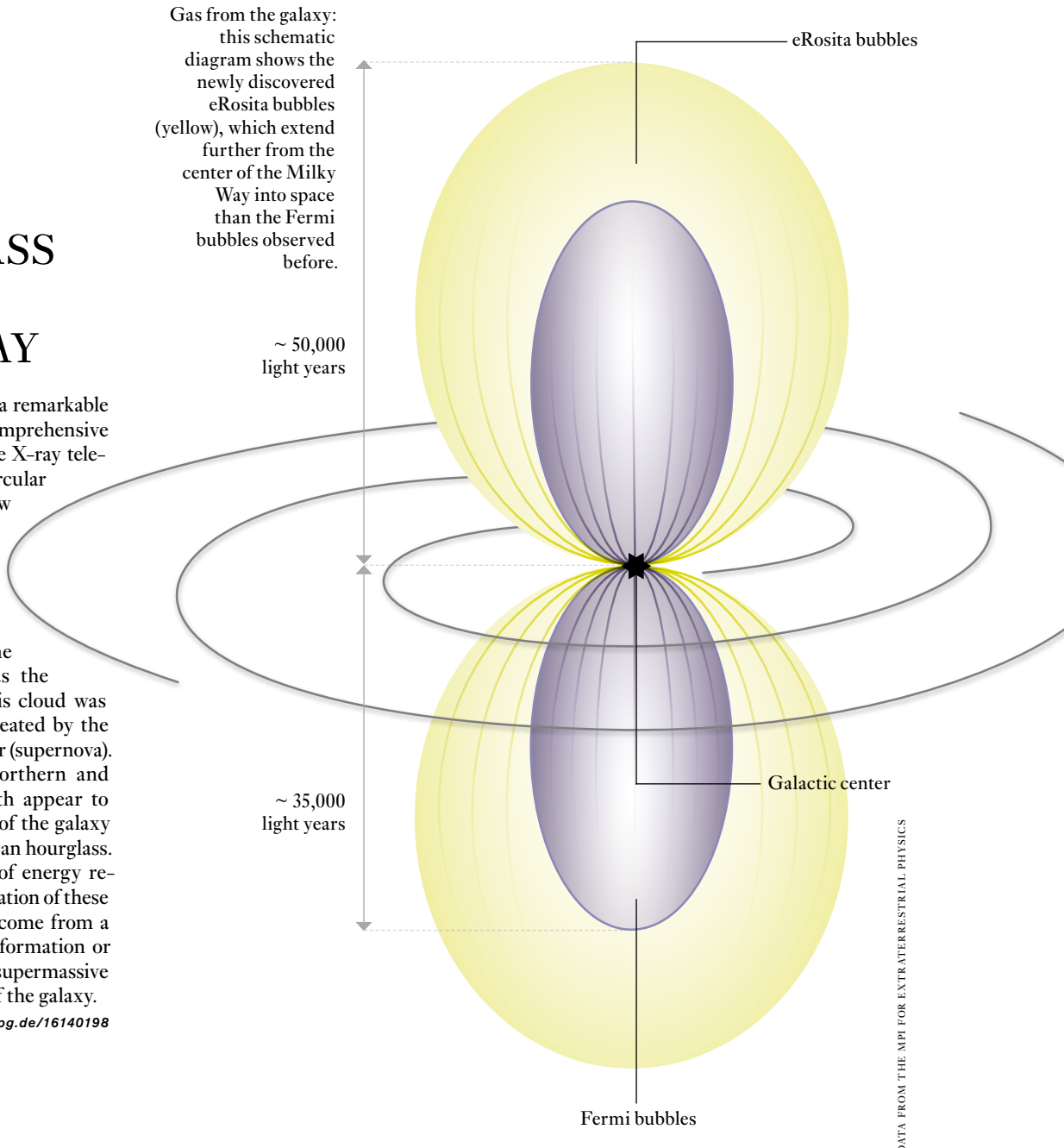
A quantum computer, tap-proof communication methods, and fundamental elements of quantum technology are just some of the goals that scientists will be pursuing in Munich Quantum Valley. Bavarian Minister President Markus Söder, Minister Hubert Aiwanger, Minister Bernd Sibler, President Thomas O. Höllmann (Bavarian Academy of Sciences and Humanities), President Reimund Neugebauer (Fraunhofer-Gesellschaft), President Bernd Huber (Ludwig Maximilian University of Munich), President Martin Stratmann (Max Planck Society), and President Thomas F. Hofmann (Technical University of Munich) gave the green light for the research initiative by signing a declaration of intent. Over the next two years, the State of Bavaria will provide start-up financing to the tune of € 120 million, some of which will be used to set up a technology park. With this backing, Munich Quantum Valley also intends to apply for funding from the federal government, which is making € 2 billion available for the development of quantum technologies as part of its stimulus package for the future.

www.mpg.de/16258573

AN HOURGLASS IN THE MILKY WAY

Astronomers have made a remarkable discovery in the first comprehensive sky map produced by the X-ray telescope eRosita – a huge circular structure of hot gas below the plane of the Milky Way that occupies most of the southern sky. Scientists have long known of a similar cloud structure in the northern sky, known as the "North polar spur". This cloud was thought to have been created by the explosion of a massive star (supernova). Viewed together, the northern and southern structures both appear to emerge from the center of the galaxy in a shape reminiscent of an hourglass. The enormous amount of energy required to power the formation of these gas bubbles could have come from a period of intensive star formation or from an outburst from a supermassive black hole at the center of the galaxy.

www.mpg.de/16140198



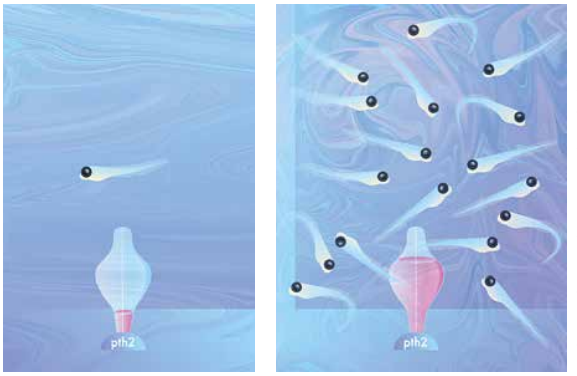
Gas from the galaxy: this schematic diagram shows the newly discovered eRosita bubbles (yellow), which extend further from the center of the Milky Way into space than the Fermi bubbles observed before.

GRAPHIC: GCO BASED ON DATA FROM THE MPI FOR EXTRATERRESTRIAL PHYSICS

A RISK CALCULATOR FOR COVID-19

A computer program can now be used to determine the risk of becoming infected with the coronavirus Sars-CoV-2 following exposure to aerosol particles in an enclosed space. The model developed by researchers at the Max Planck Institute for Chemistry in Mainz uses parameters such as the size of the room, the number of people in it, and their activity in order to estimate the risk of infection, not only for everyone in the room but for specific individuals as well. The algorithm also calculates how much the risk is reduced when people wear masks or when the room is regularly ventilated. However, it cannot assess the risk of becoming infected by larger droplets transmitted over a short distance. The algorithm is publicly available on the Institute's website.

www.mpg.de/16015780



GRAPHIC: MPI FOR BRAIN RESEARCH / J. KUHL

Measuring sociability: the levels of a hormone produced in the brains of zebrafish indicate whether or not an individual fish is surrounded by many others of its kind.

SOCIAL DISTANCING IN FISH BRAINS

Social isolation can have dire effects on both humans and animals. An international research team that includes scientists from the Max Planck Institute for Brain Research has investigated the effects of isolation on the brains of zebrafish by measuring the activity of thousands of genes. The few genes that displayed changes in activity included the gene for "parathyroid hormone 2" (pth2). This acts like a barometer of the social environment: the more members of its species that are present in an individual zebrafish's environment, the more pth2 hormone is produced in its brain. If a zebrafish kept in isolation is placed in a tank with others of its species, the levels of this parathyroid hormone rise within a short time. According to the researchers, the production of this neurohormone is controlled by the lateral line organ, a band of sensory cells that react to mechanical stimuli and are used by the fish to sense the swimming movements of their kin.

www.mpg.de/16105035/1202

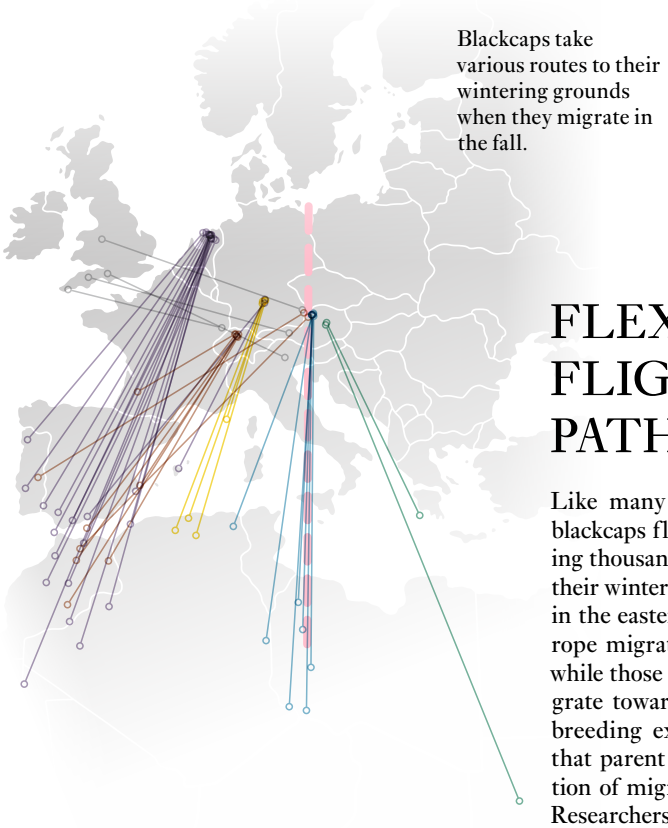
BUILDING BLOCKS FOR SOCIAL UNDERSTANDING

Being able to feel empathy and adopt the other person's point of view enables us to understand what is going on in their mind. However, it is still not clear what these skills constitute. Based on previous studies, researchers at the Max Planck Institute for Human Cognitive and Brain Sciences and other institutions have developed an explanatory model which shows that both skills are made up of many individual factors that vary depending on the situation. In the case of empathy, a primary network that can recognize critical situations – e.g. by processing fear – cooperates with other specialized regions, such as those responsible for face or speech recognition. When changing perspectives, the regions used to remember the past and imagine the future become the active core network. Here too, additional brain regions are activated for each specific situation. Complex social problems in particular require both empathy and a shift in perspective. Analyses have shown that a lack of one or the other of these two skills does not necessarily limit the individual's social competence as a whole. It may be that only one specific sub-factor is affected, such as the ability to understand facial expressions or speech melody.

www.mpg.de/16024611

PHOTO: SHUTTERSTOCK

A deep understanding: our ability to empathize with other people depends on numerous individual factors. These can vary depending on the situation.



Blackcaps take various routes to their wintering grounds when they migrate in the fall.

GRAPHIC: GCO

PORTRAIT OF AN EXOPLANET

Astronomers discover the vast majority of the planets orbiting distant stars with the help of sophisticated methods. These exoplanets do not appear in images, but reveal themselves indirectly. One of the most popular methods of discovery is the measurement of radial velocity. Because a planet pulls at its much brighter parent star like a dog on a leash pulls at its master or mistress, the star "sidesteps", i.e. makes periodic movements at a specific velocity. These cause minute shifts in the spectral lines, enabling conclusions to be drawn regarding the planet's existence. A team of researchers from the Max Planck Institutes for Astronomy and Extraterrestrial Physics has now succeeded in making the first direct observations of an exoplanet previously discovered using this method. They viewed the faint light from the planet ß (Beta) Pictoris c, some 63 light years from Earth, using the GRAVITY instrument, which combines the four large telescopes at the European Southern Observatory to form a single super telescope with a diameter of 130 meters.

www.mpg.de/15473085

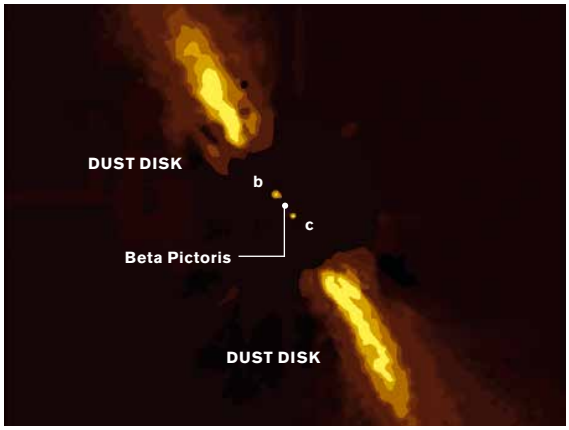


IMAGE: AXEL QUETZ / MPIA GRAPHICS DEPARTMENT

Strange worlds: this schematic image shows the ß Pictoris system with the two planets b and c embedded in a dust disk. This image was created using actual observation data.

FLEXIBLE FLIGHT PATHS

Like many other migratory birds, blackcaps fly south in the fall, covering thousands of kilometers to reach their wintering grounds. Birds living in the eastern regions of central Europe migrate toward the southeast, while those that live further west migrate toward the southwest. Crossbreeding experiments have shown that parent birds pass on the direction of migration to their offspring. Researchers at the Max Planck Institute for Evolutionary Biology in Ploen have now tracked the flight paths of 100 wild blackcaps and discovered that birds living in the zone between the western and eastern groups choose an "intermediate route". They fly directly south, successfully crossing the Alps, the Mediterranean and in some cases the Sahara, before returning to their breeding grounds in the spring. The "migratory divide" in which both groups of birds mingle is, at 30 kilometers, surprisingly narrow. It runs in a north-south direction through Europe, spanning the distance between Berlin and Prague. The results also show that blackcaps that spend the winter in Britain – a behavior that has been observed more and more often since the 1960s – come from all over Europe. These birds probably benefit from the increasingly mild winters and the food provided in British gardens.

www.mpg.de/15987699

TEETH WITH PREDETERMINED BREAKING POINTS

Biting down on a cherry stone can have severe consequences. At worst, a tooth breaks and a visit to the dentist becomes unavoidable. For the Port Jackson bullhead shark, on the other hand, splintering teeth are perfectly normal, as a team led by Shahrouz Amini at the Max Planck Institute of Colloids and Interfaces in Potsdam discovered. The researchers can now explain why the shark's teeth stay sharp: its tooth enamel consists of inner and outer layers, both made of apatite. In the outer layer, which covers the sides of the teeth, all the apatite bundles run parallel to the tooth surface. This means there are predetermined breaking points between the bundles. In the inner layer, which surfaces at the tip of the tooth, the apatite bundles are stacked crosswise so that the material does not splinter. The tip of the tooth is gradually ground down but remains sharp, because the enamel on the sides of the tooth is constantly breaking off. This knowledge could serve as an inspiration for new types of material.

www.mpg.de/16060198

PHOTO: MPI OF COLLOIDS AND INTERFACES/NATURE COMMUNICATIONS 2020

A conveyor belt of teeth: the Port Jackson bullhead shark has several rows of teeth that are constantly being renewed. The red coloration comes from sea urchins, one of the shark's most common prey.

LARGE FAMILY OR NO CHILDREN

A study of female academics in the U.S. conducted by Natalie Nitsche from the Max Planck Institute for Demographic Research and one of her colleagues has found surprising correlations between the desire for children expressed in younger years, their level of education, the time of their first marriage, and the number of children to whom they had given birth by the age of 43. Female academics who originally wanted to have at least three children were more likely to remain childless than less educated women who expressed the same desire – and than female academics who only wanted two children. The time of their first marriage also influenced the number of children, a finding that also applies to men. Men who do not embark on their first long-term relationship before the age of 35 are less likely to become fathers, even though they are able to procreate until a more advanced age than women. Another finding: female academics who want a lot of children and who become mothers at a relatively young age had more children than other groups in the study.

www.mpg.de/0420202en

The decreased use of transport as a result of the coronavirus pandemic was the main factor that caused global CO_2 emissions to fall by seven percent.

PHOTO: RICARDO GOMEZ/UNSPLASH

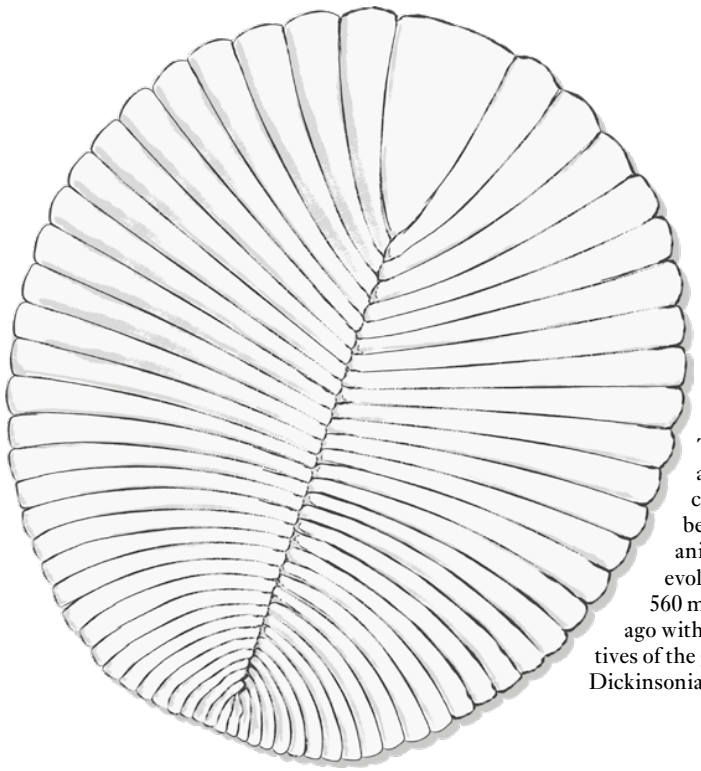
CORONAVIRUS IS REDUCING CO_2 EMISSIONS

The coronavirus pandemic has caused a record decline in fossil CO_2 emissions. In 2020, global greenhouse gas emissions from coal, oil and gas combustion were down 2.4 billion tons compared to 2019. At seven percent, this is the sharpest drop since the early days of industrialization. These findings were published by the Global Carbon Project, in which scientists from the Max Planck Institute for Biogeochemistry in Jena are involved. The decline in emissions was particularly marked in the transport sector. The total CO_2 emissions for 2020, i.e. the emissions from fossil fuel combustion and changes in land use such as the deforestation of rainforests, amounted to approx. 39 billion tons. This means that the atmospheric concentration of CO_2 did not rise as sharply as in previous years, which – with a few exceptions – saw greenhouse gas emissions increase every year. If the Paris Climate Agreement's goal of limiting global warming to 1.5 degrees Celsius is to be achieved, global emissions of CO_2 must be reduced by one to two billion tons a year by 2050.

www.mpg.de/16175501(in German)

If a person's pupils dilate only slightly when there is a prize to be won, this could be a sign of depression.

PHOTO: KALEA JERIELLE/UNSPLASH



The oldest animal: it is currently believed that animal life began evolving some 560 million years ago with representatives of the genus Dickinsonia.

ILLUSTRATION: HENNING BRUER

ANIMALS EVOLVED MORE RECENTLY THAN ONCE THOUGHT

A longstanding controversy surrounding the origins of animal life on Earth now appears to have been resolved. Researchers at the Max Planck Institute for Biogeochemistry in Jena have discovered that fossilized fat molecules found in stones dating back 635 million years are not the earliest evidence of animal life. Chemical experiments have shown that these fossilized molecules, which resemble the steroids of sponge-like organisms, are more likely to have evolved from precursor molecules of common algae as the result of geological processes. In terms of the Earth's history, they are significantly older than animal life forms, so it is currently believed that animal evolution only began around 560 million years ago. The researchers' latest work also resolves the dichotomy that animals appear to have developed before the oxygen content in the oceans began to rise some 540 million years ago, even though this was vital for the evolution of animal life.

www.mpg.de/16048936

DETECTING DEPRESSION IN THE EYE

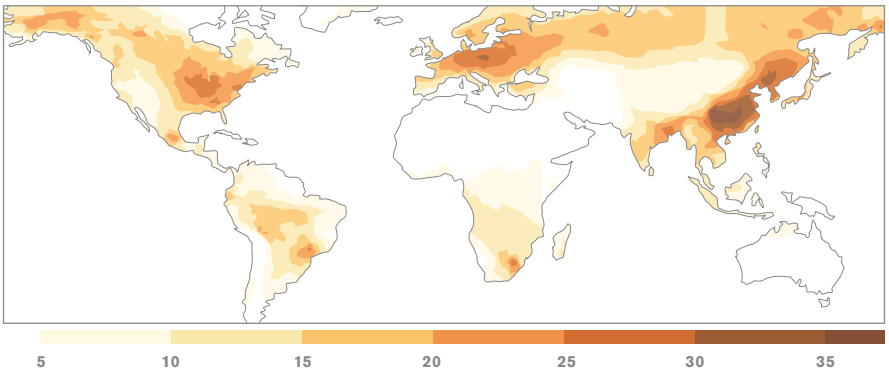
People with depression often find it hard to motivate themselves. However, this lethargy is difficult to measure. Researchers at the Max Planck Institute of Psychiatry in Munich have taken advantage of the fact that even the possibility of a reward causes the pupils to dilate. Test subjects participating in a study were offered the chance to win a small amount of money, an incentive that causes the pupils of healthy subjects to dilate. The researchers measured the study participants' pupils with great precision and at an extremely high speed. Using a special set-up, they were able to take 250 images per second; by comparison, we only blink every four to six seconds. The measurements revealed that the more severe the patients' symptoms of depression, the weaker the dilation response of their pupils. The researchers assume that the nervous system of patients with depression is unable to activate as strongly even when they are given a positive expectation. This may partially explain the lethargy frequently observed in these patients. In the future, it may become possible to classify psychiatric diseases in diagnostic groups according to measurable biological factors, such as pupil size. Patients with depression whose pupils do not react as strongly would form a subgroup and could be treated with more precisely targeted medication.

www.mpg.de/16073488

NO FALSE SENSE OF SECURITY

During the COVID-19 pandemic, both politicians and the general population are having to come to terms with the fact that scientific knowledge invariably comes with a degree of uncertainty. But should the public be explicitly informed about this? Researchers at the Max Planck Institute for Human Development and the Charité University Hospital in Berlin have now looked into this question. During a representative study, they presented the test subjects with four different scenarios, placing varying degrees of emphasis on the uncertainty of the predictions. In the scenario that emphasized the element of uncertainty most strongly, they communicated the from-to figures, e.g. the estimated number of persons currently infected, the estimated number of deaths, or the estimated R number. They also stressed that "the differences observed [could] be caused by random fluctuation or be the first signs of a second wave of coronavirus infection." In contrast, the scenario that paid the least amount of attention to the uncertainty provided specific figures and stressed that their development "leaves no doubt that a second wave of infection has already begun." Each of the scenarios ended with an appeal to comply with protective measures. In response to the question of which scenario would be best suited for informing the public about the progression of the pandemic, more than half of the participants cited a preference for formats that conveyed a sense of uncertainty; in fact, the majority preferred the scenario in which the uncertainty was clearest. In contrast, the scenario that glossed over the scientific uncertainty only convinced 21 percent of the participants. People who take a critical view of the current measures also seem more likely to comply with them if scientific uncertainty is clearly communicated.

www.mpg.de/0420201en



GRAPHIC: GCO BASED ON DATA FROM MPI FOR CHEMISTRY

Estimated percentage of COVID-19 deaths caused by man-made air pollution.

MORE COVID-19 DEATHS DUE TO AIR POLLUTION

Air pollution appears to increase the risk of dying of COVID-19. This conclusion was drawn by an international team that included scientists from the Max Planck Institute for Chemistry in Mainz. The researchers calculated the percentage of COVID-19 deaths that could have been prevented if there was no man-made particulate matter in the air, e.g. from fossil fuel combustion. It was found that 15 percent of COVID-19 deaths worldwide were caused by this pollutant. In Germany, the figure is no less than 26 percent. It appears that particulate matter makes it easier for the virus to infect cells in the lungs, and it also damages the blood vessels in a manner similar to Sars-CoV-2.

www.mpg.de/15952279

HIGH-SPEED MODEL FOR THE FIGHT AGAINST CORONAVIRUS

Before treatments for the coronavirus Sars-CoV-2 can be tested in human clinical trials, they have to be intensively studied in animals. One suitable model organism for testing treatments to be administered to humans is the mouse. However, Sars-CoV-2 cannot infect mice, because they have different ACE2 receptors. The virus cannot bond with these receptors and is therefore unable to penetrate the rodents' cells. In the record time of just one month, researchers at the Max Planck Institute for Molecular Biomedicine in Muenster, working with colleagues in China, have now bred genetically modified mice that carry a human variant of the ACE2 receptor on their cells – thanks to CRISPR Cas9 genetic scissors and a technique used in stem cell research. The results show that Sars-CoV-2 infection in these genetically modified mice causes similar symptoms to COVID-19 in humans. These new techniques will now enable researchers to investigate the effects of antibodies and therapeutics on the coronavirus, which means they will be able to react more quickly than before to the threat of new pathogens.

www.mpg.de/16164102

DEMOCRACY AMONG GUINEA FOWL

Guinea fowl in the East African savannah live in a multi-level society in which social groups of between 15 and more than 60 individuals interact. There is a clear hierarchy within these individual groups, whereby alpha animals can dominate other group members and completely monopolize food supplies. Researchers from the Max Planck Institute of Animal Behavior in Radolfszell spent several years tracking the movements of various groups of guinea fowl on foot and by utilizing video and high-resolution GPS sensors; this enabled them to determine the birds' social ranking within their hierarchy. When dominant individuals chase other members of the group away from a particularly rich food patch, the excluded subordinates band together and induce the dominant group to move on. This behavior ultimately forces the alpha animals to leave the patch and follow the group. This shows that the leaders have to bow to the majority if they abuse their power and monopolize resources for themselves. ***www.mpg.de/16034177***

PHOTO: GEOFFREY REYNAUD/ISTOCK

Caribou migrate long distances over the course of a year. A study has shown that climate change is causing northern caribou to give birth earlier in the spring than populations further south.

ARCHIVE OF ANIMAL MIGRATION IN THE ARCTIC

Warmer, shorter winters, melting ice, and increased human activity mean that the Arctic is undergoing dramatic changes that are impacting animals and their migration patterns. Researchers around the world have now set up an online data archive for documenting animal movements in the Arctic and Subarctic, which is hosted on the Max Planck Institute of Animal Behavior "Movebank" platform. The "Arctic Animal Movement Archive" enables scientists to share their knowledge and work together to find out how animals are reacting to changes in the Arctic. The archive currently contains more than 200 research projects with movement data from more than 8,000 aquatic and terrestrial animals dating from 1991 to the present. Three new studies from the archive testify to far-reaching changes in the behavior of golden eagles, bears, caribou, elk, and wolves in the region. They demonstrate how the archive can be used to identify significant changes in the ecosystem. ***www.mpg.de/15976863***

ILLUSTRATION: HENNING BRUER

THE STONE AGE LASTED LONGER THAN PREVIOUSLY THOUGHT

The earliest techniques employed by humans to make stone tools remained in use in the westernmost regions of Africa 20,000 years longer than was previously assumed. This is the result of investigations carried out under the direction of Eleanor Scerri, Research Group Leader at the Max Planck Institute for the Science of Human History in Jena, and Khady Niang from the University of Cheikh Anta Diop in Senegal. Until now, it was assumed that stone tools dating from the Mesolithic or Middle Stone Age, such as the hand ax, had been replaced by a completely different set of smaller-scale tools no later than 30,000 years ago. The research team has now discovered that groups of hunter-gatherers in modern-day Senegal were still using Middle Stone Age techniques until around 11,000 years ago. One reason for this could be that the region was fairly isolated due to its proximity to the Sahara in the north and the rainforests of central Africa. It is possible that climate changes in this region were less extreme than in other parts of Africa, which meant that there was no need to make radical changes to tool-making techniques.

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A CUSTODIAN IN THE TIME OF CORONA

The fight against COVID-19 appears to be taking place mainly at a national level, while the World Health Organization (WHO) has repeatedly been the subject of criticism. However, according to Lauren Tonti and Pedro Villarreal, the role of the WHO is often underestimated. They explain from a legal point of view what action the organization is taking during the pandemic, and where there is a need for reform.

A global challenge like the COVID-19 pandemic surpasses any single state's capacity to cope with its impact, no matter how powerful that state may be. Due to sovereignty considerations, devising and implementing a global response is a task that can only be undertaken through international cooperation. Since fighting a pandemic is a matter of concern for the international community as a whole, wouldn't it be ideal to have an institution with both technical know-how and the capacity to act beyond a strictly national purview?

The World Health Organization (WHO) is in a privileged position to act as such an institution. To date, it has played a central role in the COVID-19 pandemic, and has fulfilled a variety of functions stemming from its powers and responsibilities enshrined in a series of international legal instruments. At the same time, the WHO faces criticism of and formal inquiries into its early-stage pandemic management, with questions being asked as to whether something could, and should have been done differently.

Legal research can contribute to addressing a series of questions in this regard. First, the WHO's functions and powers are enshrined in existing instruments of international law. Identifying the core problems deriving

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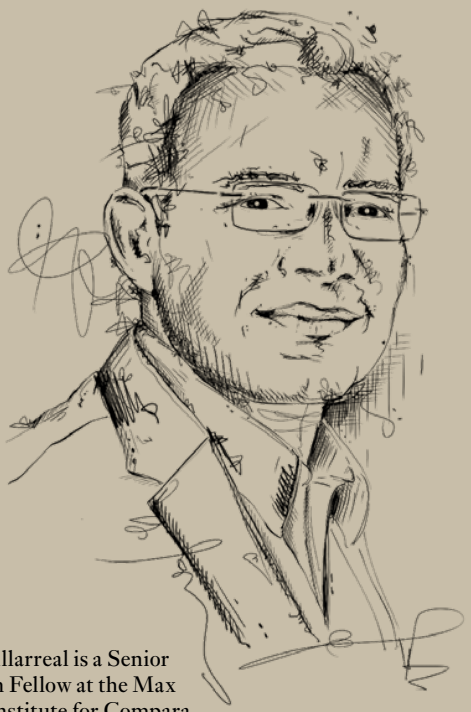
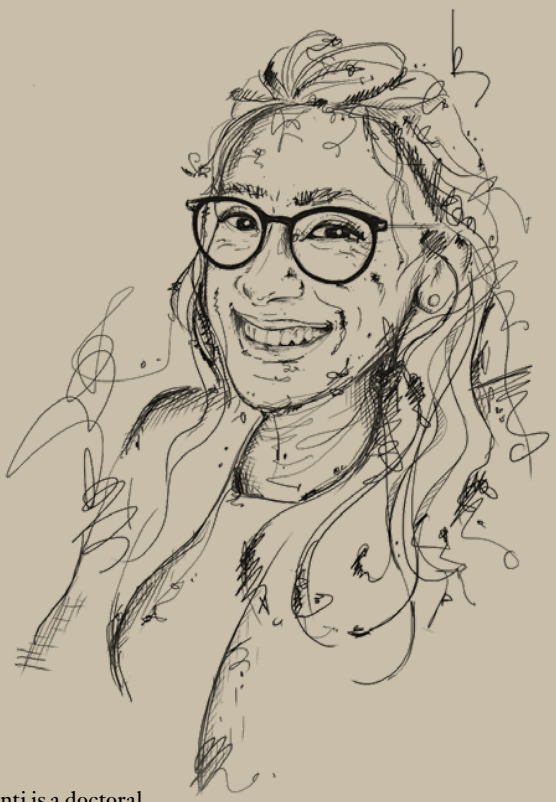
VIEW POINT

LAUREN TONTI & PEDRO VILLARREAL





ILLUSTRATIONS: SOPHIE KETTERER FOR MPG

Pedro Villarreal is a Senior Research Fellow at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg. He received a university prize for the best work in legal and social sciences for his dissertation at the National Autonomous University of Mexico on the legal aspects of the global response to the H1N1 flu pandemic. Among other topics, Villarreal is currently researching the right to health with regards to the work of the WHO.

Lauren Tonti is a doctoral researcher at the Max Planck Institute for Social Law and Social Policy in Munich. She completed her Masters in Public Health at Harvard University. Previously, she studied law at Case Western Reserve University in the U.S. and the Université Paris-Dauphine. The focus of her research is health law, particularly legal issues surrounding telemedicine.

from the legal framework is necessary in order to adjust the international community's expectations as to what the WHO can and should do. After the first step, legal research can also help address several normative questions: What should the organization do differently? Which of these actions requires legal reforms? And more generally, how can the international community better prepare for the next pandemic? With these questions in mind, we can explore the roles that the WHO has played during the COVID-19 pandemic based on its existing capacities. These roles include: architect, sentry, counselor, educator, coordinator, and champion of equity – and are probably more numerous than many people realize.

The WHO has long acted as the architect of preparedness. In 2005, the World Health Assembly, the governing forum of the WHO, approved the International Health Regulations, the main legal instrument to be applied in global health emergencies. These regulations are designed to prevent, contain and respond to the international spread of contagious disease, while at the same time avoiding unnecessary interference with international travel and trade. The main goal is to minimize the global consequences of contagion regarding both the impact on human health and the disruptive nature of containment measures adopted by individual states. To achieve these aims, the International Health Regulations contain commitments for both the WHO and the Member States. In particular, these commitments include states' obligations to notify the WHO of events occurring in their territories that may constitute a public health emergency of international concern. Notification must occur within 24 hours of assessing the events.

A WARNING – AT LEAST FOR THOSE COUNTRIES THAT TAKE NOTE OF THIS INFORMATION

Furthermore, the World Health Organization assumes the role of a global sentry. The WHO may investigate potential public health emergencies of international concern through the collection of data on communicable disease outbreaks provided either by states or non-official sources. At the beginning of 2020, the WHO worked with China to investigate and assess the danger posed by a novel coronavirus. The WHO is also responsible for sounding the global alarm, based on available epidemiological information relating to a public health event. The WHO initially identified the burgeoning global crisis as a public health emergency of international concern in its declaration of SARS-CoV-19 (the virus that causes COVID-19) on January 30, 2020. The WHO later declared COVID-19 a pandemic on March 11, 2020. These alerts gave countries an initial warning of the looming pandemic, at least to those who paid attention.

The WHO also acts as an adviser and teacher. The WHO's role in pandemic preparedness and response consists of more than just legal obliga-

tions. Even though it cannot issue orders to its Member States in the same way that national health authorities can issue directives to their own populations, both the Constitution of the WHO and the International Health Regulations direct the WHO to issue guidelines on the best measures for disease control. Through this function, the organization deploys its decades-long expertise as the authority on matters of global health. In this capacity, the WHO counterbalances the rampant "infodemic" that is currently raging. By offering guidance and educational materials to both national authorities and the general public, the WHO can offset the spread of disinformation by sharing the best available, factual information.

ALTHOUGH THE RECOMMENDATIONS ARE NOT BINDING, THEY ARE INCORPORATED INTO NATIONAL REGULATIONS

In accordance with its mandate, the WHO has issued technical guidance on a wide range of COVID-19-related topics, from clinical care to therapeutics and from diagnostics to travel guidelines. While these are based on non-mandatory recommendations for states, they are nevertheless often referenced in national health authorities' decisions. As the scientific community learned more about the novel virus, the WHO either updated COVID-19 recommendations accordingly (e.g. regarding face-mask usage) or even superseded them (e.g. by discouraging travel restrictions). Several factors may have induced the mixed reception of the WHO's guidance, including an initial lack of information on a new pathogen, a lack of scientific community consensus, or perhaps even an inadequate the WHO assessment of the numerous factors involved in healthcare service provision. The accuracy of the WHO's guidelines may be heavily contested and controversial. It is a testament to the weight of such recommendations, since faulty guidance may have adverse consequences when implemented.

The WHO also acts as a coordinator. With personal protective equipment and other necessary medical equipment in short supply, the WHO partnered with other agencies to establish and coordinate the COVID-19 Supply Chain System, through which parties can request diagnostic, biomedical and other vital medical supplies for expedited delivery. As a centralized organ of global health governance, the WHO has assumed a coordinating role in both fundraising and COVID research. The WHO established a special fund to raise the sums needed for critical response efforts. The fund has distributed hundreds of millions of dollars for vaccine development and commodity procurement, among other allocations. The WHO also coordinates the acceleration of research. The WHO partnered with other organizations to launch the Access to COVID-19 Tools (ACT) Accelerator, a global collaboration between public and private stakeholders aimed at accelerating development, production and equitable access to COVID-19 tests, treatments, and vaccines.

Finally, the WHO is committed to equity. Countering states' default tendency to prioritize their own populations, the WHO has championed a more equitable global distribution of multiple COVID-19 medical resources during the pandemic. In the competition for the allocation of such scarce resources, countries with higher financial capacities may stockpile them. By contrast, countries with lower purchasing power are neglected, thus posing the risk of being left last in the supply chain pipeline. In a resolution adopted at the World Health Assembly on May 19, 2020, full immunization against COVID-19 was deemed a "global public good." This framing provides the basis for global programs and strategies aimed at finding the best solutions to the most devastating pandemic in recent history.

One of these programs is COVAX, an ACT Accelerator branch and global initiative aimed at facilitating equitable worldwide access to safe and effective COVID-19 vaccines. While the WHO devised the fair allocation scheme, other bodies (e.g. Gavi, the Vaccines Alliance, a public-private-partnership, as well as UNICEF) will undertake the actual vaccine distribution. Based on the goal of simultaneous distribution for a proportion of countries' populations, the COVAX initiative represents the most equitable mechanism for global allocation of a vaccine against COVID-19 to date. Participating states are divided into two major groups: a self-financed group, whose members pay per dose received; and a funded group, whose members obtain vaccines through developmental aid instruments (i.e. on a concessional basis).

However, COVAX faces two major limitations. First, the initiative requires an active willingness to participate by both states and pharmaceutical companies. When the first vaccine, developed by Pfizer/Biontech, received regulatory approval in several countries, it was not in the COVAX Initiative's portfolio. The company joined the Initiative only after the purchase and distribution of its vaccine in multiple high-income countries was well underway. Second, financed states' vaccine purchases are fully dependent on donations from either international financial institutions or philanthropic non-state actors. It is a reflection of the persistent limits of solidarity when it is most needed.

Just as installing a sprinkler system during a blazing inferno is problematic, so too is implementing preventive measures at the height of a global pandemic. However, the WHO and its Member States can make the best of the momentum triggered by COVID-19 and incorporate the wisdom learned from this experience into reforms for an improved pandemic response.

First, the Member States should use the roadmap provided in the International Health Regulations. This roadmap is fully dependent on states' adherence to its provisions in order to function properly. When the pandemic first struck, only a small group of Member States was complying with the basic requirements of disease surveillance stipulated in the International Health Regulations. States should work to improve this, while the WHO can design objective evaluation and feedback mechanisms for International Health Regulations metrics.

IN LIGHT OF THE CRITICISM, THE WHO SHOULD BECOME MORE TRANSPARENT WITH REGARD TO THE WAY DECISIONS ARE MADE

Second, stakeholders at all levels of governance can place best-available evidence at the core of decision-making. Evidence-based decision-making largely depends on information sharing. Hence, effective and reliable local, national, and interstate surveillance and information sharing systems can prove decisive in battles against future outbreaks.

Third, states can demonstrate their commitment by dedicating financial resources to public health emergency preparedness.

Fourth, in the face of criticism of its decision-making, the WHO should work to increase public transparency and cooperation with bodies working on global health security. Both the WHO and the Member States can optimize communication with one another. The WHO should find clearer ways to convey to the world the severity of a health threat, so that states may take necessary precautions. The sometimes inconsistent use of technical terms by the WHO's officials is not constructive in such an endeavor. For instance, the unclear definition of a 'pandemic' led to mixed messaging from the WHO Director-General regarding the exact nature of COVID-19's spread in early 2020.

Fifth, the WHO can bolster the International Health Regulations by harmonizing them with other global health security instruments. The WHO, in conjunction with the Member States voting in the World Health Assembly, can also embrace necessary reforms to make it a dynamic governance structure in tune with contemporary challenges. In so doing, the WHO can increase confidence in the overall framework. Finally, the WHO and the Member States can strive for consensus regarding the support and mechanisms needed by institutions in order to protect global public health.

Both the WHO and its Member States can learn from COVID-19's challenges to protect populations from subsequent pandemics. These bodies and their leaders should treat pandemics as seriously as other security threats, and mobilize global governance infrastructure in order to prevent and prepare for public health emergencies.

FOCUS

ONE WAY OR ANOTHER

ILLUSTRATION: REGINA MARIA MÖLLER, VG BILD-KUNST BONN. WWW.REGINAMOELLER.NET

WE CULTURED HUMANS

TEXT: STEFANIE REINBERGER

In many ways, our thoughts and actions are influenced by our social background, which is why people's behavior varies so widely between different countries throughout the world. The psychologist Daniel Haun, Director at the Max Planck Institute for Evolutionary Anthropology in Leipzig, has made cultural diversity a focal topic of his research. His theory is that we cannot ultimately determine what it is that makes us human until we are aware of what we have in common and what our differences are.

A person who works harder ultimately gets to rake in more of a well-deserved reward. That's only fair, isn't it? That's how children as young as three see it – at least in our part of the world. They apportion rewards according to effort, and prefer to share with other playmates who have been more actively involved. This has been confirmed time and again by experiments. If you think that the result of these studies is all too logical, you probably come from Germany, or you at least live in an industrial society. However, what might seem perfectly natural to us does not necessarily apply to people elsewhere in the world.

Culture influences our perception and actions. And everything that we now know indicates that the distinct, diverse culture of Homo sapiens is unique compared to those of other species. But what enables people to develop such broad cultural diversity in the first place? What are the foundations of human cognition that make us stand out from other species and make us human? These are the big questions that the Director of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Daniel Haun, has been investigating, and which he has been studying since setting up the Department of Comparative Psychology there in 2019.

Our culture determines what we regard as being fair

"In different cultures, people have very different attitudes towards social relations, social emotions, color, numbers and space," he explains. "It's remarkable when you meet groups of people who see things that you don't, who notice things that you are unable to notice yourself, or who regularly do things that you wouldn't do." In one study, a research team from several Max Planck Institutes and the University of Jena observed just how differently people behave in certain situations. They asked children aged 4 to 11 to fish for toy blocks in a fishing game. In each case, two children fished for the blocks from two different containers. The magnetic blocks of one child had been manipulated, making it impossible to pull out some of the "fish". Afterwards, the two children received small prizes according to the total number of blocks they had both caught, and were asked to share the reward between them. As expected, the German children strictly apportioned the prizes according to performance, with each child getting the same share of the reward as the number of fish they had caught. There was no discussion.

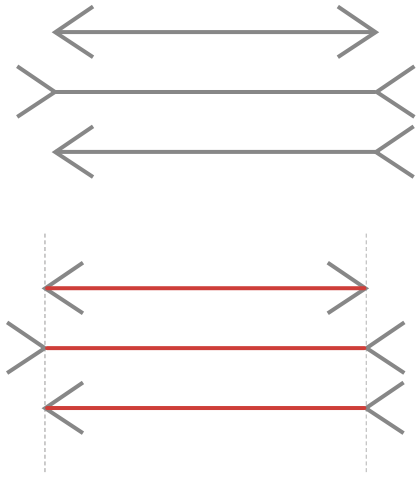
Young members of the ≠Akhoe Hai//om, an egalitarian community of hunter-gatherers in Namibia, also divided up the rewards according to the number of fish caught. However, they did so in a far less clear way than

"You have to ask yourself what validity studies have that focus solely on U.S. college students."

DANIEL HAUN

the children of the same age in Germany. Instead, they shared the reward about evenly, with the more successful child getting one block more. However, the researchers were astonished by the approach taken by the third group: Kenyan children from the Samburu people, a society with a strict age-based hierarchy. "The children chose a wide range of different distribution models, up to and including one version in which the more successful angler was left with practically nothing," Daniel Haun, who was involved in the study, explains. "We were completely unable to relate to the principles behind this approach." One important conclusion was that our concept of fairness is also influenced by our culture.

Another example that is almost even more striking is the Müller-Lyer Illusion, a well-known optical illusion. The illusion consists of lines that have arrows in the form of open angles at each end. Some of the tips point inwards and others outwards. Depending on how they are arranged, we unfailingly perceive the lines as being longer or shorter – although in fact, they are all of equal



GRAPHIC: GCO FROM FIBONACCI/WIKIPEDIA (CC BY-SA 3.0)

Partial illusion: in the western world in particular, humans incorrectly perceive the lines between the arrows as being of different lengths. People from other cultures in other parts of the world are not deceived by this optical illusion at all.

PHOTO: DANIEL HAUN/MPI FOR EVOLUTIONARY ANTHROPOLOGY

A long way from western norms: a girl from the ≠Akhoe Hai//om people in Namibia takes part in a psychological study.

length. However, this visual phenomenon doesn't work everywhere in the world. As Haun explains: "It already emerged back in the 1960s that there are societies in different parts of the world where people perceive the lines to be of equal length when they are (truly) of equal length – but it's impossible for us to see it." Both examples underline the fact that the way in which our cognitive abilities are expressed depends strongly on the environment in which we live – particularly our society and its culture. "You then have to ask yourself what general validity psychological experiments have that are conducted only with psychology students from the U.S. as subjects, or developmental psychology studies that observe only European babies and young infants," says Haun. At any rate, it is not always possible to make generalized statements about human perception and thought processes at this level.

However, Haun is not interested in challenging the psychological research that has been conducted to date. For him, cultural differences are a primary key to answering the questions that he is examining in his research. "In order to comprehend what enables people to develop cultural diversity in the first place, we have to understand the relevant fundamental development processes from which cultural variation arises. We compare these with the development of other species and look for reasons why our unique human cultural evolution was made possible."

Here, it's not enough simply to compare people from different cultures. The age of the test subjects, or the demographic composition of the population, also plays a role. "Age is a very important factor for social learning," says Haun. What he means by this is a form of learning in which we observe the way in which other people do certain things. This approach is used in all human cultures.

But do children orient themselves to others in the same way all over the world? And what criteria do they use when choosing role models? Haun investigated this question alongside an international team. The study involved children from seven different cultural groups, from Germany, Brazil and Indonesia, as well as the BaAka people in the Central African Republic, the

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PHOTO: KINDER-UNI JENA

On an educational mission: for Daniel Haun, it is important to raise awareness of the diversity among humans, as well as to point out our special characteristics. He also presents this topic at the Kinder-Uni (children's university) in Jena.

≠Akhoe Hai//om in Namibia, the Samburu in Kenya and the Bemba in Zambia. The study was centered around a simple dispenser – a box with three different colored tubes. If you put a ball in one of the tubes, a small toy falls out at the bottom. Children aged between 4 and 14 were then allowed to watch videos in which children of the same age showed them how the box works. In each case, three children demonstrated how to work the box using one and the same tube. Then, one other child demonstrated the procedure on another tube three times in succession. The result was always the same: the dispenser ejected one toy for every ball thrown in. Then, the children who watched the videos were each given a ball and had just one attempt at also getting a reward.

The extent to which the children based their actions on what they had seen in the film varied very widely depending on their cultural background. However, there were also some fascinating things that they had in common: "Although the cultural variation was high overall, across all cultures, the degree to which the children were inclined to adopt the majority approach changed proportionately depending on their age," Haun explains. Overall, both the youngest and oldest children in all groups most frequently emulated the behavior of the three role models instead of following the repeated demonstration given by the individual child.

"We're running out of time: globalization is blurring the differences between cultures."

DANIEL HAUN

"Results like these show us how important it is not only to observe individual children in different situations or performing certain tasks," Haun continues. "In fact, we need long-term development studies, from birth until they reach adulthood." In this way, he says, reliable data can be obtained that make it possible to reach a conclusion as to which cultural factors influence which developmental processes – and for which developmental processes there are no variations at all.

And all this ultimately not only applies to studies about humans. To find out which cognitive abilities and ways of behaving are uniquely human, we also need to draw comparisons between ourselves and our closest relatives, chimpanzees and other apes. Here, too, behavior varies between different groups. "This is not so clearly evident as it is for humans, and the extent of the variation also depends strongly on the composition of the population," Haun explains. "However, there is no doubt that not all chimpanzees are the same, and we have to take a much closer look before comparing the behavior and cognitive abilities of non-human primates with those of humans."

Haun's research project involves countless behavioral studies, observations in a wide range of different human cultures and in various groups of apes – with the largest possible number of test subjects and ideally over long periods of time. It is quite clear that no single research career will be able to cover all this work. And there's one more problem: "We're running out of time," says Haun. "The increase in globalization is blurring the differences between cultures, while at the same time, non-human primates are dying out because their habitats are being lost." The lower the degree of variability on the planet, the more difficult it will become to filter out similarities that go beyond cultural background – the essence of what it means to be human. "Perhaps two or three generations of researchers will be able to move this project forward. After that, it may be too late."

SUMMARY

The culture in which we live not only determines our values and preferences, but also the fundamental characteristics of our being, such as our concept of what is fair and our visual perception.

Using psychological tests in different cultures and among different ages, researchers are working to document what makes us different from each other, and what we have in common.

Comparisons with the way apes behave are also required in order to filter out what is specifically human.

The corona crisis isn't improving the situation. "Field research is almost impossible under the current conditions," Haun says. It's quite clear that the present situation is hard for him to bear – when there are so many exciting cultures out there in the world and so many interesting issues that he wants to explore. Even so, the Max Planck Director has plenty to keep him occupied. He is using the time to establish new methods. Artificial Intelligence and Machine Learning are important topics for psychologists. The aim is to use both in the future to automatically evaluate psychological studies in order to be able to study larger numbers of test subjects – perhaps even in their normal everyday lives, away from performing tasks in a study environment. A large number of test subjects is crucial in order to ultimately understand the connection between individual development, social environment and geographical surroundings among humans and apes.

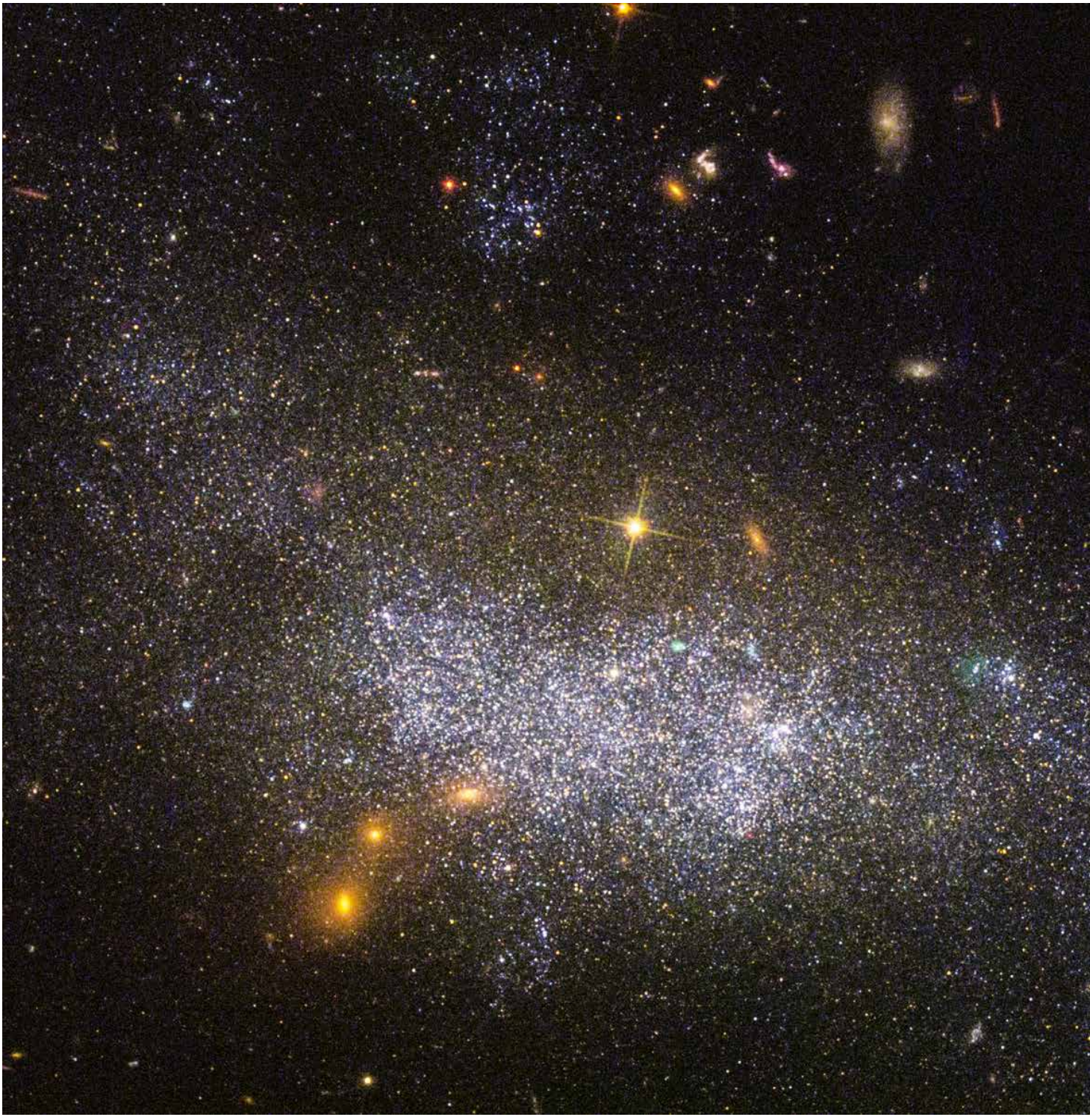
Despite all the challenges, Daniel Haun's team continues to work to make contacts and establish research units in different parts of the world that will remain firmly connected to his Department over a long period of time. This is an important prerequisite for being able to work continuously with specific cultural groups. For the scientists in Leipzig, it is also important to work closely in cooperation with people who are native to the various study sites, because as locals they are familiar with the language, culture and ways of behavior in their home countries. "Cooperation with the people on the ground is essential for the success of this project. That's the only way that we can ensure that studies are culturally appropriate and are interculturally comparable."

The aim is not to be judgmental

The team is also involved in the Many Primates project, a scientific consortium researching apes, in order to create a stable network of zoos and rescue centers. "The time when individual groups conducted their own research has passed. Science is a team sport now. For our research area in particular, it is essential that we collaborate with other researchers," Haun explains. With this in mind, he also plans to invite other psychology research groups in the future, to examine their areas of study together with his team with a focus on comparative cultural psychology. "As Max Planck researchers, we have a particular responsibility to create added value for the scientific community," he says.

He also takes responsibility for another aspect of his work. One thing is very important for him: "When we investigate cognitive differences between individual cultures, we must never judge them in the process." In the past, a lot of information has been misused for political purposes. For Haun, one thing is clear: cognitive abilities in humans are expressed in different ways. They can be fascinatingly diverse, surprising, and sometimes entirely incomprehensible from our own perspective – but they are always determined by the influences and demands of the individual living environment. Here, there is no such thing as better or worse.

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



A miniature milky way: approximately 40 million light-years away, UGC 5340 is classified as a dwarf galaxy. Dwarf galaxies exist in a variety of forms – elliptical, spheroidal, spiral, or irregular – and originate in small halos of dark matter. Dwarf galaxies contain the oldest known stars.

IMAGE: NASA, ESA & LEGUS TEAM

MIDWIFE OF THE GALACTIC ZOO

TEXT: THOMAS BÜHRKE

Stars cluster in galaxies of dramatically different shapes and sizes: elliptical galaxies, spheroidal galaxies, lenticular galaxies, spiral galaxies, and occasionally even irregular galaxies. Nadine Neumayer at the Max Planck Institute for Astronomy in Heidelberg and Ralf Bender at the Max Planck Institute for Extraterrestrial Physics in Garching investigate the reasons for this diversity. They have already identified one crucial factor: dark matter.

Nature has bestowed an overwhelming diversity upon our planet. The sheer resourcefulness of the plant and animal world is seemingly inexhaustible. When scientists first started to explore this diversity, their first step was always to systematize it. Hence, the Swedish naturalist Carl von Linné established the principles of modern botany and zoology in the 18th century by classifying organisms.

In the last century, astronomers have likewise discovered that galaxies can come in an array of shapes and sizes. In this case, it was Edwin Hubble in the mid-1920s who systematized them. The "Hubble tuning fork diagram" classified elliptical galaxies according to their ellipticity. The series of elliptical galaxies along the diagram branches off into two arms: spiral galaxies with a compact bulge along the upper branch and galaxies with a central bar on the lower branch. From left to right, Hubble classified the galaxies as early and late types, although he didn't necessarily regard this as a chronological evolution.

The idea of an evolutionary relationship between the two basic forms emerged later: "When I first started my research in the mid-1980s, many people were convinced that giant elliptical galaxies form when two spirals collide and merge," says Ralf Bender, who has been Director at the Max Planck Institute for Extraterrestrial Physics in Garching since 2002. Present-day astronomers do indeed observe such collisions in the universe, and computer simulations confirm the theory proposed at the time.

Collision with the Andromeda Galaxy

In several billion years, our Milky Way will likewise collide with the Andromeda Galaxy, currently about 2.5 million light years away, and swirl into an elliptical galaxy. "However, this process can only have created the small and medium-sized ellipticals, not the very large ones," says Bender. Bender and his team have long been especially focused on determining the age of galaxies, and their work has cast doubt on the existing model. Just how do you go about determining the age of a galaxy? The current theory is that the Big Bang only produced light elements, almost exclusively hydrogen and helium. The heavier elements first had to bake in the hot interior of stars in fusion reactions known as "stellar nucleosynthesis" and they were then released in stellar explosions. They dispersed in space and formed the raw material for the next generation of

PHOTO: PETER FRIEDRICH

Pursuing the evolution of galaxies: Ralf Bender studies the formation and evolution of galaxies. Bender is a Director of the Max Planck Institute for Extraterrestrial Physics and observes ancient, luminous star clusters, which are thought to be the forerunners of today's giant ellipticals.

"The size and density of the halos were key."

RALF BENDER

stars. This development progressed from generation to generation. The more heavy elements a star contains, the later it was born in the course of cosmic evolution and, from our perspective, the younger it is.

With this in mind, Ralf Bender observed luminous elliptical galaxies whose light had taken nine billion years to reach us. In other words, the scientists were looking far back into the past, when the universe was just under five billion years old. One theoretical analysis suggests that these galaxies are the forerunners of today's giant ellipticals, which contain up to a trillion stars. Bender and his colleagues measured the abundance of the various elements in the galaxies from then and now and discovered that these giant galaxies formed about two billion years after the Big Bang, the majority of their stars having been born within a period of just one billion years. After this early vigorous baby boom, star births declined and soon ceased altogether. The elliptical galaxies we see today, therefore, contain primarily older stars. They could be regarded as retirement homes for stars.

Spiral galaxies like our Milky Way have developed quite differently. They have developed over a longer period of time, and new stars continue to form within them. Furthermore, even the largest known spiral galaxies are not massive enough to merge and form a giant elliptical. "In much the same way that humans didn't evolve from today's apes, but from more evolved hominids, elliptical galaxies didn't evolve from the predecessors of the spirals we see today," explains Ralf Bender. "It is, however, conceivable that they were created by the merging of very large and dense star clusters."

Scientists had long doubted whether such huge accumulations of stars could have formed in the early universe, but recent discoveries confirm this. Scientists at the Max Planck Institute for Astronomy in Heidelberg, Germany, have discovered a disk-shaped galaxy that

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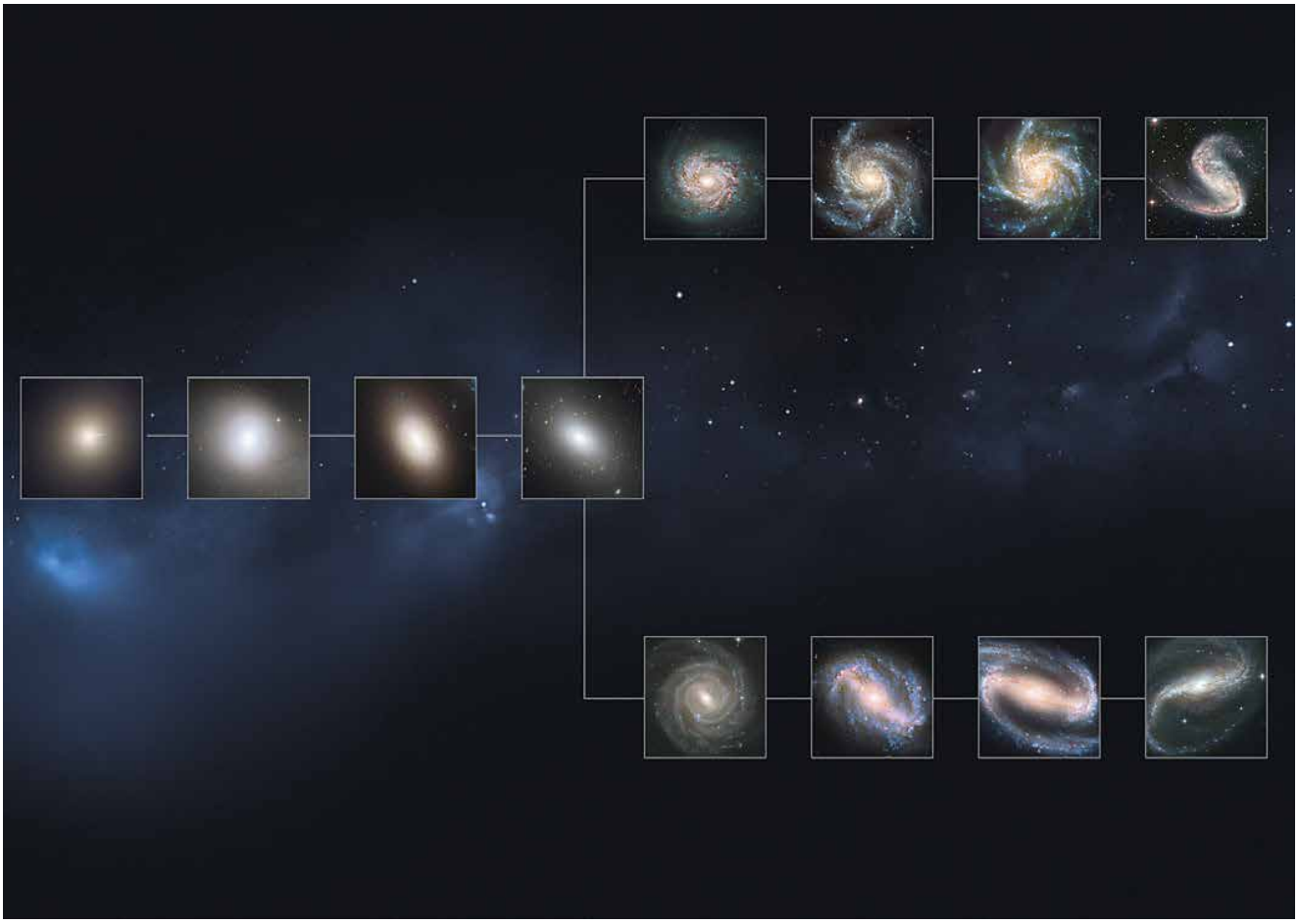
Surprising kinship: spiral galaxies (left) have long been recognized by astronomers as a conventional galaxy shape; viewed from outside, our Milky Way is similar in appearance. What is new, however, is the realization that globular clusters (right) also belong to this family – as the core regions of former dwarf galaxies.

IMAGES: ESO (LEFT); ESA/HUBBLE & NASA (RIGHT)



GRAPHIC: NASA, ESA, M. KORNMESSER

Cosmic tuning fork: the astronomer Edwin Hubble was the first to classify galaxies based on their form – from spheroidal to elliptical (top), spiral (top right), and barred spirals (bottom right). However, this scheme does not represent an evolutionary sequence for galaxies.

had already reached the impressive mass of 70 billion solar masses a mere 1.5 billion years after the Big Bang. This puts it in the size range of our Milky Way. And an international team recently used the Atacama Large Millimeter/submillimeter Array (ALMA) operated by the European Southern Observatory (ESO) to discover approximately one hundred large, highly evolved galaxies dating from one to one-and-a-half billion years after the Big Bang. All these observations are forcing cosmologists to reconsider their models. The standard theory is that initially the universe was solely composed of a large number of small star accumulations, which then collided, merged, and slowly grew. This "hierarchical" scenario would mean that large galaxies could only exist in a later phase of the universe. But this has been definitively disproved. What then determines which galaxy types arise? Dark matter is the answer.

"We've identified three populations of different ages."

NADINE NEUMAYER

Dark matter is matter that only interacts with "ordinary" matter through gravitation

After the Big Bang 13.8 billion years ago, the primordial gas consisting mainly of hydrogen and helium on the one hand, and dark matter on the other, formed a fairly evenly distributed nebula. Researchers still don't know exactly what dark matter is, but at present everything points to the existence of an unknown form of elementary particle that makes itself felt solely through its gravitational effects. Most notably, its particles exert no repulsive electrical forces on each other. This was crucial at the beginning of the universe; gravity tended to condense this mixture of matter into large clumps. However, the hydrogen and helium atomic nuclei were electrically charged and repelled each other. This prevented the hot gas from compressing. Dark matter particles, on the other hand, exert no electrical forces and clumped together to form huge clouds and long filaments. Termed "dark matter halos" by astronomers, these acted like gravity traps, sucking in the normal gas particles. The particles accumulated like marbles in a trough and condensed into the first stars and galaxies.

"The size and density of these halos, as well as their distribution, were critical in determining the diversity of galaxy types," says Ralf Bender. The denser a halo was, the faster it collapsed, and the faster it dragged the gas with it. If, in this turbulent initial phase, several halos merged together, huge galaxies could form, rapidly leading to the generation of a huge number of stars. This was how elliptical galaxies formed soon after the Big Bang. Today, we see the stars in these galaxies orbiting around the center on all possible trajectories. Spiral galaxies, on the other hand, take many billions of years to form and maintain their uniform structure. "Spiral galaxies need time in isolation without suffering major collisions," says Bender.

Hence, spiral galaxies were formed in halos that were so widely dispersed that they didn't impinge on each other. "You can still see this in our Milky Way today," says the Max Planck researcher. "Together with the Andromeda Galaxy and a few other stellar systems, it forms the Local Group, whose collective average density is very low." Large, dense halos, on the other hand, formed regions like the Coma cluster, with its two giant elliptical galaxies.

While Ralf Bender focuses on the most massive galaxies, Nadine Neumayer, who heads a Lise Meitner group at the Max Planck Institute for Astronomy, is investigating smaller "dwarf" galaxies. For a long time, these were regarded as the "gray mice" of the universe. They can also be ellipsoidal, spheroidal, spiral, and irregular in form, but because of their dimness, only the closest ones can be observed. At present, researchers know of 24 dwarf galaxies orbiting our Milky Way.

SUMMARY

Recent observations and computer simulations increasingly support the scenario that large clouds (halos) of dark matter existed after the Big Bang that acted as gravity traps, within which galaxies of all sizes formed.

Huge elliptical galaxies also formed relatively soon after the Big Bang.

Dwarf galaxies can plunge through large galaxies, stripping the dwarfs of their outer, lightly bound stars. What remains is a compact globular cluster, similar to that at the center of our Milky Way.

Their formation is consistent with the dark matter scenario: large galaxies were formed in the large halos, while in contrast only small amounts of matter flowed into the small ones, subsequently condensing to form stars. Depending on the density of the halos, small ones collided into large ones and dispersed or remained as satellites. "Because the flow of matter into these small halos dwindled very quickly, the supply for new stars likewise diminished," Neumayer says. "That's why we tend to find the oldest stars in dwarf galaxies, as evidenced by their elemental abundance."

The connection between dwarf galaxies and globular clusters is a new discovery. The latter also orbit large galaxies; some 150 of these clusters are currently known to orbit the Milky Way. However, they are not considered to be galaxies. They were once believed to be the oldest objects in the universe, in which no stars have formed for a long time. But this picture is changing. One case in point is a dwarf galaxy in the constellation Sagittarius.

Discovered only in the 1990s, this dwarf galaxy in Sagittarius is located outside the plane of the disk of our Milky Way. Astronomers at the Max Planck Institute in Heidelberg have recently discovered that it possesses a long tail of stars. This developed because the dwarf galaxy's orbit around the Milky Way is nearly perpendicular to the plane of the disk. Over the past billions of years, it has crossed the disk several times, "stripping" stars from its outer region and leaving only

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those bound more tightly within its central region. Especially significant is the fact that the core of the Sagittarius dwarf galaxy is a globular cluster. The cluster's former designation, Messier 54, is indicative that it was discovered more than 200 years ago, but the dwarf galaxy surrounding it remained unidentified.

In a departure from the previous standard explanation for globular clusters, a recent analysis of the elemental abundances within Messier 54 revealed its eventful history. "We have identified three stellar populations of different ages, approximately 2.2, 4.3, and 12.2 billion years old," says Nadine Neumayer. These ages, in combination with the calculated stellar orbits, have yielded the following explanation. The oldest of these stars formed less than two billion years after the Big Bang. The younger stars may have formed when the dwarf galaxy crossed the plane of the Milky Way, during which it accumulated gas from which the new stars formed. After further passages through the Milky Way, the dwarf galaxy will eventually shed its entire mantle, leaving only the globular cluster. "We suspect this is very similar to what happened to the globular cluster Omega Centauri," Neumayer says. Our galaxy's largest globular cluster, Omega Centauri has a mass of 3.5 million suns and can also look back on a complex evolutionary history, and also recently revealed a tail of barely visible stripped-off stars.

Invisible giant in the center of a dense star cluster

The question whether all globular clusters are in fact cores of former dwarf galaxies is at present impossible to answer. But they are definitely a source of surprises, as was demonstrated just a few years ago. An international team that included Nadine Neumayer observed a dwarf galaxy located near the center of the large elliptical galaxy Messier 60. This ultra-compact system contains more than a hundred million stars, all within a relatively small volume measuring 160 light-years in diameter. At its center, however, the researchers discovered a black hole of 21 million solar masses. No other galaxy contains a central object that accounts for such a large fraction of its total mass. "Interestingly, we find a similar mass ratio at the center of the Milky Way," says the Max Planck astronomer.

At the center of our galaxy resides a black hole of around four million solar masses. Reinhard Genzel of the Max Planck Institute for Extraterrestrial Physics and Andrea Ghez from the U.S. were awarded this year's Nobel Prize in Physics for their detailed analysis of this black hole. This dark giant resides in the middle of an ultra-compact star cluster of 25 million stars. Nadine Neumayer has measured the elemental abundance of the stars in this cluster and has deduced that most were formed more than eight billion years ago. However, it also contains a young generation, which was formed approximately one billion years ago within a comparatively short period of time.

Nadine Neumayer is investigating whether this cluster represents a merger of high-mass globular clusters that have gravitated towards the center and subsequently formed additional stars. This research also sheds light on how supermassive black holes formed. The latest research undertaken by the Heidelberg astronomers reveals that black holes containing up to ten billion solar masses existed as early as one to two billion years after the Big Bang. One of the most interesting questions in cosmology today is how these giants were able to grow so rapidly to this gigantic size and what influence they had on the evolution of galaxies. One hypothesis is that, early on, intermediate-mass black

Research in the library: Nadine Neumayer (right) heads a Lise Meitner Group at the Max Planck Institute for Astronomy. Together with her team, she studies dwarf galaxies and star clusters.

holes existed, comprising perhaps tens of thousands of solar masses, and that they grew by merging with other black holes and by sucking up gas. So far, however, no galaxies of this kind have been definitively identified. "Intermediate-mass black holes of this type should exist at the center of globular clusters," says Nadine Neumayer, "but our current telescopes are unable to detect them."

Neumayer is pinning her hopes on an instrument called MICADO, which will yield hyper-accurate images and will be Earth's largest telescope – the ESO's Extremely Large Telescope. It is being developed in an international consortium led by the Max Planck Institute for Extraterrestrial Physics with major contributions from the Max Planck Institute for Astronomy. This mega-telescope will usher in a new era for science, as well as for Ralf Bender and Nadine Neumayer.

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

GLOSSARY

DARK MATTER
About 27 percent of the universe is made up of invisible matter that only interacts through gravitation. Researchers are still unable to determine the nature of this matter. Candidates include axions, WIMPS (weakly interacting massive particles), and sterile neutrinos.

HALO
A roughly spherical region in which a galaxy is embedded. Halos are composed of various types of matter, such as hot gas (X-ray halos) or dark matter.

PHOTO: JÜRGEN LECHER FOR MPG

Over the course of evolution, plants have developed a wide array of leaf shapes. Every shape is the result of adaptation to the environment, which is why the way that leaves look is no real indication of whether or not plants are related. Even closely related species may have different leaves, in some cases as a way of adapting to different environmental conditions.

PHOTO: ADOBESTOCK

DIVERSITY IN THE LEAFY FOREST

TEXT: TIM SCHRÖDER

Lanceolate, ovate, elliptical, entire, serrated, and uni- or multi-pinnate – there are numerous names to describe the variety of leaf morphology. But how does this diversity come about? Miltos Tsiantis from the Max Planck Institute for Plant Breeding Research in Cologne and his team are looking for genes that control leaf growth. They have already found one central regulatory element.

PHOTO: FRANK VINKEN FOR MPG

In botanical guides, the lists of leaf morphology descriptions can fill several pages. These classifications distinguish between simple leaves with continuous leaf surfaces and outlines, and so-called compound leaves, which feature leaf surfaces consisting of separate units called leaflets. The vast range of morphology is well researched, because the shape of a leaf is an important characteristic for the identification of plants and because leaves are the sites of fixing atmospheric carbon into sugars in a process known as photosynthesis. But the origin of different leaf forms and why even leaves of closely related species can look very different remained a mystery until quite recently.

Together with his team at the Max Planck Institute in Cologne, Miltos Tsiantis is analyzing when and where genes that are important for shape development are switched on and off as a leaf bud slowly takes shape. He's utilizing modern technologies to do so, including advanced microscopy methodologies that allow scientists to zoom deep into leaf tissue and computer models to grow virtual leaves. "We want to find out which genes make leaves of different species look the way they do. Since flowering plants typically have over twenty thousand genes, it's a bit like searching for a needle in a haystack," says Tsiantis. For many years, he has been working with *Arabidopsis thaliana*, which is essentially the fruit fly for botanists. Thousands of researchers have analyzed the plant's genetic material, metabolism, and development. Many of its genes are therefore relatively well studied.

But studying *Arabidopsis thaliana* alone cannot tell Tsiantis how various leaf forms evolve. For this, he is researching its close relative, *Cardamine hirsuta*, a delicate plant with white flowers that also belongs to the Brassicaceae family and that the Cologne research group has used to develop a model system for comparative studies in plant genes. Although the two plants are closely related, their leaves have different shapes. Those of *Arabidopsis thaliana* resemble round spinach leaves, which have a few delicate serrations at the edge. *Cardamine hirsuta*, on the other hand, has pinnate leaves (i.e., one leaf is divided into several pinnae or leaflets). A larger, roundish leaflet grows at the tip of the petiole with small pinnate leaves on delicate stalks on the left and right below it. Tsiantis cultivates *Cardamine hirsuta* in the greenhouses at the MPI in Cologne, because he needs genetically different individuals for his investigations. To achieve this, he and his team treat the seeds of the plants with the chemical ethyl methanesulfonate. This substance induces point mutations (i.e. damage to the genetic material). "This helps us modify individual genes. However, the muta-

Exchange of ideas during the COVID pandemic: Miltos Tsiantis, Angela Hay, Neha Bhatia, Ziliang Hu, David Wilson-Sanchez und Shanda Liu (from left to right).

tions occur randomly. We can't influence where they occur," says Tsiantis. But if one of the treated plants develops leaves of a different shape, he and his research team can analytically reverse engineer the process to pinpoint which genes have mutated and are thus responsible for the change in shape.

This is how Tsiantis's former student, Huw Jenkins, has cultivated thousands of *Cardamine hirsuta* plants with varying leaf shapes – from curly, parsley-like leaves to elongated ones resembling lavender. Among all the plants, the group discovered one in which the leaves looked familiar – round, with fine indentations at the edges and completely without pinnate leaves. "This *Cardamine hirsuta* plant looked a bit like an *Arabidopsis thaliana* plant," says Angela Hay, who also uses *Cardamine hirsuta* in her studies. A genetic analysis showed that the chemical treatment had altered a DNA segment of *Cardamine hirsuta* that does not occur at all in *Arabidopsis thaliana*. The researchers had thus discovered a gene that was missing in the simple leaves of *Arabidopsis thaliana* but that, when it is damaged, causes *Cardamine hirsuta* to develop simplified leaves as well. These results were further confirmed by using the recent breakthrough technology of genome editing, which allowed the Cologne group to induce targeted mutations in the RCO gene: and again they observed the formation of that same, simple leaf phenotype. That made it clear that this gene controls the shape of the leaf. Because the leaves of

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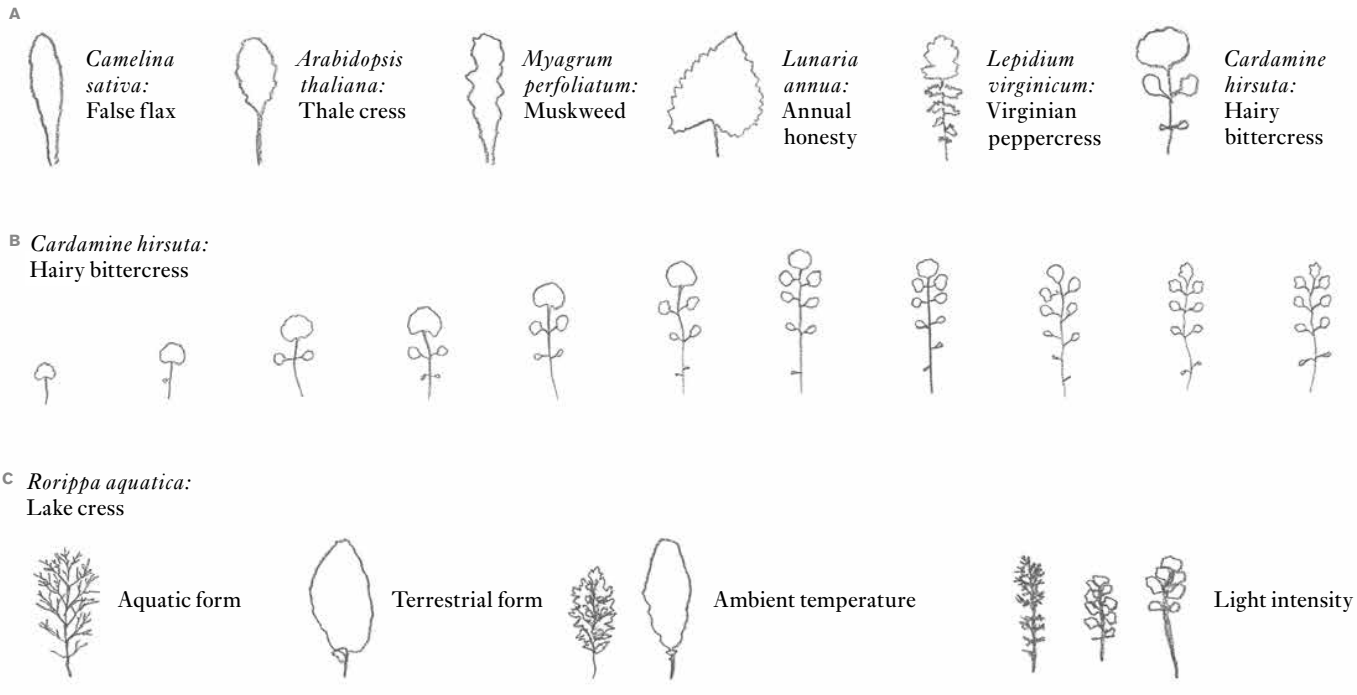
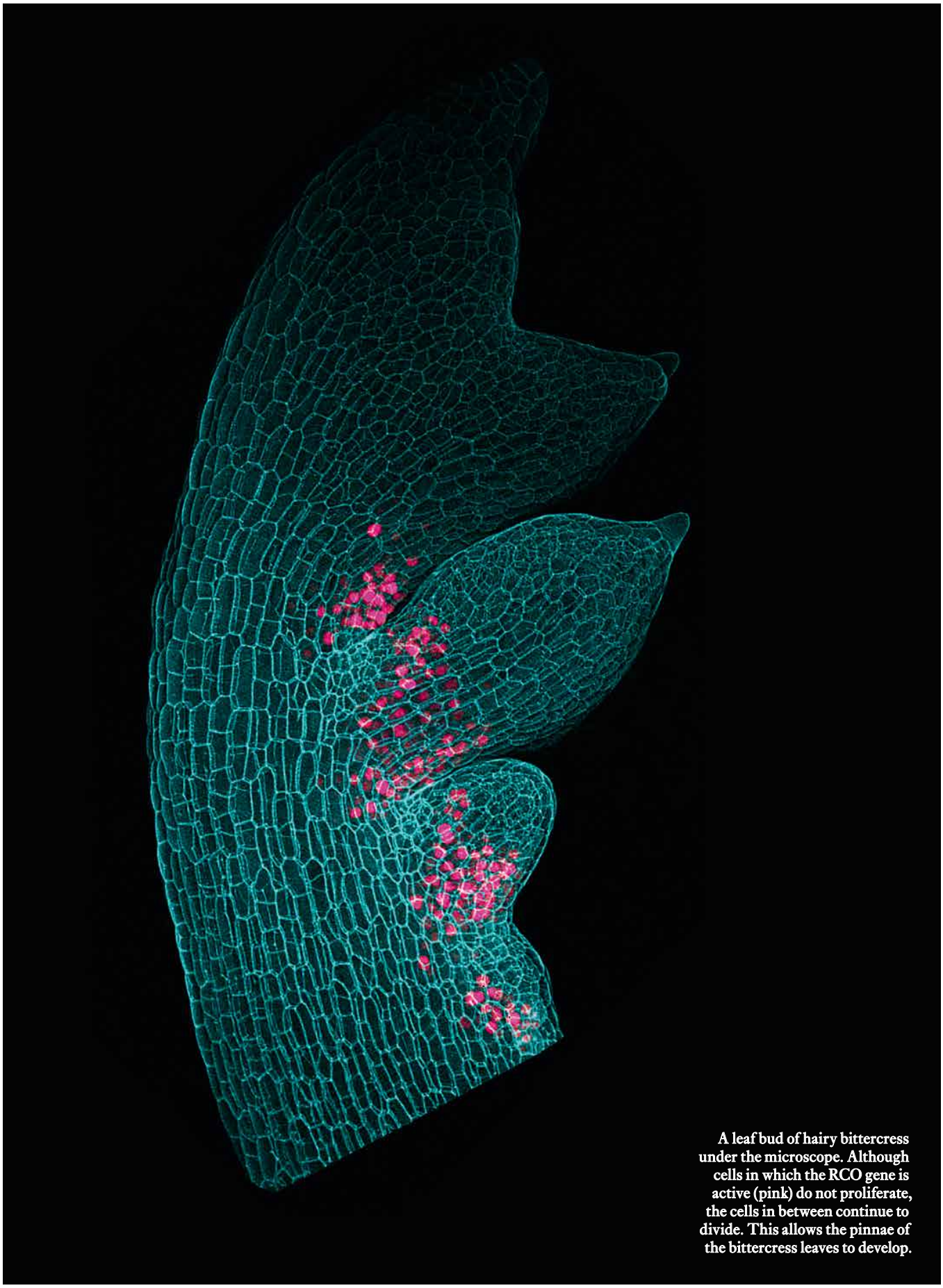


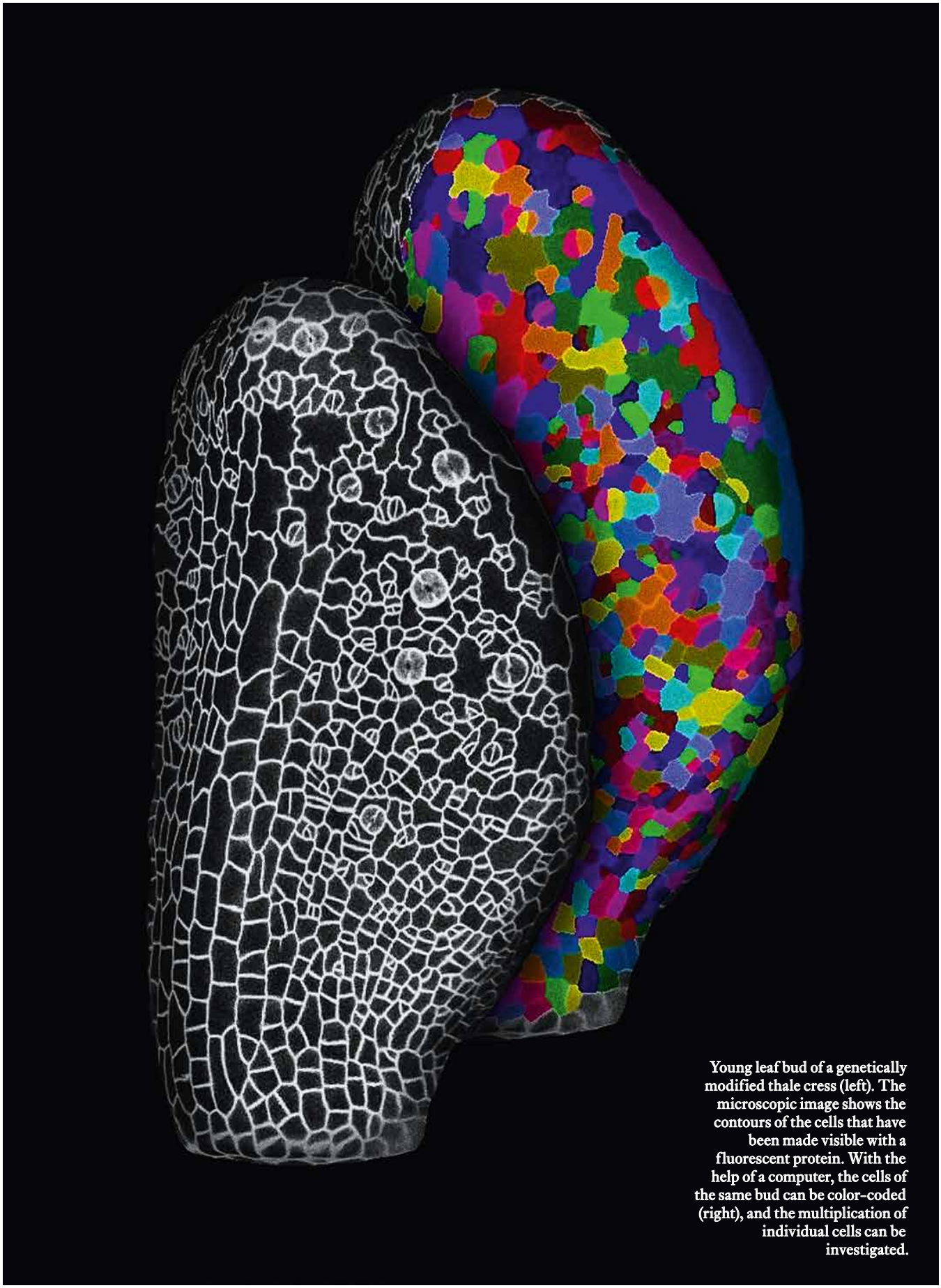
GRAPHIC: GCO BY NAKAYAMA ET. AL. (2014). REGULATION OF THE KNOX-GA GENE MODULE INDUCES HETEROPHYLLIC ALTERATION IN NORTH AMERICAN LAKE CRESS

Leaf diversity among crucifers: differently shaped leaves occur not only in different plant species (A) but also in the same plant depending on its age (B). Environmental conditions also influence leaf shape (C).



A leaf bud of hairy bittercress under the microscope. Although cells in which the RCO gene is active (pink) do not proliferate, the cells in between continue to divide. This allows the pinnae of the bittercress leaves to develop.

IMAGES: MILTOS TSIANTIS/MPI FOR PLANT BREEDING RESEARCH



Young leaf bud of a genetically modified thale cress (left). The microscopic image shows the contours of the cells that have been made visible with a fluorescent protein. With the help of a computer, the cells of the same bud can be color-coded (right), and the multiplication of individual cells can be investigated.

Cardamine hirsuta have a less complex structure without the gene, the researchers named it "RCO" (Reduced Complexity).

Tsiantis's team then conducted a more detailed analysis of how leaves of *Cardamine hirsuta* develop. Using fluorescent protein labeling, the researchers were able to observe under a microscope that the RCO gene is active at certain places along the leaf edge – specifically, in distinct bands at the base of emerging leaflets. The RCO gene inhibits cell growth at these sites, while the cells in between the RCO bands continue to grow. The bulges created in this way gradually grow into the distinct leaflets or pinnae. "RCO thus helps the individual leaflets to emerge and grow into separate pinnae, instead of producing a continuous leaf surface," explains Tsiantis.

"The RCO gene is one of our most important discoveries – because it gives us a clear glimpse of how evolution works."

MILTOS TSIANTIS

Thus, if the RCO gene is a pivotal gene in the evolution of leaf shapes, then an *Arabidopsis thaliana* with an artificially transferred RCO gene should also develop pinnate leaves. And indeed: an *Arabidopsis thaliana* plant modified to contain the RCO gene has roundish leaves with clearly visible protrusions. Although the plants do not grow pinnate leaves on stems, the resemblance to *Cardamine hirsuta* is truly astonishing. "The results of these experiments caused some excitement in the scientific community, because it is very rare for a single gene to influence the differences between plant species to such an extent," says Tsiantis. "Actually, we expected that the minor, respective effects of a large number of genes would work together to cause evolutionary changes in such fundamental traits." So, together with Donovan Bailey from the New Mexico State University, Tsiantis then began studying the phylogeny of Brassicaceae in order to find the origin of the gene. Apparently, the Brassicaceae family did not originally possess an RCO gene. Consequently, species of Brassicaceae that are developmentally similar to ancient members of the family have simple leaves. When RCO emerged from a gene duplication event during the course of evolution, species such as *Cardamine hirsuta* or *Arabidopsis lyrata* (which is even more closely related to *Arabidopsis thaliana)* were able to form deeply indented or compound leaves. The gene was lost later in the phylogenetic history, so that *Arabidopsis thaliana* was able to form simple leaves. Since the discovery of the RCO gene, Miltos Tsiantis, and his team have been studying the regulation of leaf growth even more closely. Although Tsiantis's work is basic research, his findings could certainly have practical relevance, for example in agriculture. "In light of climate change, knowledge about the development of different leaf forms could become increasingly important and contribute to the environmentally sustainable cultivation of higher-yielding plants," says Tsiantis. When Miltos Tsiantis moved from Oxford to Cologne in 2013, he was able to readily acquire state-of-the-art microscopes. They make individual cells visible to Neha Bhatia, a post-doctoral scientist in the group. With great dexterity, she first removes the mature leaves of the seedlings, and then places the tiny plant under the microscope. This allows her to observe the newly formed leaves which can be as small as a few micrometers long. Then she switches on the screen, focuses the microscope and suddenly the cells marked with fluorescent proteins begin to glow. "We can now mark several genes simultaneously with different colors and see where in the leaf they are currently active," explains Bhatia.

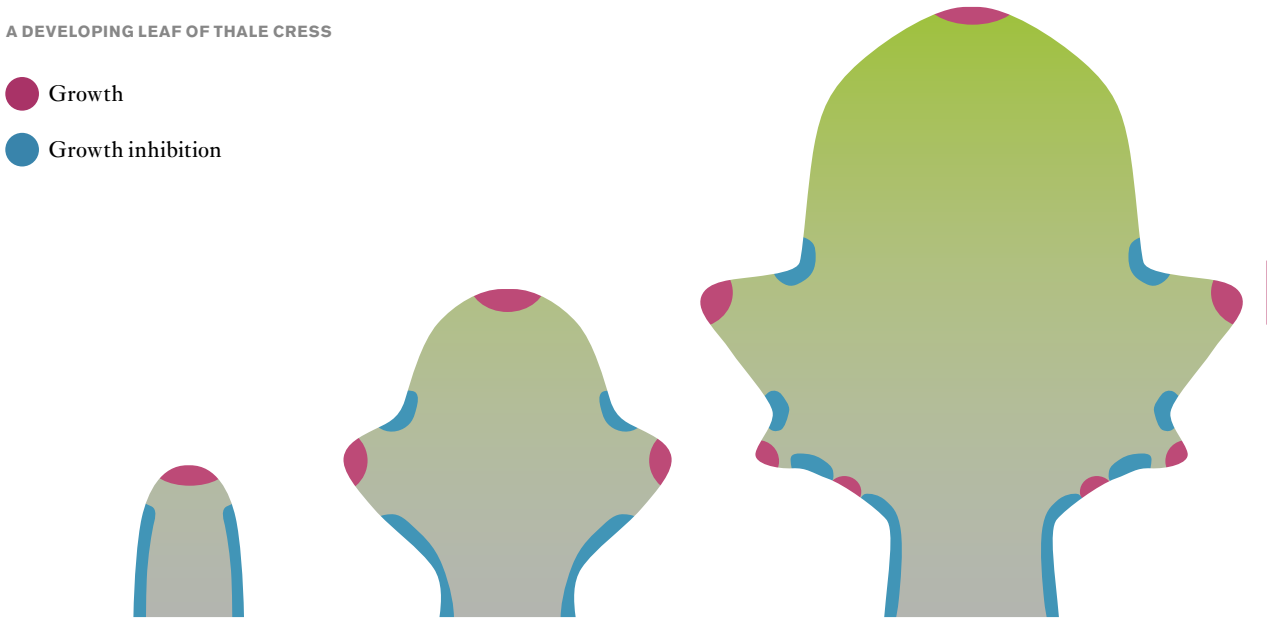
In the meantime, the researchers have also discovered that a previously discovered gene called the STM gene acts together with RCO to initiate leaflet formation. While RCO inhibits leaf growth, STM causes cells to continue growing. Normally, cells no longer divide when they specialize. However, when STM is active, the cells can continue to multiply so that the leaf grows wider at this point. If RCO and STM are active at the same time, broad bulges form at the edge of the leaf. "When we activate both genes in the *Arabidopsis thaliana* leaves, the leaves formed by these genetically modified plants look like those of *Cardamine hirsuta*," says Tsiantis. This experiment shows that, by having an in-depth understanding of how plants differ from one another in their specific characteristics, we might then also use that understanding to modify the traits of crop plants as well. However, the shape of a leaf is not determined

SUMMARY

Developing *Cardamine hirsuta* as a model system for studying plant biology helped the scientists make new discoveries about how plants develop and diversify. For example, the 'RCO gene' is active in some species and not others, and it plays a significant role in determining the shape of a leaf.

RCO is active in the cells located at regular intervals along the edge of the leaf. It prevents those cells from growing.

STM is another important gene that is active in leaves of some species but not others. STM is active more broadly in the leaf than RCO and it allows prolonged proliferation of leaf cells. This feature, together with the more local growth repressive action of RCO, allows small bulges at the leaf margin to eventually grow into separate leaflets.



A growth zone forms a gradient from strong (green) to minimal (gray) growth.

Zones of growth activation and inhibition alternate and lead to bulges along the edge of the leaf.

As the leaf grows larger, more local growth zones emerge.

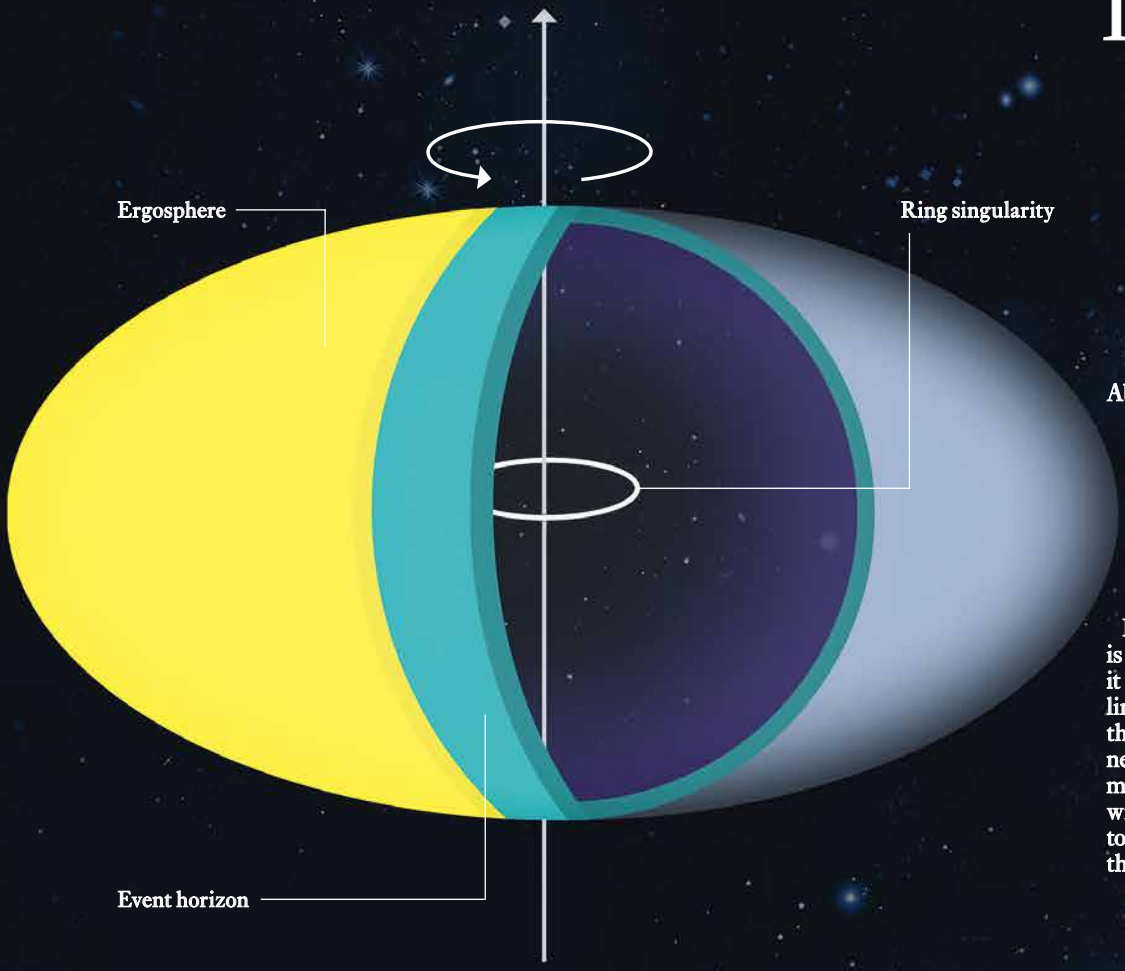
by its genes alone. The physical properties of leaf tissue also influence the development of the leaf, by means of the mechanical resistance it exerts on growing cells. Adam Runions, a computer scientist in Tsiantis's team, developed a mathematical model that takes into account physical interactions within the leaf tissue. This allows him to "program" leaves that grow virtually. "If we suspect, for example, that a gene functions in a certain way, we can use our model to test this hypothesis," says Tsiantis. "In this way, we can identify the basic rules according to which the leaves develop."

But why do plants have such dissimilar leaves in the first place? To answer this question, the Tsiantis team studies different *Cardamine hirsuta* plants from Europe and other parts of the globe to learn how the local environment may affect the shape of a plant's leaves. "For instance, we have observed that plants that grow in regions where they can produce flowers quickly and reproduce rapidly also produce more leaflets more quickly. This strategy may support a more efficient assimilation of carbon and consequently a better supply of nutrients for the next generation. Conversely, in areas like central Europe or Scandinavia, where plants bloom late because they have to survive a cold winter, they tend to 'wait' to attain their maximum leaflet numbers until just before they flower in spring. Perhaps this strategy also ensures the leaves' ability to supply an optimum level of nutrients for the seeds, which will form soon after flowering," the scientist explains. The various methods, the wealth of ideas, and the unusual perspectives implemented by Tsiantis and his team have made important insights into leaf growth possible. Tsiantis himself considers the RCO gene to be one of his most important discoveries, "…because it very clearly illustrates how innovations can arise during evolution."

Most genes have several functions. For this reason, the mutations of one gene can trigger a wide variety of changes in a plant's form and function. A mutation can improve one function and impair another. Experts refer to this as "pleiotropy". "Just imagine: a bird develops wings that can help it fly better. But if the genetic modifications responsible for this improvement also change the bird's color and thus make it less attractive to potential mates, that change in wing shape will most likely not be successful," explains Tsiantis. RCO on the other hand is a gene that is hardly pleiotropic at all. It largely controls the shape of a plant's leaves, but otherwise has few other functions. "The example of RCO lets us not only reveal the secret of leaf diversity, but also learn how evolution works." For example, the role of RCO in leaflet separation can be considered analogous to processes that lead to the separation of digits on developing limbs. In this case, however, the separation is primarily driven by programmed cell death, and not growth inhibition.

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

BLACK HOLES – SPACE-TIME TRAPS



Abstract mathematics is being used to determine the structural design of a rotating black hole. It is impossible to imagine a *ring singularity* with no spatial extension. Easier to envision is the *event horizon*; it defines the size and limit beyond which there is no return, neither for light nor matter. Everything within the *ergosphere* has to rotate in sync with the black hole.

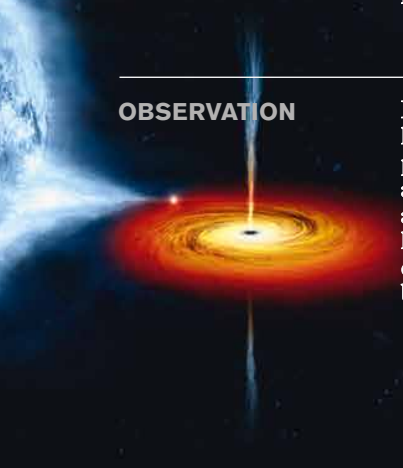
An incredible thought experiment: compress the Earth to the size of a cherry and you turn it into a black hole.

THEORY

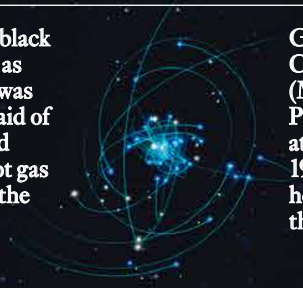
In 1783, John Michell first imagined "dark stars", which do not emit light because of their gravitation.

In 1915, Albert Einstein created the mathematical basis for such objects in his general theory of relativity. A year later, Karl Schwarzschild described the geometry of a static black hole.

OBSERVATION



In the early 1970s, the first stellar black hole (Cygnus X-1) was discovered as part of a binary star system. This was accomplished indirectly with the aid of an X-ray satellite, which registered high-energy radiation from the hot gas disk (accretion disk) surrounding the black hole.



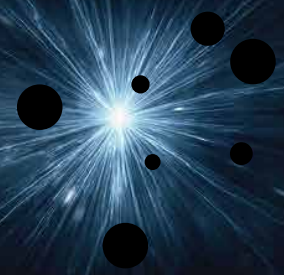
Groups led by Andrea Ghez (University of California, Los Angeles) and Reinhard Genzel (Max Planck Institute for Extraterrestrial Physics) had been observing the orbits of stars at the center of our Milky Way since the 1990s and concluded the existence of a black hole of 4.3 million solar masses, for which they received the 2020 Nobel Prize in Physics.

IMAGES GCO; ISTOCK; NASA/CXC/M. WEISS; ESO/L. CALÇADA/SPACEENGINE.ORG (FROM TOP TO BOTTOM)

VARIOUS TYPES

Four types of black holes can be differentiated according to their respective masses:

Primordial black holes
Mass: approximately equal to that of the Earth's moon
Origin: Big Bang



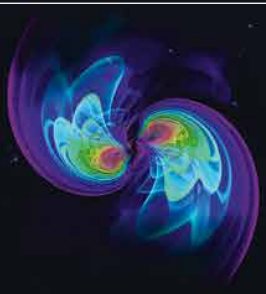
Stellar black holes
Mass: between 3 and 65 solar masses
Origin: Supernova (how heavier black holes of up to 120 solar masses are formed remains unclear)

Supermassive black holes
Mass: between a few million and billions of solar masses
Origin: mergers between numerous black holes, each comprising several hundred solar masses; collisions between galaxies or accretions of mass gathered from surrounding space

Moderately heavy black holes
Mass: between 120 and 100,000 solar masses
Origin: collisions between stellar black holes; mergers between massive stars or the Big Bang

IMAGES: ISTOCK; NASA, ESA, AND D. MILISAVLJEVIC (PURDUE UNIVERSITY); ISTOCK; S. OSSOKINE, A. BUONANNO (MPI FOR GRAVITATIONAL PHYSICS); SIMULATING EXTREME SPACETIME PROJECT, D. STEINHAUSER (AIRBORNE HYDRO MAPPING GMBH); EHT COLLABORATION (TOP TO BOTTOM)

In the 1960s, the theory of relativity experienced a renaissance as a result of new observations. Roger Penrose (2020 Nobel Prize in Physics) and Stephen Hawking demonstrated the presence of a singularity of infinite density, as well as an infinite curvature of spacetime within black holes.



The gravitational waves predicted by Einstein were detected for the first time on September 14th 2015 and emanated from the merger of two black holes having 29 and 36 solar masses, respectively.

Scientists published the first image of a black hole in 2019, which was pieced together from images taken by the Event Horizon Telescope – a network of eight radio observatories scattered over half the globe – and shows the massive monster at the heart of Galaxy M87.

AN INFECTIOUS INTEREST IN THE CORONAVIRUS

Viola Priesemann's life has changed a great deal since the corona epidemic first started in Germany: Priesemann, the head of a research group at the Max Planck Institute for Dynamics and Self-Organization, is now investigating not only information processing in the brain, but also how the SARS-CoV-2 virus spreads. And ever since, her daily routine has included consultations with policymakers, giving interviews, and appearing on TV.

TEXT: UTA DEFFKE

It was past 11 p.m. on an evening in late March 2020 when Viola Priesemann sat back down at the computer in her home office in Goettingen. Her usual tasks as a physicist – developing new models, performing calculations, and fine-tuning new academic papers – were not on her mind. She was focused on a completely different matter: drafting a position paper for policymakers written from the point of view of a scientist. The COVID-19 pandemic, just a few weeks old at the time, was gripping the world's attention. Germany had also just gone into lockdown: events were prohibited, daycare centers, schools and universities were closed, as were most stores, restaurants and cultural institutions. Social distancing was the order of the day. Even the streets of the big cities were filled with an eerie stillness.

But Viola Priesemann's mind was racing. The head of the Max Planck Research Group "Theory of Neural Systems" at the Max Planck Institute for Dynamics and Self-Organization in Goettingen had only begun analyzing the spread of the virus and the effectiveness of the countermeasures in the past few weeks. But the physicist already recognized one fact: the pandemic can only be controlled over the long term by keeping case numbers low. It's the only way to avoid excessive collateral damage to public health, society and the economy. A lockdown, she realized, would have to reduce case numbers to the point where health departments can reliably detect and isolate a sufficient percentage of cases by means of consistent testing and tracking. If this can be achieved, restrictions could be relaxed again. Any local flare-ups could then be quickly identified and easily contained with short, but tough, measures.

That was the conclusion Priesemann arrived at based on her calculations of several alternative scenarios. And that's what she wrote in the draft of her statement. "I suddenly recognized that my working group had expertise that was important to society, but it was not yet known to others. That's a really strange feeling." She was certain even then that we were going to be dealing with the pandemic for many months to come. Her assessment of the benefits of the shortest possible hard lockdown was shared by colleagues in the fields of psychology, social sciences, and economics. She shared and discussed her findings with them. Because one thing was clear to her: her own epidemiological findings on the spread of the pandemic were only one perspective on how the disease would develop. She was particularly impressed by an article in *The Economist* on the "90 percent economy", which argued that a short, sharp restriction would be less damaging to the economy than repeated curtailments over months or years. Priesemann coordi-

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VISIT TO

VIOLA PRIESEMANN

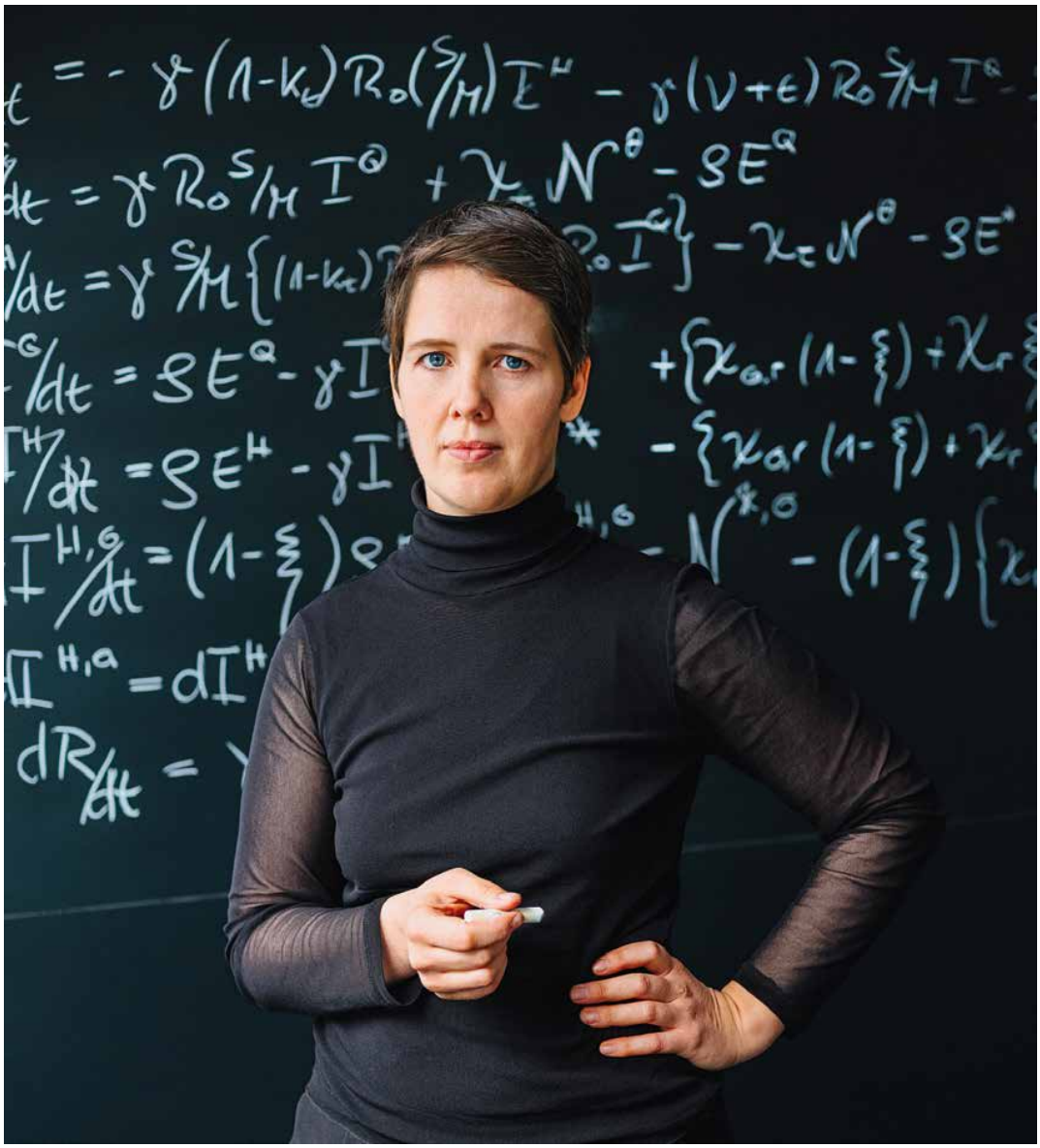

PHOTO: JULIA STEINIGEWEG

Theorist of the epidemic: Viola Priesemann develops mathematical models of information processing in the brain. She employs similar methods to predict the spread of the coronavirus.

PHOTO: JULIA STEINIGEWEG

A rare chance to find some balance: when she can make the time, Viola Priesemann likes to go horse riding. Right now, however, she has little opportunity to do so.

nated her draft with colleagues at the other major German research institutions. "It was important and reassuring that we all came to the same conclusions, each with our own specific approaches," she says, looking back. A first version of the position paper quickly entered the political realm. Nonetheless, the message that sprang from the research institutions largely went unheeded in the "orgy of discussions on opening back up," as Chancellor Merkel is said to have called the ongoing debates in the German states. When the paper officially appeared on April 28th, an end to the lockdown had already been decided. But a second wave was on its way, at the latest in the fall; of that the researchers were certain.

Over the summer, a modicum of calm returned – at least in hospitals and health departments. Viola Priesemann continued to work flat out, both on the COVID-19 pandemic and on her other scientific pursuits. Her main area of research, after all, is the theory of information processing in the brain. To understand her sudden involvement in research into COVID-19, you need to trace her career back a few steps.

For many years, it was far from clear whether Priesemann would follow a scientific career path or not. With a grandfather who was a classical philologist and pedagogue, as well as vice president of the University of Kiel, her social background certainly placed a high value on education. But for a long time it never occurred to Viola that women could also become researchers, inventors, or even professors. For example, she remembers a schoolfriend's father telling her about his work in speech recognition, the technology involved in translating spoken words into written text: "Right now, the methods known as 'deep learning' are revolutionizing speech recognition, but even back then, I thought it was pretty cool. But at the same time, I was subconsciously aware that this was not anything that I

would ever work on." Because it's just not something that women do. Studying was still the order of the day though – in Darmstadt. Physics appealed to her, because she had always felt an urge to understand the world. "Looking back at it now, physics was the perfect foundation for what I now enjoy doing," she says. The theory of complex systems fascinates her the most. How do swarms develop? Why do zebras have stripes? How do natural structures form? The underlying premise is discovering how numerous individual entities are transformed into a single large one that has its own unique properties. In her fifth semester, Priesemann happened to notice a new sign on an office door: Prof. Barbara Drossel. "That's when it hit me for the first time – wow, a woman can become a professor too. In theory, so could I."

"It's an incredibly dynamic time, especially for us scientists. Because new information is emerging every day."

As it turned out, she called her career goals into question once again during her Erasmus study year. A passionate rider from childhood ("Some people just seem to have a horse gene."), she headed off to Lisbon. It's a part of the world with a great tradition in classical dressage. Priesemann spent more time on horseback than in the lecture hall. But nonetheless, in the end, she made up her mind: her professional future was definitely going to be in physics.

She took great care in choosing the subject of her diploma thesis. It should, she felt, be something that was both complex and relevant to everyday life. And that's how she ended up working in the field of theoretical neuroscience with Wolf Singer, Director at the Max Planck Institute for Brain Research in Frankfurt/Main. After all, the brain is a complex system as well – perhaps the most complex one that we know of. And the fundamental principle underlying how we think and learn is the formation of new structures. Each of the 80 billion neurons interacts with thousands of other neurons by creating connections known as synapses. How these interactions lead to information processing – for instance, how information reaching the brain via the sensory organs is then combined with pre-existing information stored there – is something that Viola Priesemann is investigating using mathematical techniques. Another thing that attracted her to Wolf Singer's group at the time was its interdisciplinary perspective. Her work in the group would involve collaboration with physicists, psychologists, biologists, and philosophers. It was clear that the processes in the brain are self-organizing, since a network of that size and complexity could never be programmed.

Such self-organization is governed by local rules of learning, which determine the strength of individual synaptic connections. Insights into these processes help us, on the one hand, to better understand the biological brain, while on the other, they can help in optimizing artificial neural networks.

As she began delving into her diploma thesis, Viola Priesemann made an important discovery: if you want to get to grips with a system as complex and large as the brain, you'll inevitably need to limit yourself to examining its individual components. It had long been thought that the big picture could be extrapolated from such components, because the brain is a scale-independent system. Just like fractals, which are similar in appearance when you zoom in, it shouldn't matter whether you are observing such a system on a large or a small scale. However, on the basis of contradictory data, Priesemann discovered that unlike the system itself, the properties of a scale-independent system do not appear to be scale-independent when only a small subcomponent of that system is viewed. In other words, the properties of the subsystem can't simply be extrapolated to infer the properties of the system as a whole. This insight doesn't just apply to the brain; it's a general principle.

A discovery like that gave her self-confidence – and toughened her in scientific debate. After all, a young scientist – and a young female scientist to boot – isn't likely to endear herself by calling esta-

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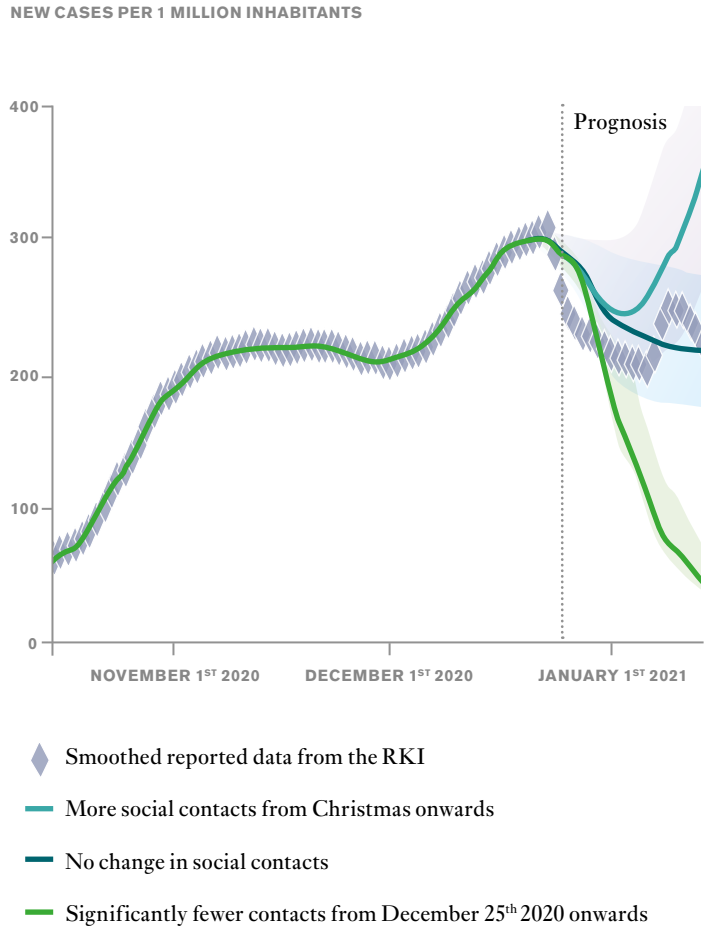

Scenarios of the epidemic: the model developed by Viola Priesemann's group makes it possible to track the numbers of new infections and forecast future developments based on various assumptions. The sharp reduction in cases over New Year is due to reduced testing during this period. The temporary increase in January is partly due to a return to normal testing operations and also to increased personal contacts during the Christmas holidays.

GRAPHIC: GCO BASED ON RESEARCH BY THE MPI FOR DYNAMICS AND SELF-ORGANIZATION

blished theories into question. But for Viola Priesemann, that insight was the foundation upon which her further research work was built. She asked herself: how could conclusions drawn from the sub-system nevertheless be applied to the entire system? She developed mathematical techniques to help her investigate.

Nonetheless, with a view toward broadening her expertise for the future, she sought a new subject for her doctoral thesis at the interface between theory and experiment. Priesemann's dissertation would lead her first to the École Normale Supérieure in Paris and then to Caltech in California to Gilles Laurent, who she later followed back to the Max Planck Institute for Brain Research when he became Director there. Above all, this meant years of hard work as an assistant setting up a laboratory. However, Priesemann has never shied away from technology and hands-on labor, even as a child when she once single-handedly repaired the family toaster because she was determined not to get a new one. She was working on more delicate objects in her lab: the brains of turtles – a good model system for studying the role of the outer corrugated structure of the brain known as the cortex, which plays an important role in vision and the processing of visual information. Her work confirmed a general but crucial insight into scientific research that she learned from her doctoral supervisor: "Making an observation that fits one's hypotheses is exciting. But then the real work begins. You have to scrutinize and check your results and be your own most critical reviewer."

In 2013, Priesemann returned to theoretical work – moving to the Max Planck Institute for Dynamics and Self-Organization in Goettingen. "I can perform experimental work. But I love to understand data and to develop theories to explain it." This she has done, first as a postdoc and then, soon after, as a Bernstein Fellow and Max Planck Research Group Leader. "This gave me independence, my own budget and, with an additional research grant, the ability to recruit my first students." She certainly has a gift for it. She learned from one of her mentors that working with people who stimulate you and are pleasant to be around is important. Her team has now expanded to around twenty researchers.

Among their most important findings is a learning rule for how neurons interconnect to form stable and effective networks that can process any and all types of information, and how they accomplish this by adjusting the strength of their connection. Connection strengths are not fixed, as was long assumed, but are adapted to the task at hand. Priesemann's team discovered this when they were working on the "Human Brain Project" with research colleagues from Heidelberg. They constructed artificial neurons from semiconductor materials and combined them to create relatively large networks that could autonomously learn using the applied rules.

When COVID-19 erupted in the spring of 2020, Viola Priesemann's own synapses immediately went into overdrive: "It was just such a good fit," she asserts. Brain research and the spread of a virus? In the brain, information propagates as one neuron activates its neighbors; similarly, corona virus infections spread from one person to the next. "In both cases, we can make inferences about the big picture (with a high level of uncertainty) by observing a small subset: drawing conclusions about how the activity of a few

PHOTO: JULIA STEINIGEWEG

Presenting her findings to other scientists is a regular part of the work of a research group leader. But Viola Priesemann also aims to disseminate her findings about the corona epidemic to politicians and the public – as a physicist, that is a new experience for her.

hundred neurons results in information processing in the brain and, in much the same way, about how a comparatively small number of known cases of COVID-19 cause the spread of the virus throughout the population." Fired up by this parallel and motivated by its relevance to society, Priesemann threw herself into the subject. She already had at her disposal a set of fundamental mathematical tools. These she developed further, adapting them to the new challenge. To quickly find out everything there was to know about viruses, she networked with experts: medical scientists, virologists, and epidemiologists. She also contacted psychologists, economists and social scientists – first experts in Goettingen and then all around the world – to attain a holistic view. "I'd always been interested in interdisciplinary discourse," says Priesemann, recalling the salons from her Frankfurt days, where people from all walks of cultural, political and business life could meet and engage in casual conversation. "Frankfurt at the time was the hotspot of the financial crisis. My partner and I discussed the crisis in all its dimensions with a large circle of friends from the worlds of philosophy, sociology, and economics, seeking to comprehend it." Living in the banking city of Frankfurt, the tensions and contrasts were palpable. After the pandemic, she hopes to revive such salons and discuss issues such as the concentration of power, self-organization, and social justice. Scientists have had a good understanding of how infectious diseases spread since the 1970s, but it was barely active as a field of research when she began exploring it. Nevertheless, Priesemann was able to introduce new ideas based on her mathematical methods from neuroscience, enabling her to model much more complex influences. "It's an incredibly dynamic time, especially for us scientists. New information is emerging every day – new figures and new publications. I have spoken with an incredible number of people, increased the size of my team, engaged in external press relations and written advisory reports. Sometimes I don't even know how I've managed it – Monday to Sunday from six in the morning until midnight," she says.

For Priesemann and everyone else, the corona crisis dominates our lives, with all its restrictions and insecurities. However, the virus isn't having a negative impact on her research activities – despite working from home and having a child in daycare

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since March. "Our work is purely theoretical. It requires, above all, the ability to think, free from distractions and with access to powerful computers – which we can fortunately operate from home." She can meet up with her team in two video chatrooms, which are accessible around the clock if needed. One is dedicated to research into the COVID-19 pandemic, the other to neuroscience issues. It's a system that works really well, she says. Everyone has been working fantastically together, scattered as they are across Hamburg, Leipzig, Hanover, Amsterdam, Lyon, and Granada. In the summer of 2020, small groups regularly met for extended walks around the grounds of the Institute, which is nestled in a beautiful wooded setting. The purpose of these meetings was to help develop a new project and to – literally – walk through the group's ideas at length.

One important finding from the fall of 2020 was that in addition to an R score above 1, another tipping point existed for the epidemic: the capacity of public health departments to trace cases. If this capacity proves insufficient, the virus spreads uncontrollably. "And then the longer we wait to initiate countermeasures, the harder it will become to contain high case numbers again." This is the message Viola Priesemann disseminated in talk shows, radio broadcasts, online media and newspapers throughout October 2020, and sometimes even on the front pages of those newspapers. Nonetheless, the second wave of the pandemic continued to spread. Researchers were alarmed, but policymakers dithered. It took until November 2nd for a "lockdown light" to be declared. Anne Will, the host of a German TV show, asked Priesemann whether she thought the measures that had been taken were sufficient. Priesemann measured her words: "We can succeed in lowering R from 1.4 to 0.7, but to achieve this, we need to employ every tool in our toolkit." And by "tool" she meant all possible measures to contain the epidemic. She's aware that science can only provide data and facts. Deliberating on those facts and making decisions is the task of politicians: "That's not a métier I would venture into." Four long weeks later, the politicians finally decided to tighten the lockdown. Way too late for a carefree Christmas.

Does Viola Priesemann feel that politicians have adequately heeded her advice? One thing she's sure of is that the chancellor herself must have been quick to take note of her publications. That much was evident from Merkel's press conferences. Priesemann is less certain when it comes to the heads of Germany's federal states. In truth, Priesemann had been planning on scaling back her media activities in November – the time commitment was enormous, and she was also about to take the next steps in her scientific career. But as long as the corona pandemic is still rampant, and as long as new, politically relevant findings are still emerging, she's decided to stay involved.

For example, Priesemann is currently refining her corona model to take into account, among other things, the age structure of the population, its geographic distribution, and the uncertainties involved. Up to now, the calculations have been based on comparatively simple assumptions that the distribution of infected persons is homogeneous. An expansion of the model should help to more accurately estimate the number of undetected cases and the effectiveness of the measures taken. Priesemann is also expanding her perspective to take in all of Europe. She has coordinated a joint position paper, supported by over 300 colleagues from many countries, which was published in the British journal *The Lancet*. The paper calls for a reduction in the number of new infections to about seven per 100,000 people per week throughout Europe. Viruses are no respecter of borders, after all.

"The longer we wait to initiate countermeasures, the harder it will become to contain high case numbers again."

Now, at the beginning of 2021, it's impossible to predict when the next period of respite from the virus will be. Priesemann took a break over Christmas anyway, at least in her public capacity. She likes to spend her free time riding – a hobby, it turns out, that is shared by other female scientists. At a meeting with the president of the University of Frankfurt, she discovered that the president owns two horses. She also knows other top female scientists who ride: "Maybe it's a sport for strong women," Viola Priesemann says with a laugh. That bodes well for her next career leap.

DNA ORIGAMI

TEXT: MARA THOMAS

What is life? How did it emerge? And could it possibly look completely different? At Kerstin Göpfrich's lab at the Max Planck Institute for Medical Research in Heidelberg, scientists are working on answers to the really big questions. Her research group's plan is no less ambitious: to create artificial cells and, by so doing, to discover what is essential for life.

Even the simplest bacterial cell is so complex that disentangling the interplay of its varied components is hugely challenging. It is similarly difficult to determine which of these elements is indispensable for the life of the cell and which is merely a biological "spandrel" – a by-product of the process of evolution. "What I cannot create, I do not understand is a maxim of the physicist Richard Feynman, and for me it holds true: I can only fully understand something if I can create it myself," says Kerstin Göpfrich. This approach is not solely the central theme of her own scientific work, but of an entire field of research: synthetic biology. Some scientists in this field use living cells as a starting point, while others begin with individual cellular components, which they try to reassemble like pieces of a jigsaw puzzle.

And other researchers even go one step further: they plan to design a cell from scratch, using as few building blocks from nature as possible. Because these scientists almost exclusively use new components that have been produced in the laboratory, Göpfrich refers to this approach as "de novo synthetic biology." Proponents of this method are attempting to detach their work from the natural building blocks of life. Are there, for instance, alternatives to cellulose as a material for cell walls? What potential ways are there for a cell to generate energy, and how might it store information?

Components such as the cell membrane, nucleus, or the mitochondria can also be simplistically regarded as systems, respectively, for packaging, information storage, and energy production. These researchers are now looking for alternatives that can accomplish these tasks as well as, or better than their natural counterparts. "Emancipating ourselves from nature provides us with a lot of creative freedom. It allows us to overcome hurdles more quickly," explains Göpfrich. But in any event, laboratory-developed systems like this need to fulfill one condition: they should eventually enable the creation of a new type of cell that possesses all the characteristics of life, in particular, its ability to reproduce and evolve.

Göpfrich's enthusiasm for her field of research is so infectious that it comes as no surprise that she manages to excite non-scientists about her field of specialism as well. Her videos and essays about scientific research are both entertaining and informative. She regularly gives public lectures, presents science talks in schools, and founded the "Ring-a-Scientist" initiative, which links up researchers and teachers to bring science into the classroom via videoconferencing. "Dialog with the public helps me focus on the questions I want to answer through my research: what constitutes life, how might it have arisen, and what other forms of life are possible."

Well packaged in fat molecules

In recent years, Göpfrich's team has been working on the cell membrane, the structure enveloping cells. Life depends on boundaries, at least on a biochemical level. Only by means of boundaries can living systems separate themselves from their environment and create the conditions for their survival within. In nature, the cell membrane consists of a double layer of fat molecules called lipids.

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PHOTO: KATRIN BINNER FOR THE MPG

KNOWLEDGE FROM

BIOLOGY & MEDICINE

Like paper in traditional origami, DNA can be formed into almost any shape. DNA is a long, thread-like molecule, but the technique can be used to fold it into sheets, tubes, boxes, or, if desired, into a cloverleaf.

Scientists already know how to produce such envelope structures in large quantities. Termed "vesicles", they are surrounded by a lipid bilayer and filled with water, just like natural cells. "They are our basic model of a cell," says Göpfrich. "The aim now is to fill the vesicles with life." To accomplish this, the team is utilizing tools from a wide variety of disciplines. One of these is "microfluidics", the targeted maneuvering of tiny amounts of liquid onto microchips the size of a fingernail. This tool allows scientists to sort vesicles by size or content, inject them with substances, and merge two vesicles together. The vesicles are stable enough that researchers can endow them with life-like functions. Reproduction is at the very top of their list. "Regardless of who you ask, the answer to the question of what constitutes a living cell is usually that it must have the ability to divide." The capacity to reproduce is indeed one of the scientific criteria for life.

SUMMARY

To better understand the nature of life, researchers are seeking to develop artificial biological systems. This research involves looking for completely new ways of recreating the properties of cells.

Artificial fat vesicles can mimic the membrane of natural cells. Some can even divide and move around.

Targeted combinations of DNA molecules autonomously fold into a desired shape to form structures that can perform different tasks (DNA origami). Scientists can precisely predict what form multiple DNA molecules will take.

It's a challenge that Göpfrich's team has already surmounted. They can cause vesicles to divide, for instance with the aid of a pulse of light. The light causes a specific type of molecule in the surrounding liquid to decompose and thereby increase the surrounding solute concentration. To counterbalance the resulting osmotic disequilibrium, water flows out of the vesicles. The trick is to make sure the vesicles don't just shrivel but, instead, actually divide. To achieve this, the researchers introduce two different types of lipid molecules into the membrane of the vesicle. These molecule types have a tendency to segregate from each other, and this, together with the shrinking process, causes the vesicle to divide into equally-sized daughter vesicles. There's a catch, though. The daughter vesicles formed in this way cannot continue to divide using the same method, since they now each consist of only one of the two fat molecule types. The researchers therefore allow them to fuse with small globules of fat, each composed of molecules of the other fat type. This allows the daughter vesicles to divide once again.

Cells can assume a wide variety of shapes depending on their type. This is another property that Kerstin Göpfrich has also imbued in her vesicles. It requires an artificial cytoskeleton that, ideally, molds itself in response to a stimulus from the surroundings. To achieve this, the team uses building blocks incorporating a pH-sensitive molecule. These blocks attach themselves to the lipid membrane at a high pH, forcing the membrane to flatten out locally. "The material we use to make our cytoskeleton is nothing really unusual; it's in every one of our cells: DNA," says Göpfrich. The DNA molecule contains a pH-sensitive region and a molecular region that can bind to the

PHOTO: KATRIN BINNER FOR THE MPG

Kerstin Göpfrich is fascinated by the idea of constructing a living cell. She wants to not only make use of prototypes found in nature, but also to completely redesign individual cellular components.

lipid envelope, enabling it to deform the vesicles when the pH in the environment changes.

DNA, in general, is a material that Göpfrich has high hopes for – not only as a carrier of inherited information, but also as a versatile biological building block. This technique, in reference to the Japanese art of paper folding, is also referred to as "DNA origami", because, analogous to paper, DNA molecules can also be designed to fold and take on almost any required shape. The technique can be used to construct tunnels, plates, boxes, or connectors between components that are only millionths of a millimeter in size. Along with microfluidics and 3D printing, DNA nanotechnology is one of the key technologies that Göpfrich's team is utilizing. They offer researchers a wide range of possibilities for constructing components for cells and assembling them into a single unit. As part of her doctoral thesis, Göpfrich had already designed and investigated one such component: artificial membrane pores made of DNA to facilitate the exchange of signaling substances.

DNA molecule pair bonding

As Göpfrich explains, the principles underlying DNA folding have been known for a long time: "The secret is chemical interactions between the four different molecular building blocks of DNA, the bases thymine, adenine, cytosine, and guanine. In DNA origami, multiple DNA molecules combine in such a way that as many base pairs as possible are formed. Hence, a long strand of DNA can be shaped by many short DNA snippets until the entire DNA structure attains an energetically favorable state," explains Göpfrich. Using computer software, she can calculate the DNA sequence required for a particular shape. In addition to playful structures such as smileys, stars and other geometric shapes, the technique also makes it possible to produce components for an artificial cell.

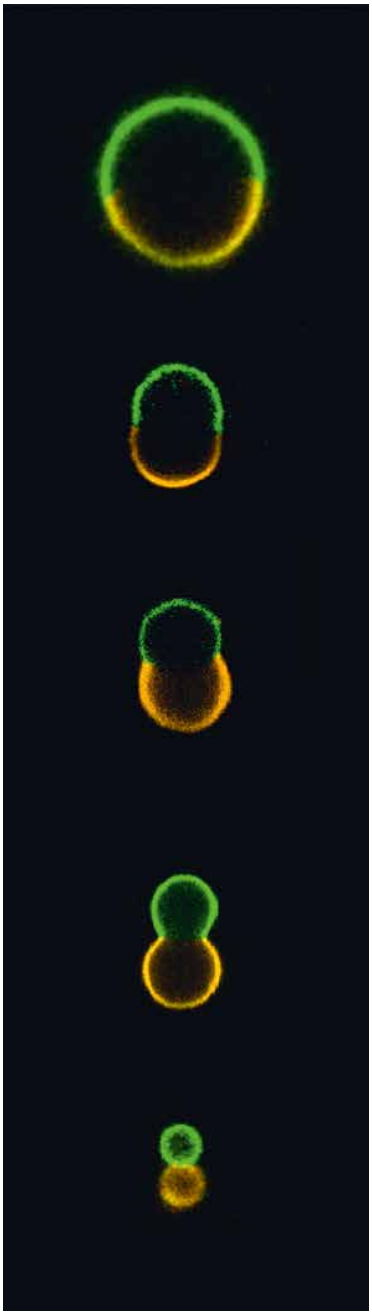

IMAGE: YANNIK DREHER/MPI FOR MEDICAL RESEARCH

When a vesicle's fat molecules (yellow, green) segregate and it simultaneously shrinks, the vesicle starts to divide. Is this a model for artificial cell division?

Equipped with such structures, artificial cells could one day perform a variety of tasks, for example, serve as miniaturized helpers in the human body. "We're still a long way off from creating living systems from scratch," Göpfrich says. But researchers are already making discoveries that are proving useful in other areas of research and in medicine. Göpfrich's self-dividing vesicles, for example, can be used as a sensor to determine solute concentrations, something which, to date, has been very difficult to accomplish during microscopy experiments. This has led Göpfrich to patent some of her findings.

The next big step is to develop a system for encoding information. "In natural cells, the genetic information is in the DNA of the cell nucleus. Right now, we're searching for artificial systems that can encode information. They need to be able to store data permanently and replicate themselves within cells. If we could find a system that can not only produce copies that are accurate but that also occasionally deviate from the originals, we would even have met one of the prerequisites for evolution," explains Göpfrich. It would allow the artificial cells to autonomously evolve. The researchers would then only need to steer this evolution in the desired direction.

Terms like "artificial life" and "artificial organisms" are often used in a misleading way and arouse fear. "Synthetic biology, however, is not in the business of creating monsters like Frankenstein; what primarily interests us are cells. Our research could lead to the development of artificial cells that could one day be programmed to perform medical tasks," says Göpfrich.

At present, the science of building cells is in its infancy. Artificial cells today possess, at most, a small number of characteristics of life, and even then, only in the laboratory. As Kerstin Göpfrich explains: "As yet, our work barely touches on ethically sensitive issues; at this point, artificial cells are little more than molecular aggregates – constructs made of dead matter, no different to those in other areas of materials science and nanotechnology. Nevertheless, it's important that we don't lose sight of the ethical dimension of our research."

www.ring-a-scientist.org

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CAUTION – TOXIC GREEN!

TEXT: CLAUDIA DOYLE

For humans, plants are a source of food, building material, and medicine. But not everything that is green is good. Some plants produce toxins that can make us sick – or even kill us. Thus, a wariness of plants makes sense from an evolutionary point of view, especially for infants and toddlers. Annie Wertz from the Max Planck Institute for Human Development in Berlin is investigating which behaviors protect children from dangerous plants and how they learn from adults which plants are safe to eat.

As Annie Wertz was jogging through the mountains in California one day, an unpleasant thought came to her: if she were to get injured or lost in that moment, that would be the end of her. She would starve to death. But the then doctoral researcher from the University of California, Santa Barbara was surrounded by trees, ferns, and grasses. A veritable cornucopia of nourishment. But she had no idea which plants were edible and which were poisonous. She had never learned this life-saving information.

This realization gave her an idea. In western cultures, most food comes from the supermarket. Only a few people still cultivate their own food or forage for wild plants. But for the greater part of human history, foraging for plants and hunting animals has ensured a sufficient supply of food. Our ancestors once had extensive knowledge of which plants were edible and how to best prepare them. They passed on this wealth of experience to their descendants. "It would have been a deadly endeavor if each individual had to find out for themselves which plants can be eaten and which ones cannot," says Wertz. The psychologist has since left California and has been heading the "Naturalistic Social Cognition" research group at the Max Planck Institute for Human Development in Berlin since January 2015. There, she researches the evolutionary strategies that enable infants and toddlers to safely learn about plants.

When Wertz talks about her project at conferences, she often receives skeptical looks. But her research question is by no means a niche topic. "Which plants around me are edible, which ones can kill me, and how can I distinguish one from the other – these are crucial questions that have ensured our survival throughout human evolution," says Wertz. Humans are curious by nature, and especially in the first months of life, they have an insatiable urge to discover and explore many objects with their mouths. At this age, the tongue has a particularly large number of nerve cells. But when it comes to exploring plants, this strategy alone could be fatal; after all, quite a few plants are inedible – or even deadly – for humans. "Humans have always co-existed with plants. Therefore, strategies that facilitate safe co-existence should have emerged during the course of evolution," says Wertz.

Whether a plant has the potential to become your favorite food or your last meal can't be deduced from its looks alone. White flowers? This could indicate a harmless apple tree or the poisonous wood anemone (Anemone nemorosa). Blue fruit? This applies to

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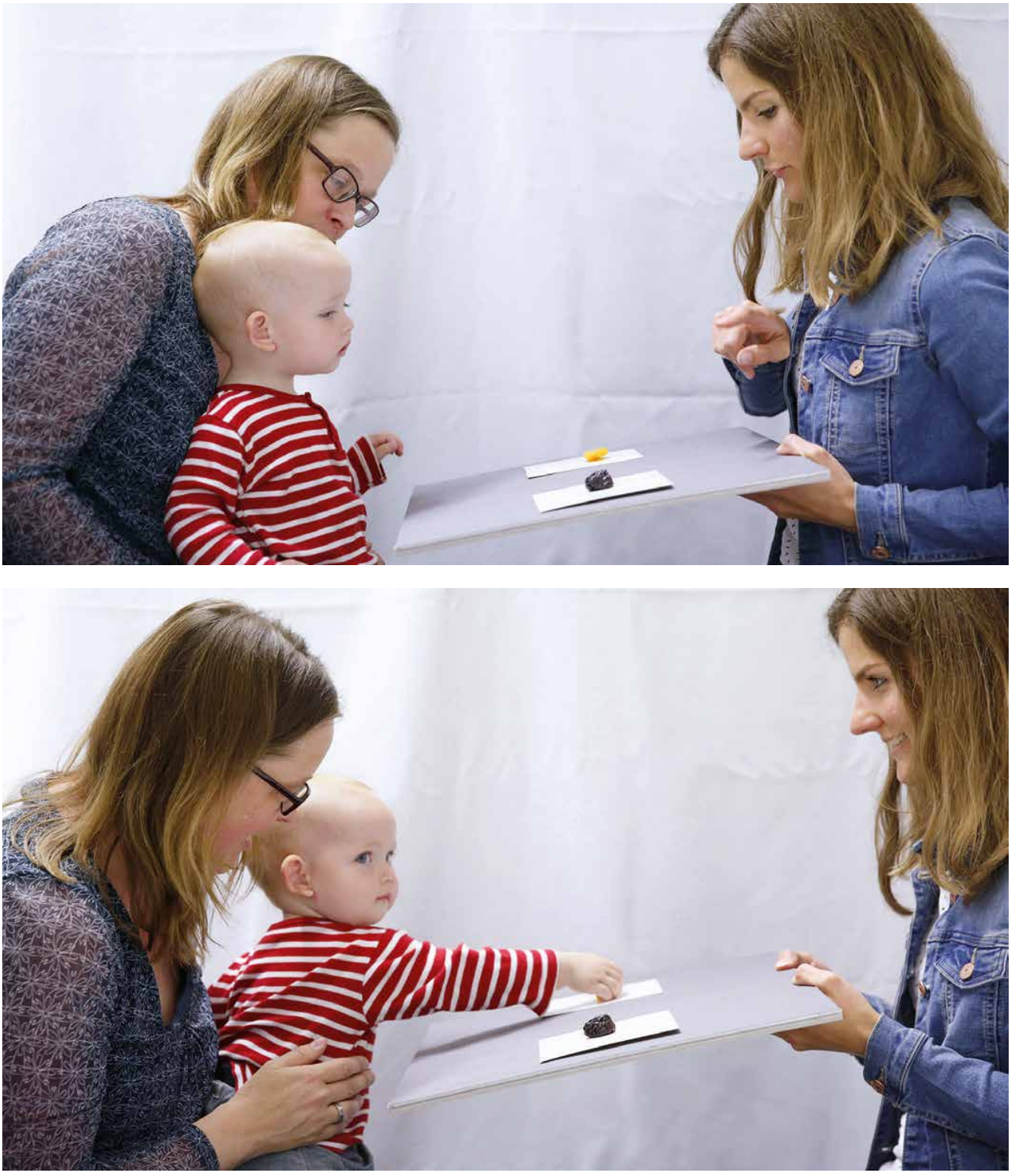
PHOTO: IMAGO IMAGES/DANITA DELIMONT

From tree to mouth: children learn to distinguish between edible and poisonous plants at a young age – like this girl in the Ecuadorian rain forest.



PHOTOS: MPI FOR HUMAN DEVELOPMENT

Dried fruit from the tree: in this experiment, the child had observed an adult picking orange dried fruit from a real plant and purple fruit from a silvery artificial plant and eating it. Like most of the children in the test, this child reaches for the fruit that comes from the real plant.

both delicious blueberries and the poisonous buckthorn. Even mechanical defense mechanisms such as thorns are found in both edible and poisonous plants. Therefore, infants and toddlers should ideally be wary of all plants from birth, so that they do not accidentally put a poisonous plant in their mouths. With this thesis, Wertz started her postdoctoral position in 2009 with Karen Wynn at Yale University. To test their theory, she invited parents and their infants to the laboratory. The infants, aged eight to 18 months, sat on their parents' laps and were presented with different objects one after the other.

These objects were green potted plants, like parsley or basil, as well as artificial plants. There were also novel man-made objects, which were matched to the characteristics of the plants. "We designed these objects so that we could rule out the possibility that the infants would simply avoid any green object or objects with a plant-like shape," explains Wertz. Finally, natural materials (e.g., shells) and everyday objects (e.g., spoons) were used. In general, the infants wanted to touch all the objects. But there were big differences in the speed at which their little hands reached out for them. The infants hesitated for only three to five seconds when it came to natural materials, everyday objects, and the objects that were modeled after plants. On the other hand, it took about twice as long for the infants to reach out toward the real and artificial plants.

Five seconds more to intervene

"With this study, we showed for the first time that infants are reluctant to touch plants," says Wertz. This could be an evolutionary strategy to protect young children from poisonous plants. At first glance, a five-second delay does not seem long. However, this small window of opportunity could well give parents enough time to intervene and prevent their children from coming into contact with the plant. This effect was independent of the age of the children. "That surprised me," says Wertz. "I had expected that there might be greater differences as children became more mobile." In a second experiment, Wertz found out that when it comes to deciding what can serve as a food source, young children distinguish between plants and artificial objects, learning through observation that you can eat fruits from plants, but not artificial objects. Toddlers aged 18 months watched as an adult picked dried fruits attached to a potted plant and put them in their mouth. The same procedure was repeated with dried fruits that were attached to a silvery artificial plant. The adults then picked the remaining dried fruits from a living plant as well as from the silvery artificial plant and presented them to the children – most of whom chose the fruits that came from the real plant.

These first two experiments laid the foundation for Wertz's research work, which she is now expanding upon in her own research group. She has already been able to demonstrate that, to a certain extent, toddlers can abstract information about the edibility of plants. For example, if they observe that an adult eats an apple from an apple tree, they learn that they can eat the apples from other apple trees as well. This kind of generalization makes learning about food much more efficient. But it is a tremendous achievement to be able to recognize an apple tree among a variety of trees. Wertz now wants to identify which characteristics infants use to categorize an object as a plant and to distinguish between different types of plants. It does not seem to depend on one characteristic alone but rather on the sum of many details. This can be illustrated using the example of color. Although children avoid green plants, they readily touch green objects. Because edible plants vary greatly in appearance, size, smell, shape, and texture, the learning process is also complex. When learning to use tools, children tend to pay more attention to shape. But when learning about the edibility of food, they seem to prefer neither specific shapes nor specific colors. This is only logical if you consider the differences between blueberries, kiwis, and oranges, for example – although all of them are edible.

Distrust of vegetables

Despite all their curiosity, many children eventually develop an aversion to vegetables. Many toddlers push broccoli florets off their plates in disgust or listlessly poke around at their carrots. This strong aversion to new foods is particularly common with vegetables, and is referred to as food neophobia. Together with post-doctoral fellow Camille Rioux, Wertz wanted to test whether it was possible to detect the basis for this aversion in infancy.

To this end, children aged between 7 and 15 months were presented with plant-based foods at various stages of processing: whole fruit still on the plant, picked fruit, fruit cut into strips or slices, and heavily processed, plant-based foods such as rice wafers. Control objects were also used, such as a sponge shaped like a fruit. Once again, the infants hesitated longer before touching plants and the picked and sliced plant-based foods than they did for the heavily processed foods and the control objects. The infants also looked for more eye contact with their caregivers, possibly to learn about the correct behavior when dealing with the plant-based foods. One year after the experiment, the

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Set up for children: psychologist Annie E. Wertz in the BabyLab.

PHOTO: GESINE BORN FOR MPG

parents completed a questionnaire about their child's neophobic behaviors toward food. It emerged that the children who had hesitated the longest to touch sliced pieces of fruits and vegetables had a more pronounced aversion to these foods one year later. Parents with picky toddlers can therefore breathe a sigh of relief. It is not all upbringing – some children seem to be more careful from the very beginning.

Contact with plants from early infancy

But do these results apply to infants all over the world? Cross-cultural studies are needed to find out. Unlike in the U.S. or Germany, many children in other societies still live in close contact with nature and have frequent interactions with plants. With the help of an anthropologist from Victoria University of Wellington, Wertz worked with a population of Indigenous Fijians known as iTaukei. These families live with and from nature, and most of them also grow their own food. Infants and toddlers in this culture also showed wariness of plants. But there was one major difference. While children from Western societies typically avoid all plants, iTaukei children showed this behavior only with plants they did not know. "These children have presumably observed adults interacting with certain plants quite often and therefore know that these plants are safe," says Wertz. Children from Western societies often lack this kind of experience.

In a second cross-cultural project, Wertz, in collaboration with anthropologists from the University of California, Los Angeles, is investigating Indigenous Shuar children in Ecuador. Here too, she would like to find out how the cultural context influences children's behavior towards plants. The results so far suggest that infants' avoidance behavior towards plants is deeply anchored in the brain. Could it be that even primate species related to humans show similar behavior? After all, they too face the same challenges when it comes to determining which plants are food and which are deadly. Wertz and her post-doctoral fellow Linda Oña are currently investigating this question in five non-human primate species. However, Annie Wertz' innovative and still growing research program suggests that learning mechanisms have developed through evolutionary processes. ←

SUMMARY

Infants and toddlers take much longer to reach for plants than for other objects.

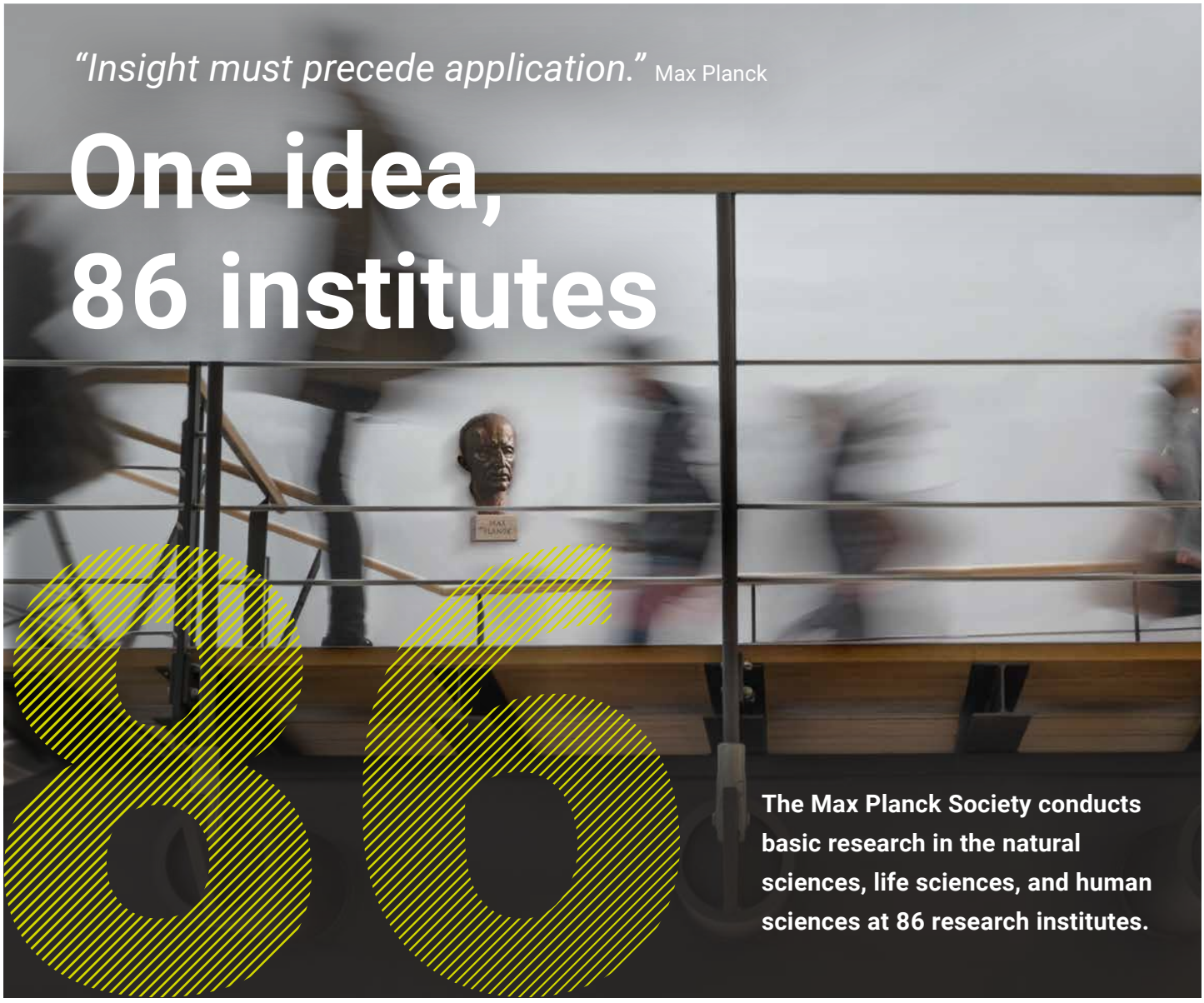
By observing adults, they learn that certain plants or their fruits are edible.

Infants and toddlers outside industrialized societies who live in close contact with nature avoid only the plants they do not know.

Experiments have shown that toddlers who have an aversion to fruit and vegetables were also particularly wary of slices of plant-based foods as infants.

“Insight must precede application.” Max Planck

One idea, 86 institutes



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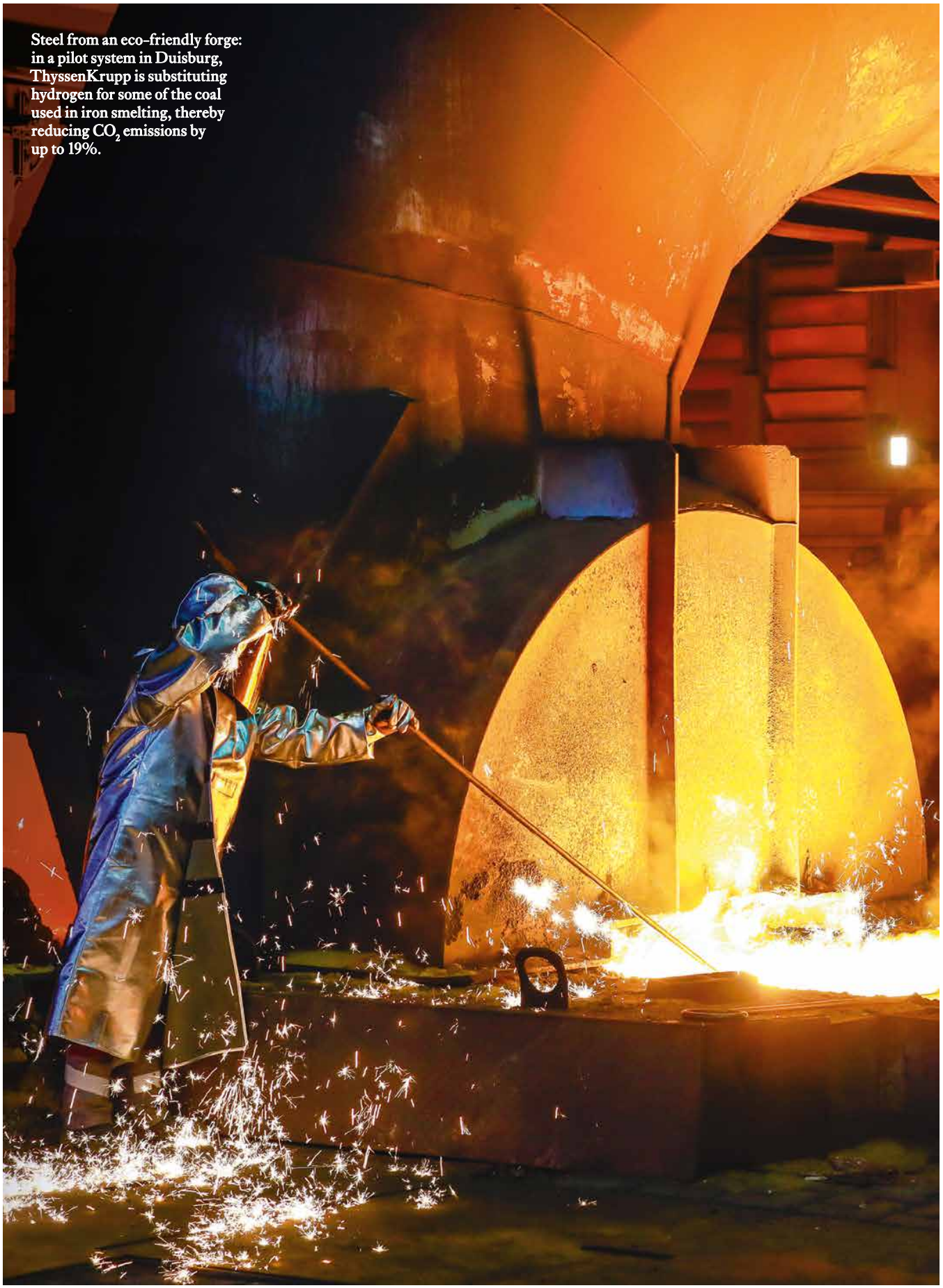

Steel from an eco-friendly forge: in a pilot system in Duisburg, ThyssenKrupp is substituting hydrogen for some of the coal used in iron smelting, thereby reducing CO_2 emissions by up to 19%.

PHOTO: PICTURE ALLIANCE/RUPERT OBERHÄUSER

ENERGY REVOLUTION IN THE BLAST FURNACE

TEXT: TIM SCHRÖDER

It's impossible to imagine modern life without metals, but today's metal industry is responsible for a third of all industrial greenhouse gas emissions. Dierk Raabe and Martin Palm, scientists at the Max-Planck-Institut für Eisenforschung in Duesseldorf, are working on a more sustainable way of producing – and using – metals. Their ideas could completely revolutionize the metal industry.

Everyone knows that extracting and forging metal requires heat. Indeed, the production of iron has not fundamentally changed in thousands of years: the ore is heated with charcoal or coke, the molten metal is collected and allowed to solidify, and the material is then formed into the desired shape. This method was already used 3,500 years ago in Asia Minor when the Hittites needed iron for their swords – although in those days, production was limited to a few piles of charcoal burning here and there. Today, the production of steel, aluminum and many other metals is big business – and presents a problem in terms of climate change. Around a third of all industrial carbon dioxide emissions originate from metal production, which also accounts for almost one-tenth of global energy consumption.

There are certain behavioral changes that we can make in order to tackle climate change: flying less, traveling by bus or train instead of by car, or limiting meat consumption. But how can we make metal production more climate-friendly? Producing metal requires a lot of heat – that's unlikely to change. And it would be hard to make do without metal – steel is an essential construction material for buildings, bridges and industrial facilities, and today's society would be unwilling or even unable to get rid of cars, ships and aircrafts, which primarily consist of metal. Even bicycles are made of steel or aluminum. That is why it is imperative for the metal industry to reduce its CO_2 emissions. "There's growing interest in climate-friendly production," says Dierk Raabe. "In the future, industry innovators will want to advertise these sorts of products in order to set themselves apart from competitors." Raabe, a materials scientist and Director at the Max-Planck-Institut für Eisenforschung in Duesseldorf, is part of a growing group of experts around the world who are working on more-sustainable forms of metal production and manufacturing. This will require the industry to bid farewell to long-established principles, some of which stretch back thousands of years.

Steel is largely made up of iron, which is extracted from iron ore in blast furnaces the size of lighthouses. Iron ore is essentially the same thing as pure rust – in other words, iron oxide (Fe_2O_3). In order to turn iron oxide into iron, the oxygen must be removed. Even today, this is still

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achieved by heating the ore with coke so that – via several intermediate steps – the oxygen from the ore bonds with the carbon from the coal. Iron is left behind, and the resulting CO_2 escapes. "If we can succeed in establishing sustainable new methods in this area, they will be a powerful tool for reducing global greenhouse gas emissions," says Dierk Raabe.

The scientific community is currently discussing various approaches to green steel production. For example, steel could be produced by electrolysis – as is done with other metals, including aluminum. This would be a clean undertaking if the necessary power were obtained from renewable sources. However, the processes are still nowhere near sophisticated enough and would presumably be incapable of producing the huge quantities of steel that are used around the world each year. So at least initially, Raabe sees greater potential in replacing a proportion of the coal with biogas, methane and, above all, hydrogen. These substances are also capable of extracting oxygen from iron ore (Fe_2O_3). Hydrogen would be the best option from a climate protection perspective, provided it was produced using electricity from renewable sources. Following several intermediate stages, water vapor would then be formed as the exhaust gas instead of carbon dioxide. Before hydrogen can be used to produce pure iron on an industrial scale, however, Dierk Raabe and his team still have a few issues to clarify – such as how the hydrogen can penetrate far enough into the ore for the iron oxide to react quickly and completely. After all, this reaction

PHOTO: PICTURE ALLIANCE/JOCHEN TACK

faces an obstacle: the conversion of iron oxide (Fe_2O_3) to pure iron passes through an intermediate product known as wustite (FeO), which has only one oxygen atom per atom of iron. The problem is that wustite likes to surround itself with a shell of pure, newly formed iron, which is produced during the reaction with hydrogen. It takes a long time for the hydrogen, as well as the released oxygen, to pass through this iron cladding, which can therefore slow down the production of iron considerably. "With that in mind, we're trying to break down the grains of wustite so that they fully react with hydrogen," says Dierk Raabe. His team is studying the reaction between ore and hydrogen at different pressures and temperatures with a view to identifying the ideal conditions for the conversion of wustite into a sort of permeable nanosponge. "I'm also currently reading some specialist articles published around 80 years ago by Fritz Wüst, the founder of our Institute," says Raabe. "He worked intensely with iron oxide, which is why the compound was named after him. His work provides us with vital information to this day."

An industry facing radical change: steel production – for example, at the Tata Steel iron and steel works in IJmuiden, Netherlands – is indispensable for industrial companies. However, if climate goals are to be met, the metal industry will need to make greater use of energy from renewable sources in the future.

There are other challenges when it comes to the reaction between iron oxide and hydrogen. Gaseous hydrogen occurs as a molecule of H_2, but it is only reactive in the form of an ion – that is, as H^+. Accordingly, it must first be split up (or cleaved) quickly and without expending a great deal of additional energy. "Iron ore always contains a small proportion of foreign atoms that, like the iron, are present in the form of oxides," Raabe explains. "We want to find out whether some of these impurity oxides could act as catalysts to accelerate the splitting of H_2 molecules." In that case, the ore itself would produce reactive H^+ ions. "Accordingly, we then have to turn our minds to the issue of catalysis, which isn't usually the focus of our work," says Raabe.

Who will foot the bill for the transition?

So hydrogen might not be the most sustainable way of producing iron in the long term, because it must first be converted into its reactive form. Overall, the more efficient method would be to use hydrogen plasma. This is the most reactive form of hydrogen and is made up of atoms that have been separated into H^+ ions and electrons. Formed in the flash of an electric arc, for example, hydrogen plasma reacts with iron oxide much more vigorously. "Here, we're working on a completely new alternative to the traditional process," says Raabe. In the new technique, iron oxide is converted into iron within a plasma state, and the material it contains is smelted down simultaneously. "All in all, hydrogen is going to be a major focus of our work over the next 10 to 15 years," says Raabe. "With the equipment available here at the Institute, we can perfectly control iron production with hydrogen and observe it as far down as the atomic scale." This equipment includes atom probes, which can determine a material's composition atom by atom, and transmission electron microscopes, which the researchers can use to inspect the ore right down to the electronic level, as well as equipment usually used to study the quantum mechanical properties of metals and semiconductors.

However, switching over to hydrogen and green steel will not be without cost, says Christian Vietmeyer, managing director of the Association of the Steel and Metal Processing Industry (WSM). The association's members include companies that process raw metals, including making automotive parts out of steel. "We strongly suspect that the automotive industry will be the first to express a clear demand for steel with a significantly smaller carbon footprint. But this steel will initially be more expensive." Steel producers have already called for state subsidies for the green transition, so that German steel production can remain competitive in the face of cheaper, conventionally produced steel from abroad. "We are very critical of this approach, as it would lead to long-term subsidization." It remains unclear, therefore, how the transition to green steel production could be financed. "We take the view that regulatory policy must seek to achieve this the other way around – by way of customer demand." He suggests a reformed motor vehicle tax as one possibility. Today, cars are taxed according to their CO_2 emissions, but Vietmeyer says that, in the future, it will be possible to consider the entire life cycle, including the quantity of greenhouse gases a vehicle had given rise to

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during its manufacture and the production of the steel used to build it. Dierk Raabe also recognizes that the development of climate-friendly methods of iron and steel production won't be enough: "There is a need for a continuous chain from the basic research through to a good understanding of the steel manufacturing process." The transition to lower-carbon or even carbon-neutral production of iron and steel will require companies to invest large sums of money. "Hasty and potentially incorrect decisions could pose a threat to their survival," says the researcher.

It is certainly a gargantuan undertaking, with global demand for steel standing at 1.8 billion tons per annum – an almost inconceivable quantity of metal that corresponds to almost twice the weight of all cars currently on the road. With this in mind, a more sustainable method of steel production would indeed be an important tool when it comes to climate protection. But there are also other aspects to consider, says Raabe. One major issue is longevity. "It's estimated that some 3.5% of global GDP is lost to corrosion alone – and these huge losses could be avoided if metals, buildings and products were more durable." The fact that car bodywork is fully galvanized is, he says, a testament to the value of corrosion protection and has meant that – unlike 30 years ago – cars are no longer destroyed by rust. However, corrosion protection is about more than simply sealing the surfaces of metals, says Raabe. For example, many bridges are apparently now being demolished after standing for only a few decades, because we don't know how advanced the corrosion is inside the structures. "There are neither sensors nor pH meters nor voltmeters to give us information on the material's condition – it's like we're in the Stone Age." For Raabe, self-monitoring features of this kind are indispensable in the modern era.

In addition to this measurement technology, another possible solution would be metals with self-rejuvenating or self-repair capabilities – which already exist in plastics. These capabilities can, for example, be achieved by melting capsules containing liquid plastic ingredients into components in order to fill cracks if the need arises. "The plastics themselves notice when damage occurs. Aluminum and iron haven't reached that stage yet – there's still a lot of work to do," says Dierk Raabe. That being said, some initial ideas have already been floated. One possibility is that, when oxygen enters the material as a result of damage, solid metal oxides could form in order to repair minor defects. Likewise, pores in some alloys can seal themselves at high temperatures by means of atomic transport processes. Indeed, the Duesseldorf researchers have been involved in another project, in which steel was mixed with small quantities of molybdenum that can seal up fine pores. In other words, in order to reduce greenhouse gas emissions in the metal industry, it also makes sense to preserve these products, instead of building them again.

SUMMARY

Approximately one third of the world's industrial CO_2 emissions come from the production of metal. Emissions from steel production could be reduced if at least part of the required coal were replaced with methane, biogas or, above all, hydrogen.

In order to use hydrogen to produce steel on an industrial scale, Max Planck researchers are working to speed up the chemical reaction. They are also investigating the possibility of producing steel in a completely new process using hydrogen plasma.

Improved corrosion protection and a higher recycling rate could also help to reduce the carbon and energy footprints of metal products.

As iron aluminides are corrosion-resistant, lightweight and readily recyclable, they represent a sustainable alternative to steels. By adding boron, Max Planck researchers have also succeeded in optimizing the alloy for use at high temperatures – for example, in turbines.

Recycling is to become simpler

When it comes to sustainability, aluminum faces similar problems to those affecting iron and steel. Aluminum is produced in "electrolysis cells" that operate at very high temperatures and consume large quantities of power, so its production is every bit as energy-intensive as that of steel. "Aluminum recycling is therefore a key factor, because melting down scrap aluminum only requires about 5% of the energy," says Dierk Raabe. However, many industries take a dim view of aluminum that contains recycled material, because it could contain impurities. In particular, contamination with iron and copper – from screws or cables included in the scrap aluminum, for example – can influence the properties of the aluminum during processing or when a part is exposed to mechanical loads. In the aviation industry, for instance, aluminum that contains recycled material is mostly ruled out due to safety concerns. "Aluminum alloys have to satisfy 20 or sometimes 30 parameters laid down by the manufacturers," says Dierk Raabe. "Impurities can change their properties." However, many manufacturers won't even use the unmixed production waste from their own manufacturing process. Nowadays, for example, a laptop housing is milled from a block, and more than half of the material is lost as chips. It is still mostly less expensive for the manufacturers to buy new aluminum alloy than to process their own scrap.

For some time, Dierk Raabe has been working with his team to conduct a systematic study of how the behavior of aluminum changes in response to the tiniest recycling-related impurities – and is one of the first scientists in the world to do so. He is initially fo-

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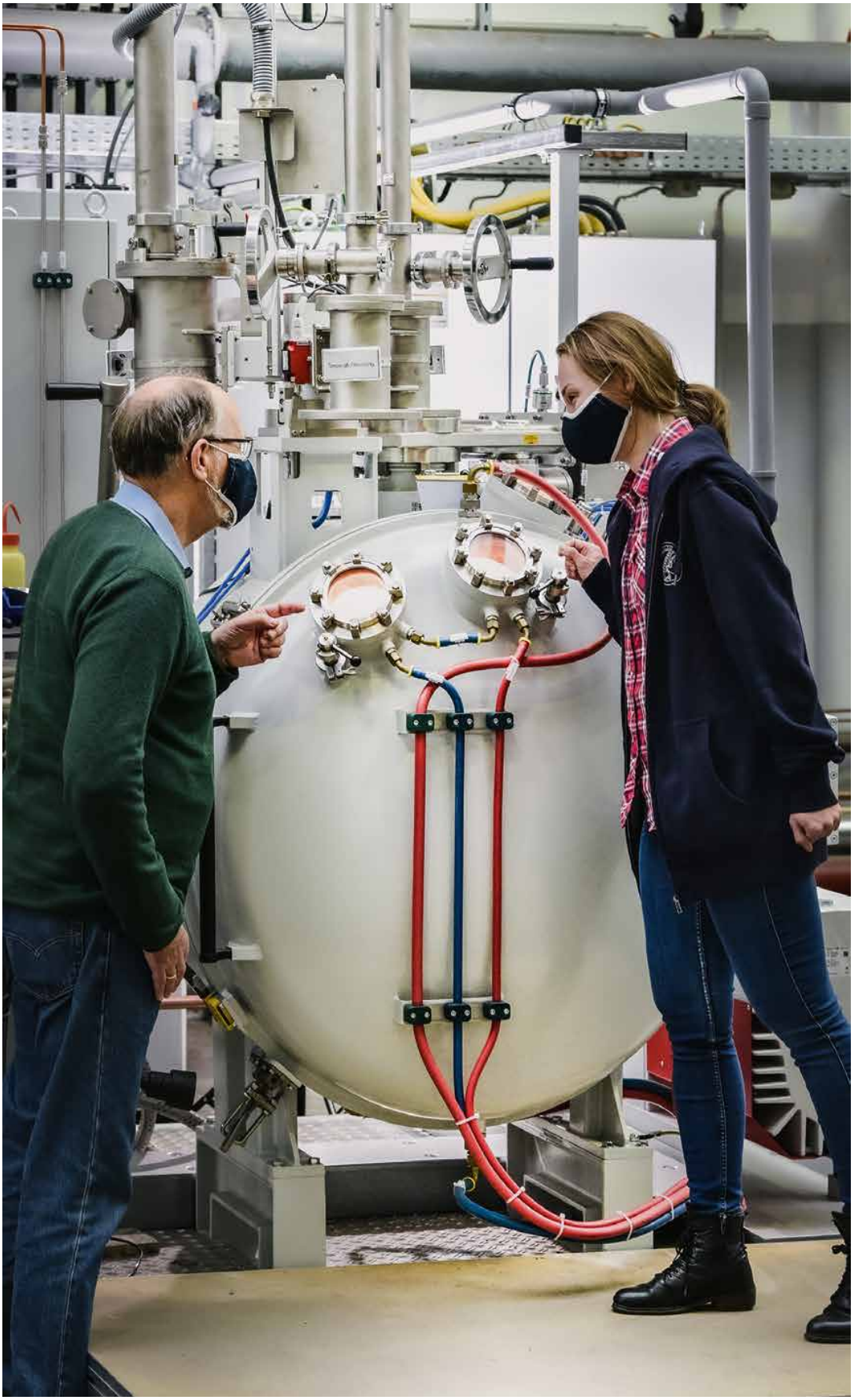
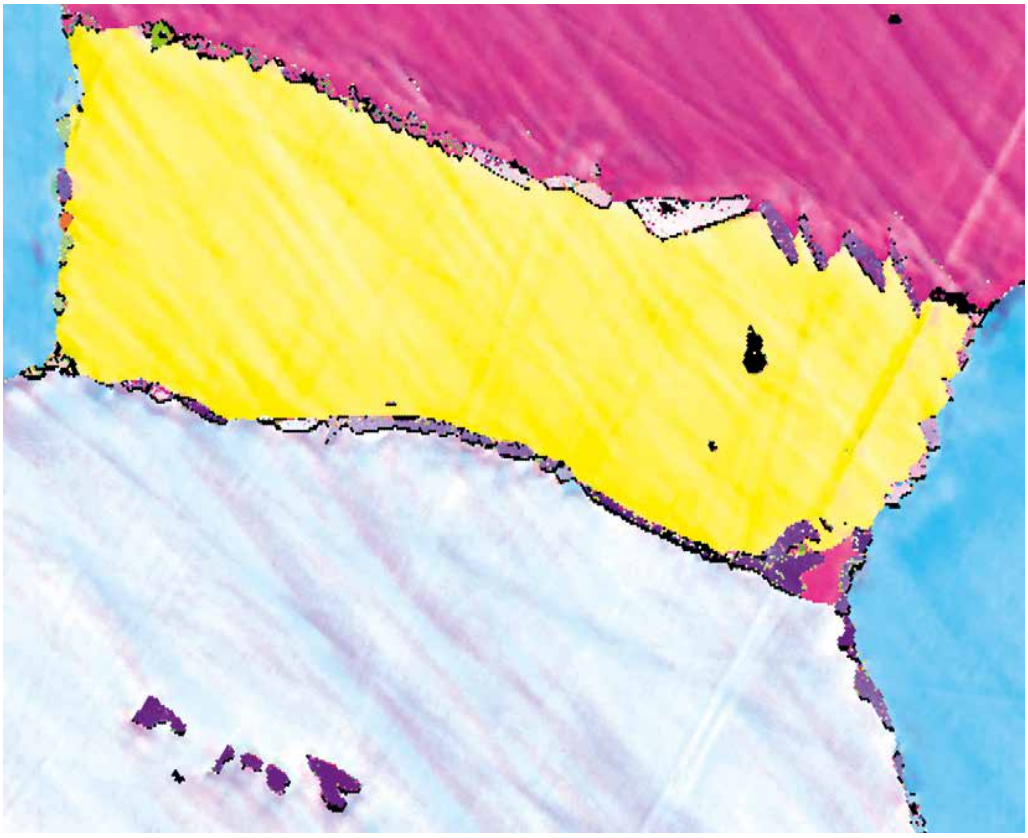


PHOTO: FRANK VINKEN FOR MPG

On the hunt for sustainable metallic materials: Martin Palm and Angelika Gedsun produce lightweight, durable and cost-effective iron aluminide alloys in an induction furnace.



GRAPHIC: ANGELIKA GEDSUN / MPI FÜR EISENFORSCHUNG

Heat-resistant, thanks to nanoparticles: the alloy is prevented from softening at high temperatures by tiny boron-containing deposits at the boundaries between the iron aluminide structures, which are shown in different colors in the microscope image.

cusing on what he terms the "big problem bears" – iron and copper. Working in a vacuum, his team deposits pure aluminum onto a surface and then gradually mixes in iron to produce an iron gradient within the material sample. This allows the researchers to seamlessly track detailed changes in the aluminum's characteristics as the iron content increases. Their objective is clear: in the future, it should be possible to mix increasing amounts of scrap aluminum into aluminum alloys without reducing the quality of the products. "How dirty can the child get and still stay healthy? That's what we want to find out," says Raabe. "If we achieve 90% of the desired product parameters with recycled aluminum, that will be sufficient for many applications." Although safety-relevant applications would initially be ruled out, this green aluminum is easily good enough for use in elevator cladding or spare tire wells in car trunks.

Considerable interest from industry

Whereas Dierk Raabe tends to view iron in aluminum as an impurity, this is not the case for Martin Palm, head of the "Intermetallic Phases" research group at the Max-Planck-Institut für Eisenforschung. Indeed, Palm sees a bright future for materials that deliberately combine the two elements. For a number of years, his work has focused intensively on iron-aluminum alloys, which are seen as a future substitute for expensive steels with admixtures of nickel, chromium or cobalt. Iron aluminides are corrosion- and wear-resistant and hence extremely durable. They are also relatively light and could therefore help to improve the sustainability of metal products. For a long time, however, one factor has stood in the way of a major breakthrough: the materials lose their strength at temperatures above 700 degrees Celsius. At the same time, their low weight means they would be especially suitable for turbines in power stations and aircrafts – because less mass requires less fuel. In the last few years, however, the materials scientist Martin Palm and his team have solved the temperature problem. Specifically, they have made iron aluminides heat-resistant by using sophisticated methods to penetrate deep into their microstructure.

If you look at solidified metal under an electron microscope, you can clearly make out light and dark areas alongside one another – like countries on a

map. Experts refer to these "countries" as metallic phases. They differ in terms of their chemical composition and atomic arrangement, because atoms join together in different ways from one place to another as the alloy solidifies – forming phases that contain more iron or more aluminum, for example. This separation into different phases is what gives iron aluminide alloys their strength – at least at low temperatures. "Unfortunately, when they get very hot, the phases tend to merge with one another, causing the material to soften," explains Martin Palm. However, his team has succeeded in finding ways to suppress this merging of phases, including by mixing low concentrations of boron into the alloy. When the alloy solidifies, the boron forms boride nanoparticles that accumulate at the phase boundaries like poppy seeds on a bread roll. And, as borides are among the most heat-resistant materials, they prevent the iron aluminide phases from merging with one another at high temperatures. Martin Palm has therefore paved the way for a prosperous future for iron aluminides. "There's no doubt about it: the industry will inevitably turn its attention to iron aluminides in the next few years, because all of the other elements in today's alloys are gradually becoming scarce." Iron and aluminum are the most common metals on earth and are available in large quantities, whereas reserves of chromium, cobalt and nickel have already shrunk significantly. These scarcer metals are therefore becoming a plaything for speculators – and their prices are becoming incalculable. "Even today, iron aluminides would be 20% cheaper than chromium steel and as much as 80% cheaper than nickel-based alloys," says Palm. "This trend is set to intensify."

There is another characteristic iron aluminides have that makes them unusually sustainable: they require almost no other alloying elements and therefore offer excellent recyclability. Moreover, unlike certain chromium compounds, for example, they are not ecotoxic. Given the advantages of these materials, there is considerable interest from industry. Martin Palm's partners therefore include Siemens, Rolls-Royce Deutschland and the company Leistritz Turbinentechnik, among others. In Palm's view, the Duesseldorf researchers can clearly put their unique expertise regarding alloys to good use – after all, this know-how is almost non-existent in industry today. "We have the plant technology to produce the alloys, but above all we have the fundamental knowledge about phase transitions – in other words, how alloys and their phases change with temperature." We can therefore look forward to the day when the first lightweight iron aluminide turbine goes into operation. And, of course, it should ideally run on environmentally friendly biofuel – or even hydrogen. This outcome would represent a big achievement in terms of sustainability.

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GLOSSARY

ELECTROLYSIS
This is a process in which electricity is used to break down substances such as water or metal oxides into their constituent parts. Industry produces hydrogen and aluminum electrolytically, but steel can also be produced in this way.

PHASE
In chemistry, this term refers to an area of matter with uniform physical and chemical properties. In a material, areas with different compositions are described as different phases.

PLASMA
In the fourth state of matter, the particles of a gaseous substance are entirely or partially ionized – in other words, they take the form of positively charged ions and free electrons.

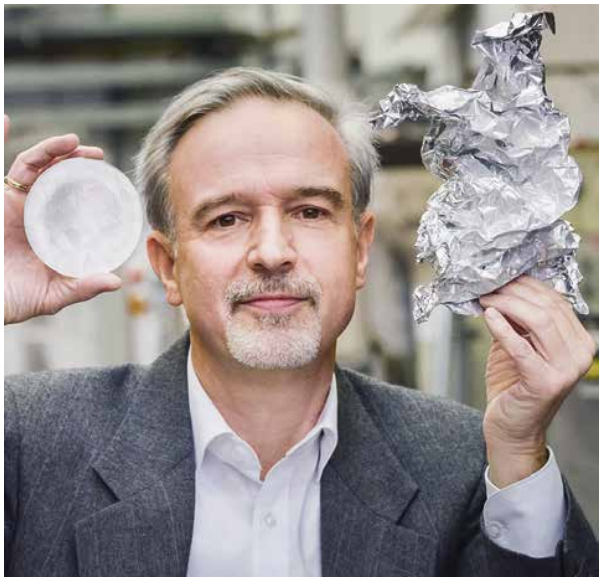
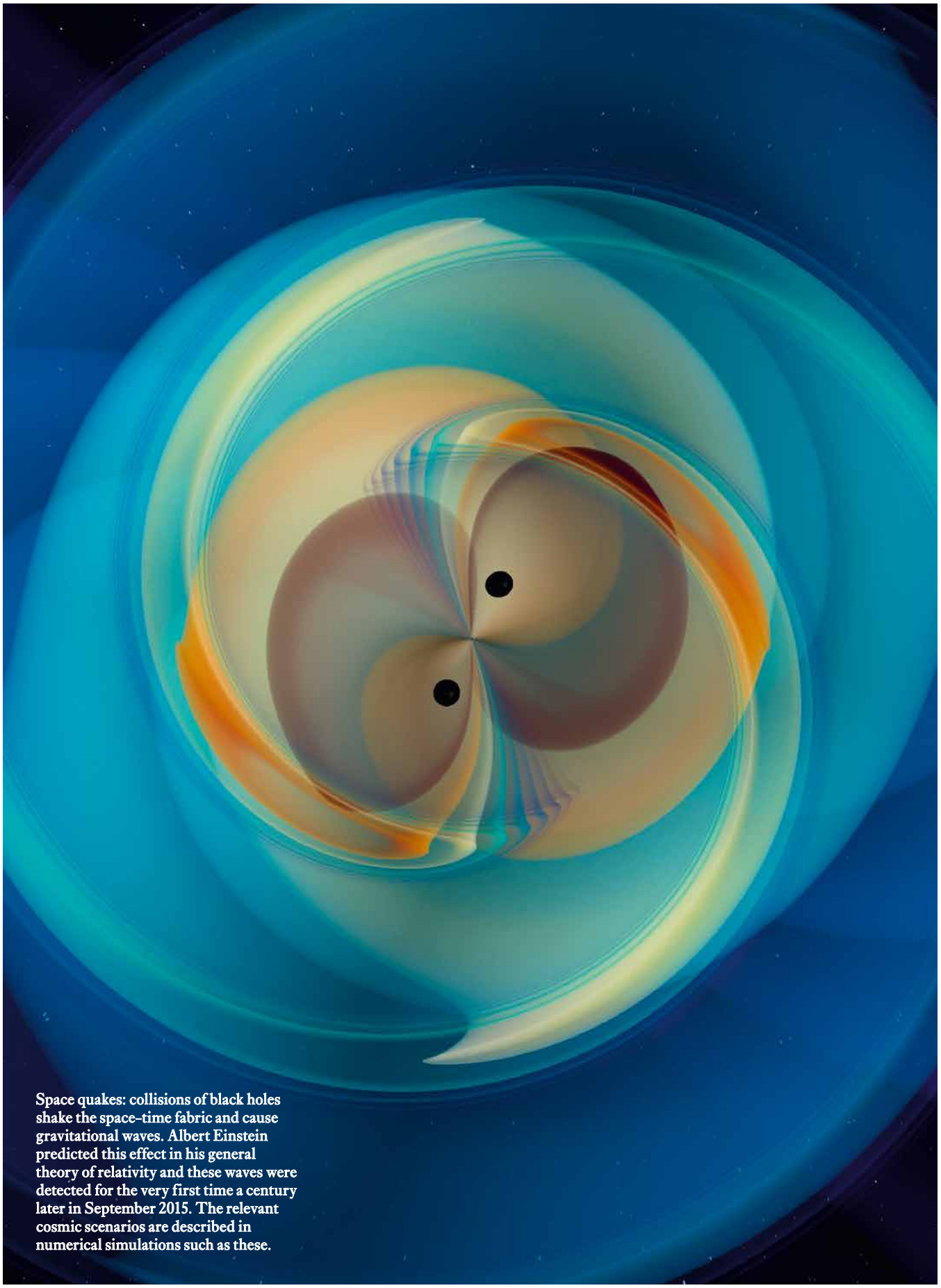


PHOTO: FRANK VINKEN FOR MPG

Masterminding a sustainable metal industry: Dierk Raabe sees the increased recycling of scrap aluminum, for example, as an opportunity to reduce the industry's carbon footprint.



Space quakes: collisions of black holes shake the space-time fabric and cause gravitational waves. Albert Einstein predicted this effect in his general theory of relativity and these waves were detected for the very first time a century later in September 2015. The relevant cosmic scenarios are described in numerical simulations such as these.

IMAGE: N. FISCHER, H. PFEIFFER, A. BUONANNO/MPI FOR GRAVITATIONAL PHYSICS, SIMULATING EXTREME SPACETIMES (SXS) COLLABORATION

A BIG FISH IS MAKING BIG WAVES

TEXT: HELMUT HORNUNG

It should not actually exist – a black hole with a mass 85 times that of our sun. But that is precisely what astronomers have discovered. Apparently, this heavyweight used to be part of a binary star system before it merged with its equally massive partner. The resulting space-time quake unleashed gravitational waves that are posing many a puzzle for researchers at the Max Planck Institute for Gravitational Physics in Potsdam and Hanover.

Gravitational waves are messengers from the dark universe. Albert Einstein described them in two papers published in 1916 and 1918 respectively, but temporarily came to doubt their existence during the 1930s. In any case, he considered these waves – whose existence is predicted by his general theory of relativity – to be immeasurable. However, they became entangled in the scientists' finely spun web for the first time on September 14th, 2015, and shook the two Advanced LIGO detectors at the Hanford and Livingston sites in the U.S.

But what lies behind this cosmic quiver? In the ultimate analysis, general relativity is a field theory, according to which the accelerated motion of masses within the gravitational field results in disturbances that propagate at the speed of light. These disturbances are referred to as gravitational waves. It sounds incredible, but they stretch and compress the space through which they pass. Theoretically, they occur when, for example, a child bounces around on a trampoline. But humans have a small mass and bounce comparatively slowly, so the gravitational waves the child causes are immeasurably minuscule.

By contrast, masses out in the universe are large and there is even a "trampoline", i.e. space-time itself, in which everything is in constant motion, because there isn't a single celestial body that remains motionless in one place. The Earth creates a bulge in the fabric of space-time too as it orbits the Sun, emitting gravitational waves with a power of 200 watts. But even these waves are too weak to be detected. However, there are some extremely large masses and super high velocities out in the universe. The signal detected on September 14th, 2015, for example, was caused by two black holes that merged in a fraction of a second following a turbulent dance of death. Each of the objects, which were about 1.3 billion light-years from Earth, had a mass around 30 times that of the sun.

By the time this issue of *Max Planck Research* went to press, scientists had reliably detected 50 gravitational wave events since their initial discovery five years ago. The majority of these events were caused by colliding black holes, and such discoveries had gradually become a matter of routine. But something powerful occurred on May 21st, 2019. Rather than detecting a "chirp" in the LIGO (U.S.) and Virgo (Italy) detectors, what the astronomers perceived was, as it were, a plop! It lasted just a tenth of a second and reached a maximum frequency of only 60 Hertz – the lowest observed so far.

"Right from the beginning," says Alessandra Buonanno, Director at the Max Planck Institute for Gravita-

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tional Physics in Potsdam, "this extremely short signal presented a challenge when it came to identifying its origin. But we were able to match the signal to one expected of black-hole mergers." Based on the recently analyzed data, the scientists conclude the event involves two true heavyweights of around 85 and 65 solar masses, respectively. This event, referred to as GW190521, also broke another record: the merger happened about seven billion years ago when the universe was just half its current age. And because looking into the universe's past also entails a journey into the distance, the signal is the most distant ever observed.

What's more, eight solar masses were converted into gravitational energy during that cosmic collision, resulting in the creation of a colossus with 142 times the mass of our home star. "We realized we had witnessed, for the first time, the birth of an intermediate-mass black hole," says Alessandra Buonanno. Scientists had only ever suspected the existence of such objects, which are heavier than the lighter black holes with masses of up to 65 times that of the Sun, and less massive than the extremely heavy ones at the centers of galaxies. In short, their masses equate to around 120 to 100,000 solar masses.

All of this sounds very plausible. Yet one of the protagonists involved in the GW190521 event confounds expectations: "According to our understanding of how stars age and evolve," says Frank Ohme, group leader at the Max Planck Institute for Gravitational Physics in Hanover, "we would expect to find black holes with masses of either less than 65 solar masses or greater than 120 solar masses, but none in between." However, this is precisely the gap into which the black hole of 85 solar masses falls. "Either our understanding of stellar evolution is incomplete, or something fundamentally different took place here," Ohme concludes.

According to astronomers' models, black holes of up to about 65 solar masses form when heavy stars reach the end of their lives. When the nuclear fuel in the interior is depleted, the stellar gas spheres first enter an energy crisis phase and then become unstable before finally exploding as supernovae, leaving behind a lightweight black hole. At the other end of the weight range of these gravity traps, scientists suspect the presence of extremely heavy stars that, rather than exploding as supernovae at the end of their lives, immediately collapse with no such fireworks, to form intermediate-mass black holes of over 120 solar masses.

SUMMARY

Astronomers used gravitational wave detectors to observe the coalescence of the most massive black holes to date.

This event was the first time the scientists had witnessed the formation of an intermediate-mass black hole.

Prior to the merger, one of the two black holes had had a mass equivalent to 85 solar masses and – in theory – should not exist.

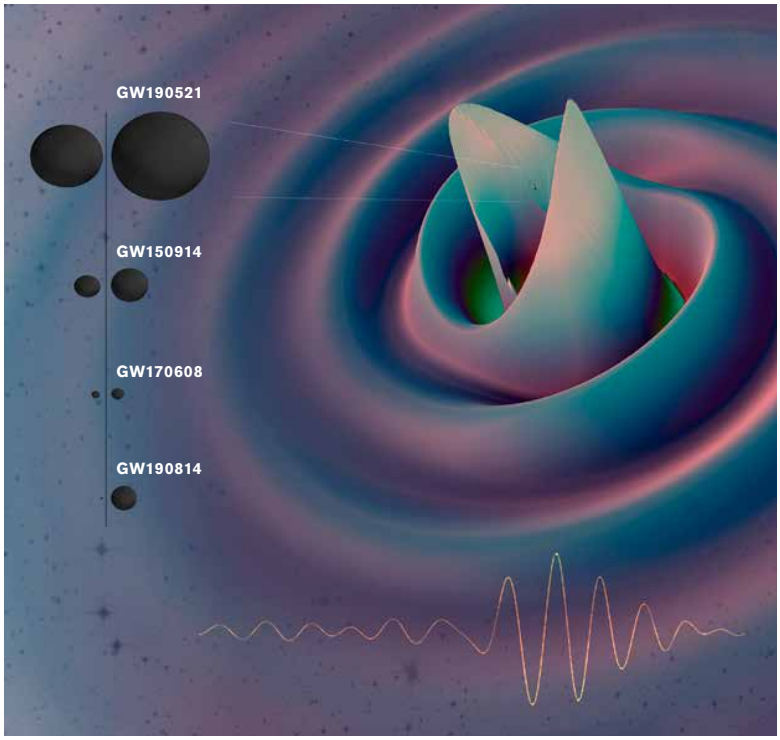
PHOTO: SVEN DÖRING FOR MPG

Light into the dark: Alessandra Buonanno is developing theoretical models to identify and interpret gravitational-wave signals. The work being carried out by the Director at the Max Planck Institute for Gravitational Physics is helping to decode the secrets of black holes and neutron stars and allows conclusions to be drawn about the physical properties of these exotic objects.

This gives rise to the mass gap of around 65 to 120 solar masses mentioned by Frank Ohme, in which no stellar black holes ought to exist because, theoretically, those stars from which black holes could form within this range fail to explode as supernovae and therefore do not collapse into black holes. Instead, these stars undergo one or more brief episodes of instability, during which they eject significant quantities of their matter. Only following this radical weight loss will a star remain, which then explodes in a supernova to produce a black hole, but this will have a mass of less than 65 solar masses.

So how was the black hole with 85 solar masses created in the GW190521 event? One possibility is that our current evolutionary models of stars are flawed or incomplete, and that certain supernovae may still spawn black holes with masses in excess of 65 solar masses. However, the researchers consider this rather unlikely, as Alessandra Buonanno explains: "My assumption is that this object emerged from an earlier merger of a binary system, probably as the result of a coalescence of two smaller black holes or of two massive stars."

In fact, according to the general theory of relativity, the signal could be well described as a merger of two black holes. Nevertheless, the scientists are also investigating other potential explanations for their observation, for example that the signal may be the result of an interaction between cosmic strings, i.e., hypothetical objects that may have formed in the early universe. Or could it be the result of a supernova after all? Could GW190521 ultimately be not nearly as distant as it seems, and the event thereby involves less massive black holes, which in fact merged at a shorter distance from Earth, and their waves were subsequently distorted by a gravitational lens? And finally, could the signal have been generated by primordial black holes that formed in the infancy of the universe before the first stars appeared?



GRAPHIC: D. FERGUSON, K. JANI, D. SHOEMAKER, P. LAGUNA, GEORGIA TECH, MAYA COLLABORATION

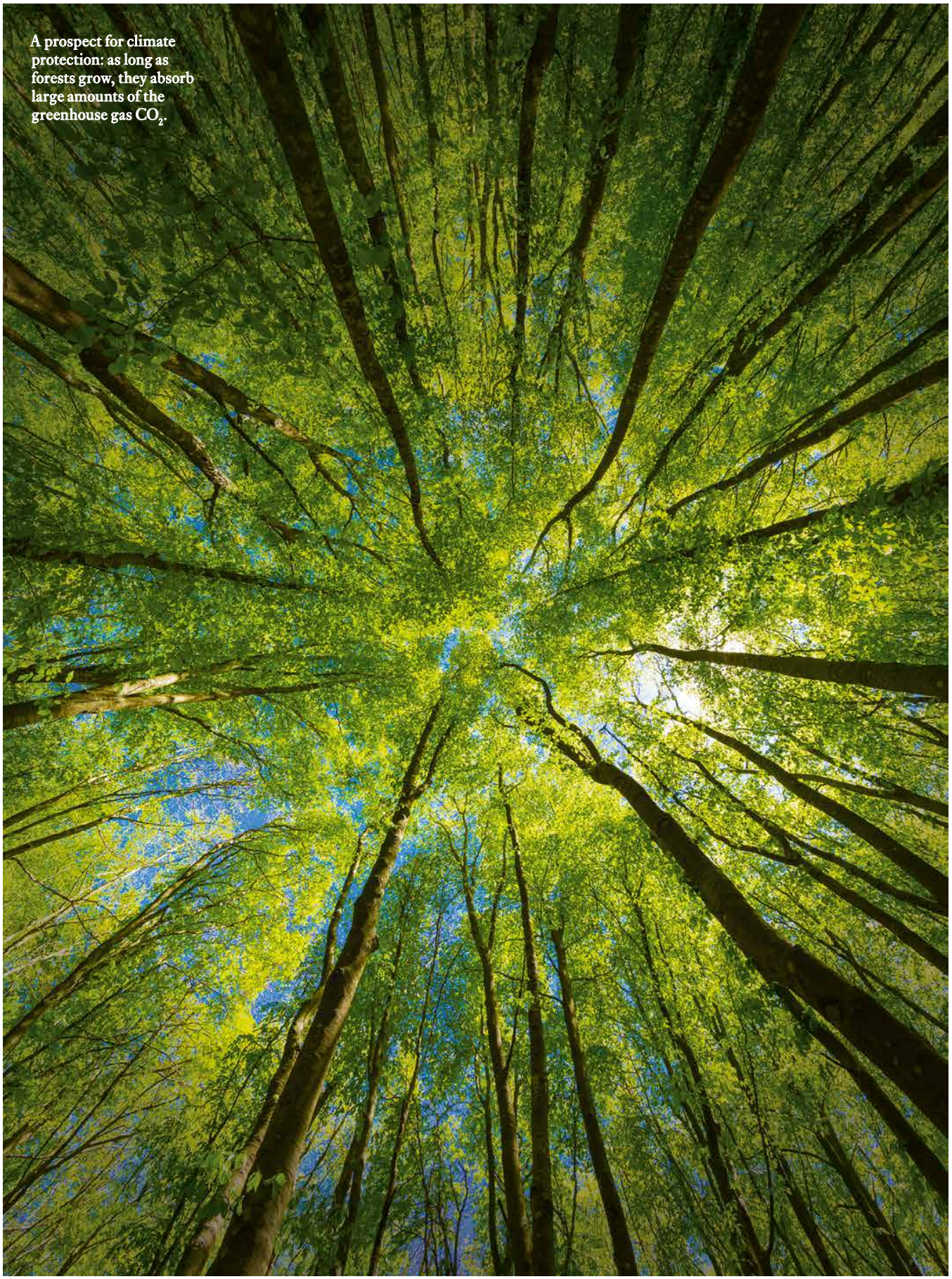
Heavyweights: this graphic shows a freeze frame from a numerical relativity simulation of the GW190521 event. About seven billion years ago, two black holes with about 85 and 65 solar masses had merged – a record! For comparison, the image on the left shows a schematic representation of the masses involved in other gravitational wave events.

However, in the final analysis, none of these scenarios quite fits the data.

"We don't yet know whether the GW190521 event represents an entirely new class of binary black holes, or just the high-mass end of the source spectrum we've observed so far," says Karsten Danzmann, Director at the Hanover-based Max Planck Institute. "Hopefully, we'll know more once we've analyzed all binary black hole mergers seen by LIGO and Virgo during their third observation run (O3)." The scientists certainly have no shortage of data to work with. During the O3, which lasted from April 1st, 2019 to March 27th, 2020, they recorded data from no fewer than 56 potential gravitational wave candidates.

GLOSSARY

GRAVITATIONAL WAVE DETECTOR
The largest facilities currently in operation are LIGO in the U.S. and Virgo in Italy. Their working principle involves interferometry: laser light travels in two vacuum tubes, or arms, arranged at right angles to one another. These arms lengthen or shorten whenever a gravitational wave passes through the detector, which causes the laser light waves to get out of sync, thereby altering the intensity of the measured light. The LIGO sites in Hanford and Livingston each have arms that are four kilometers long, while the Virgo site in Tuscany uses tubes that are three kilometers long.



A prospect for climate protection: as long as forests grow, they absorb large amounts of the greenhouse gas CO_2.

PHOTO: ADOBE STOCK

FORESTS CHANGE THE CLIMATE

TEXT: KLAUS JACOB

Forests can remove large amounts of CO_2 from the atmosphere. So far, there is consensus about this throughout the scientific community. However, there is some dispute about how forests can best protect the climate – whether they should be managed sustainably or left undisturbed. Right in the middle of this dispute is Ernst-Detlef Schulze, Director Emeritus at the Max Planck Institute for Biogeochemistry in Jena.

The fight against climate change can be won only with allies – and forests can be one of them. They are a natural counterpart to oil and coal because trees assimilate CO_2 from the atmosphere, convert it into sugars with the help of sunlight, and use it to produce wood, among other things. On average, one cubic meter of wood contains about 0.3 tons of carbon, which corresponds to about 1 ton of CO_2. Thus, forests remove huge quantities of greenhouse gases from the atmosphere. Along with the oceans, forests are one of the world's major "carbon sinks" (to use the experts' terminology) – and for Germany, forests are the nation's largest sink.

Researchers at ETH Zurich led by Jean-François Bastin have even calculated that large-scale afforestation could solve the climate problem – at least for the next few decades. However, many experts doubt that this is realistic – partly because an area of the size of the U.S. would have to be planted with additional trees, at a time when suitable areas for afforestation are becoming increasingly scarce as a result of climate change and of intensified competition with food production in many places. Development is currently pointing in a different direction. According to the UN Forest Status Report for 2020, around 10 million hectares of forest are lost every year – an of area the size of Bavaria and Baden-Wuerttemberg combined. In Brazil, plantation owners are burning the Amazon rain forest. They are encouraged by a president who believes that the export of agricultural products – not least to Europe – is more important than climate and environment. In the U.S., increasingly devastating wildfires are blazing; these are exacerbated by climate change. And in Europe, heat, drought, and storms are damaging the forest, making it easy for bark beetles and harmful fungi to take hold.

Many experts are deliberating the question of how the world's forests must be transformed in order to resist climate change. In this context, they also disagree about what kind of forest is the most favorable for climate mitigation. Is it better to leave a forest alone – as is the case in some nature reserves? Or can a forest benefit the climate more if it is managed sustainably? Ernst-Detlef Schulze, Director Emeritus at the Max Planck Institute for Biogeochemistry in Jena, has studied the forests in Central Europe together with other scientists – and has come to a conclusion that may sound surprising at first. Schulze calculates that a sustainably managed forest makes a much greater contribution to climate mitigation than one that is left undisturbed.

The reason is that a natural forest helps the climate only if it is growing (i.e., if the mass of its wood – and thus of sequestered carbon – is increasing). In older forests, where the wood increment is reduced, the carbon balance has largely reached equilibrium. And as soon as trees die and their wood rots, the stored carbon is released as CO_2. What's more: the forest can even become a source of carbon, for exam-

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ple when drought, windthrow, or pests, such as the bark beetle, attack the vegetation – as can currently be seen in the Harz Mountains. A study by the University of Leeds confirms: the capacity of undisturbed tropical forests to absorb CO_2 has been declining since the 1990s. Scientists warn that the Amazon could even become a source of CO_2 by the mid-2030s.

However, different rules apply to managed forests. There is no natural state of equilibrium here because logs are constantly being removed. According to data from the Federal Ministry of Food and Agriculture from 2014, about 11 m^3 of wood per hectare grow each year in German forests. Most of this is used commercially. Only a small proportion of this wood decays on the forest floor, and roughly two-thirds of the annual growth serves humans in many ways. The wood is processed into durable products (such as wooden houses or furniture), used in consumer goods (including paper, cardboard, or tissues), or provides cozy warmth in the form of firewood or pellets. Wood that is burned replaces fossil fuels. Without firewood, many homeowners would turn to oil or coal. However, many durable products are also incinerated after use and thus serve to generate energy. In an article published in early 2020 in the journal Global Change Biology – Bioenergy (GCBB), a team led by Schulze assessed the CO_2 flows for German commercial forests (as far as the data allowed) and concluded that replacing fossil fuels with wood alone saves 1.9–2.2 tons of CO_2 per hectare of commercial forest per year. However, this applies only if the wood actually replaces oil or coal. If Germany were to begin generating 100% of its energy from wind and solar resources, this calculation would no longer add up, even though wood is also a renewable resource.

The climate balances of different forests

Not all wood that grows back is harvested. Schulze assumes that only about two thirds of the growth is removed. About one third remains in the forest. Among other things, the wood volumes of forests grow. According to the calculations made by Schulze and his team, each hectare removes 1–2 tons of CO_2 from the atmosphere every year stored in biomass. On average, the replacement of fossil fuels and the increase in wood compensates the CO_2 emissions or CO_2 concentration of around 3.5 tons per hectare of forest. In the meantime, a group led by Schulze has also quantified how much greenhouse gas the atmosphere would be spared if products were made out of wood requiring relatively low energy input instead of using materials that require more energy input or from fossil raw materials, such as a house constructed of wood instead of concrete or bricks. "We estimate this contribution of the forest to reducing CO_2 emissions to be about 2.8 to 4.9 tons per hectare per year," says Schulze. This contribution is in addition to the replacement of fossil fuels and the increment of wood volumes. Schulze and his colleagues have published their results in the journal "Biologie in unserer Zeit". But does a managed forest really contribute more to climate protection than a natural one? Schulze has also calculated that it does. But we must also bear in mind that true primeval forests have not existed in Germany since time immemorial. German forests have been used and cultivated in one way or another since ancient times.

Today's nature reserves, in which the forests are left undisturbed, are all relatively young. They have by no means reached the stage where the carbon dioxide balance has reached equilibrium. They are therefore capable of sequestering additional CO_2 for years or decades to come. These years are particularly important for climate mitigation while restructuring of the energy industry is being driven forward. In Germany, about one-third of the land area is forested, of which around 3% goes unused. But which nature conservation area provides meaningful figures for comparison? There are very different kinds of forests: deciduous, coniferous, and mixed forests: young and old forests, forests growing on sandy soil, limestone, or clay; forests in mountainous or flat terrain, forests interspersed with large and small clearings. We should be ascertaining the growth in each forest and calculating its average value. However, we don't have enough data to accomplish this. In his article in GCBB, Schulze cited forest inventories in Hainich National Park in Thuringia from 2000 and 2010 for comparative calculation. At the turn of the millennium, the survey documented a timber inventory

A passion for forests: after his retirement, the forest scientist and biologist Ernst-Detlef Schulze acquired tracts of forest, which he manages with great care.

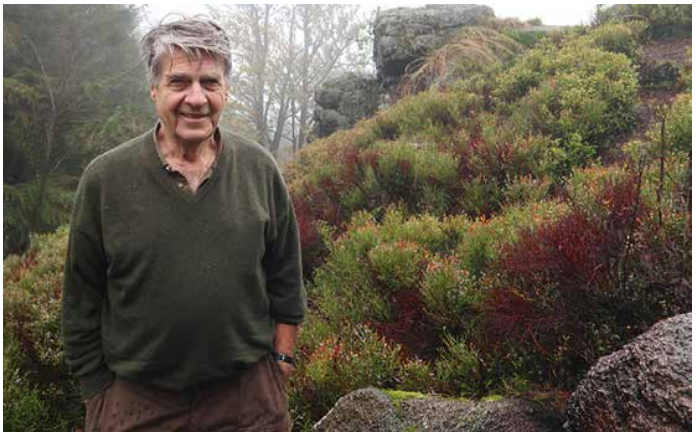

PHOTO: KLAUS JACOB

TIMBER GROWTH IN THE HAINICH

GRAPHIC: GCO

Different perspectives: Schulze's team considers the Hainich as an operational unit (A). The fact that the forested area sampled (shaded area) has increased in size between 2000 and 2010 is irrelevant here. The young, thin trees on the new forest plots only lead to a slight reduction in the 2010 timber stock inventory. This results in an increase of only 0.4 m^3/ha/yr. In the 2010 inventory, researchers led by Manfred Grossmann therefore consider either only the areas that were already forested in 2000 (B), for which they determine a wood increment of 9 m^3/ha/yr. Or they factor the areas that were newly forested in 2010 into the 2000 inventory as areas without wood supply (C) and arrive at a wood increment of 6 m^3/ha/yr.

of 363.5 m^3/ha; 10 years later, the figure was 367.5 m^3/ha. Using these figures, as published by the National Park, as a basis, Schulze arrived at an increase of 0.4 m3/ha/yr for the unmanaged natural forest. This corresponds to a CO_2 equivalent of 0.37 tons – compared with 3.2–3.5 tons in the commercial forest. Schulze's conclusion: a sustainably managed forest is about 10 times more beneficial to climate protection than a natural one. The use of wood in durable products was not even considered here.

This calculation sparked fierce criticism, which led to weeks of heated exchange in specialist journals and the media. The bone of contention was that the size of the forest area in the Hainich had increased between the first and the second inventory. Thus, the number of sample points increased from 1,200 to 1,421. Where before there had been only bushes, 10 years later, arm-thick saplings had grown. This young forest reduced the average timber stock because the figures always referred only to the forested area of the National Park as a management unit. Schulze justifies his approach with the fact that the Hainich is an operational unit that must always be considered as a whole – even if partial areas grow and shrink in size and the number of sample points changes. "The national forest inventory follows the same procedure. Only then can we compare the results," Schulze explains.

However, Forest Torsten Welle from the Natural Forest Academy in Luebeck thinks this kind of calculation is wrong: "This is cherry-pi-

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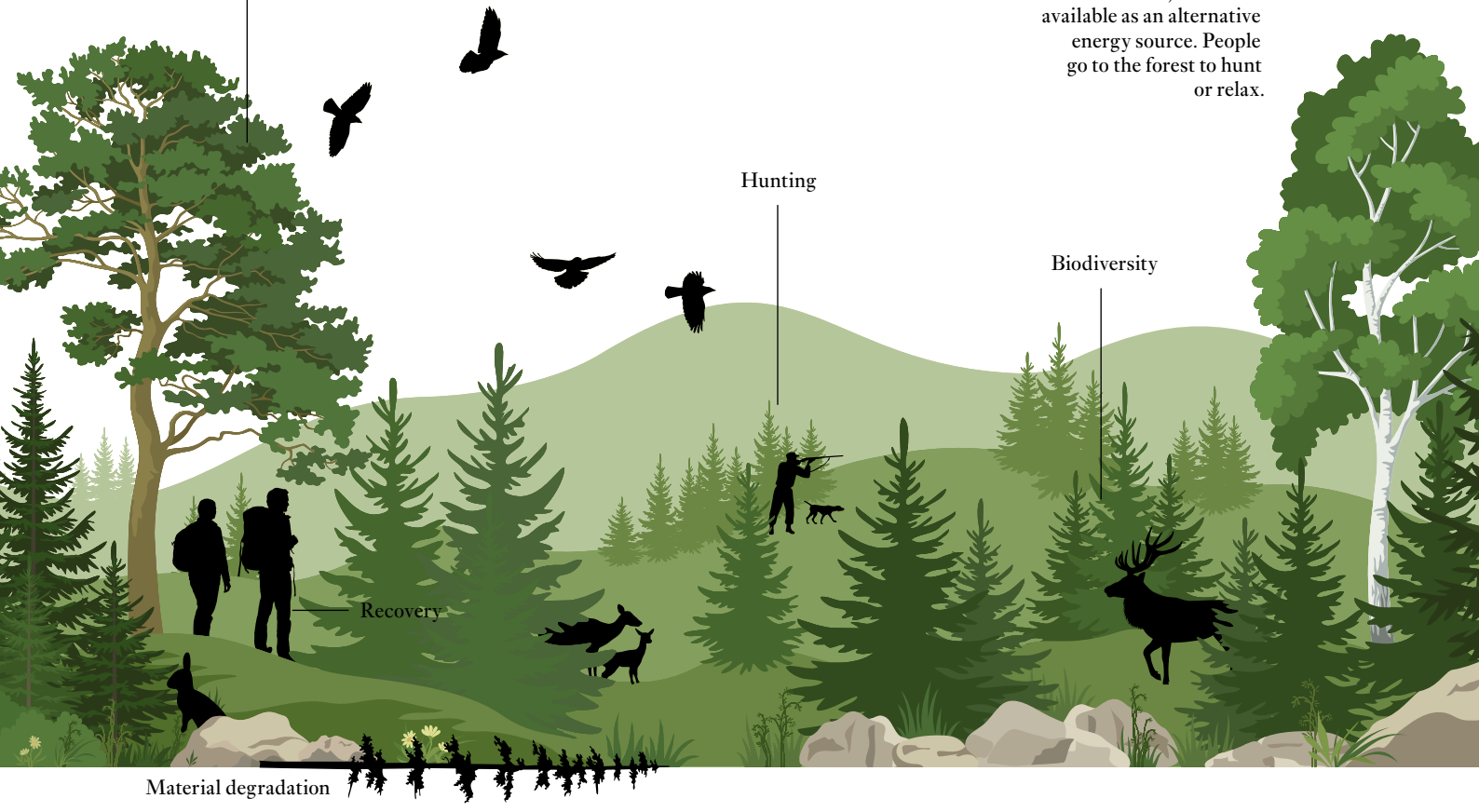
cking!". The head of the Hainich National Park, Manfred Grossmann, also criticizes the approach. He suggests a different calculation: if you consider only the 5,015 ha with 1,200 measuring points from the second inventory that were recorded in the first, you get an annual increase of just under 9 m^3; this corresponds to about 9 t of CO_2 absorbed from the atmosphere. And for a reference area of 5,287 ha with 1,421 measurement points (i.e., if part of the area is included in the calculation as unforested in 2000), it comes to 6 m^3/ha. In terms of climate protection, both values mean that the natural forest rates better than the commercial forest – but only as long as the former is still growing and the CO_2 savings from wood products are not taken into account. Forestry scientist and ecologist Henrik Hartmann, a colleague of Schulze's at the Max Planck Institute in Jena, also believes Schulze has left himself open to criticism with his comparison with the corrected reference area. Moreover, he thinks Schulze should have looked at additional nature reserves, including ones outside Germany. Corresponding figures for natural parks in Slovakia are even listed in the paper. When they are factored in, the average increase in the wood supply of unmanaged forests totals approximately 3 m^3/ha/yr. When this calculation is applied, sustainably managed forests do not contribute 10 times more to CO_2 storage than unmanaged ones. However, they are at least as beneficial to climate protection. "That, too, would be a good argument," says Hartmann. However, Schulze and his co-authors use only the Hainich National Park in Thuringia for a direct comparison with commercial forests. Schulze justifies this by saying that they wanted to draw up a balance for Germany and that no further inventory data of National Parks in Germany were available for this purpose.

The data from the Slovakian nature reserves were from relatively small ex-

FUNCTIONS AND BENEFITS OF THE FOREST



Versatile green: forests not only absorb CO_2 and counteract climate change, they also store water and provide a habitat for many plants and animals. Furthermore, they provide wood that is processed into paper and furniture, used in construction, and made available as an alternative energy source. People go to the forest to hunt or relax.

perimental plots, not comparable to National Inventories. Therefore, they did not take into account all of the changes found in a contiguous forest area, such as losses resulting from storm or beetle damage. "The only way to do that is to conduct inventories at the landscape level," says Schulze. The Thuenen Institute of Forest Ecosystems, which reports to the Ministry of Agriculture and publishes the annual forest condition survey, supports Schulze and his team – albeit with reservations. They believe that the Hainich is not representative of a typical German forest because it is on limestone terrain. Based on these figures alone, it is impossible to judge whether protecting forests is better for protecting the climate than using wood for energy.

The discussion shows that forest inventories and plot studies have their limitations. Timber inventories take only the trunk wood into account – and only from trees that are thicker than seven centimeters in diameter at breast height (DBH). But carbon is also in the soil: in the roots, in the soil litter, in the mineral soil, and in the underground biomass. Critics of the climate balance drawn by Schulze and his colleagues also argue that the side effects of logging are not taken into account: to get to the logs, heavy machinery must work its way through the undergrowth; this can alter the soil structure. Pierre Ibisch, a professor at the Eberswalde University for Sustainable Development, also points out that complete clearance leads to a significant increase in temperature because the sun's rays can then reach the ground. He says that even thinning, which creates more space for usable trees through selective interventions, leads to warming. German foresters therefore describe it as "hot cutting". The consequences: the ground heats up, carbon dioxide escapes, and the trees at the edge of the new clearing come under stress.

Comparing a natural forest with a managed forest is always risky from a scientific point of view. This is because many assumptions have to be made because not all details have been researched yet. In addition, a forest not only protects the climate – it also performs a variety of tasks and has environmental advantages. People therefore seek forests for recreation, hiking, cycling, and jogging. Forests also store water and thus prevent flooding. At the height of summer, they lower temperatures through evaporation. Finally, forests provide a habitat for many plant and animal species, including deer, which like to eat the shoots off young trees in particular.

Schulze, who owns several tracts of forest, knows all this from experience. "I bought the forest because I wanted to manage it in my retirement," says the Director Emeritus, who at the beginning of his career was on a path to taking a high-up position in the Forest Service. As a forest owner, he has learned not only about the ecological but also the economic and social aspects of forest management. One of his forests surrounds a long-extinct volcanic cone, and the terrain is fairly steep. The 79-year-old clambers up the 400-meter elevation difference with the vigor of someone half his age. When you ride along the breakneck paths with Schulze in his off-road vehicle, you get the impression that he is talking about a garden that he lovingly tends. In one place, he bemoans the loss of some hundred-year-old beeches that were damaged by a late frost and will probably die sometime in the next year. In another, he has planted a few rowan trees. But these do not seem to be thriving. Apart from individual spruce monocultures, the forest, with its abundance of bushes and undergrowth, appears wild and rich in biodiversity. No wonder it is popular with hikers, especially because the ancient volcano is the highest elevation in the area. The rocks at its summit are an attractive destination. But these visitors are giving Schulze cause for concern. He has painstakingly built paths in order to be able to harvest wood. But the hikers leave their trash behind, and mountain bikers recklessly race down to the valley, frightening the wildlife. He bears the costs, while others are benefiting from his investment and dedication.

GRAPHIC: GCO, ILLUSTRATIONS: ISTOCK

Too many deer

Schulze shows me a photo of a stag in a clearing on his phone. What would delight any city dweller presents another problem for Schulze. There are simply too many deer. Large predators like bears or wolves, which could help to decimate the population, were wiped out centuries ago. Even though wolves are gradually returning and lynx are back in some forests – including Schulze's – there are too few natural enemies of the deer. Moreover, when forest owners are primarily concerned with hunting, they feed the animals throughout the winter. The

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animals then continue to gnaw away at the young trees during the rest of the year. Schulze prevents this by putting up fences – a lot of them. But even intensive hunting does not limit the game population – because animals keep migrating into his relatively small forest. But the problem under consideration goes beyond gnawing dear and reckless mountain bikers. The challenge is ultimately how to manage forests in Germany and Europe in the future. Forests are about to reach a turning point. On the one hand, the trees are supposed to have effects on climate change. On the other, climate change is increasingly affecting trees. According to the 2019 German Forest Survey, the crown condition "has never been as bad as in 2019." Not even a quarter of the trees had a healthy crown. The dry summers are increasingly leaving their mark – with long-term consequences. Pierre Ibisch speaks of the "physiological memory" of trees. And there is no sign of climate change letting up; in fact, temperatures are continuing to rise. Ibisch warns that in the long term, a forest steppe with a high proportion of grass could even develop in many places. Even today, storms, bark beetles and fungi are already destroying entire forests. In turn, the large amount of damaged timber causes timber prices to fall. Forest owners are extremely concerned about this – according to Ibisch, there is even a sense of panic. Many of them sell off the damaged spruce wood to China in order to at least partially mitigate their losses. And they're cutting down their beech trees while they are still relatively healthy. According to the Thuenen Institute, in 2018, felling increased by 10% compared with the previous year because of the removal of damaged timber. However, it stabilized again to some extent last year – albeit at a high level.

PHOTO: PICTURE ALLIANCE/IMAGEBROKER | ANDREAS VITTING

Shaped by humans: in the 15th century, mendicant monks cut a cavity into the oak tree so that travelers could leave alms inside it. Over time, the hole grew, and the landmark of the Hainich National Park gradually took on its current appearance.

The human psyche also plays a role when it comes to forests, and this can hinder objective discussion. Almost everyone instinctively feels at ease and calms down beneath a canopy of oaks and beeches. Germans in particular have an almost romantic relationship with forests. It is the perfect counterpart to a hectic city life. Forest enthusiasts embrace trees to strengthen their souls, and some people even express a desire to be buried under oaks or beeches when they die. However, sometimes the love of forests goes too far: Hartmann learned that environmental activists in Weimar have destroyed forestry workers' machinery in order to prevent logging. Against this background, a calculation like the one Schulze presents also carries considerable political significance. His demands are derived from his calculations. He believes that forest owners should be rewarded for their sustainable management efforts. For example, they could benefit from a CO_2 tax levied on the burning of fossil fuels. But if one assumes that a natural forest protects the climate better than a commercial forest, then demands would be made for a policy that leads to different measures being implemented. Large swathes of the German forests would have to be left undisturbed, and a CO_2 levy would be demanded from the owners of the commercial forests every time they log. However, this would be shortsighted; wood cannot be replaced as a raw material – especially in light of the fact that there are plans to increa-

singly use wood as an alternative to building materials that are manufactured using a great deal of energy. As Hartmann points out, "How are we supposed to do without forest management if we need wood products?" If the logs do not come from Germany, they will have to be imported from Siberia or the tropics. This would most certainly be more harmful to the climate because forestry practices in those regions are usually not sustainable. In the worst case scenario, forests there – which store large amounts of carbon – will be cut down and will be unable to recover and grow back quickly enough.

Of course, financial interests also play an important role, since about half of Germany's forests are privately owned. The list of landowners who want to make money from forests reads like a directory of the old noble families: from Thurn and Taxis to Hohenzollern to Knigge and Guttenberg. So far, their sole source of income is the sale of wood. That is hard enough at the moment. However, according to Hartmann, forcing them to pay a CO_2 levy for each logging operation would not be justifiable. After all, the forests have served the general public in many ways – whether as flood protection or as recreational spaces. However, Ibisch points out that funding programs should not be used to create false incentives that lead to increased felling. Wood should not replace coal, but what else could be used? No matter how the forests are managing to slow down the increasing global warming, this is not a panacea. Even in the largest forest, the capacity for absorbing carbon dioxide is exhausted. In the long run, there is only one way to combat global warming: by drastically reducing greenhouse gas emissions.

SUMMARY

A team led by Ernst-Detlef Schulze has published a study showing that the climate balance of sustainably managed forests is significantly better than that of unmanaged forests.

Other researchers criticize the way in which the climate balance of a natural forest is calculated in this study. They conclude that the benefits to climate protection from these forests are greater.

It is difficult to quantify all the factors that would need to be taken into account in such a comparison. There is still no final verdict on which form of forest is more beneficial to climate protection. Various interests also play a role in the discussion.

In addition to their effect on the climate, forests fulfill many functions (e.g., as sources of raw materials, recreational areas, or water reservoirs). Managed and unmanaged forests are differently suited for this purpose. However, these functions currently have no economic value.

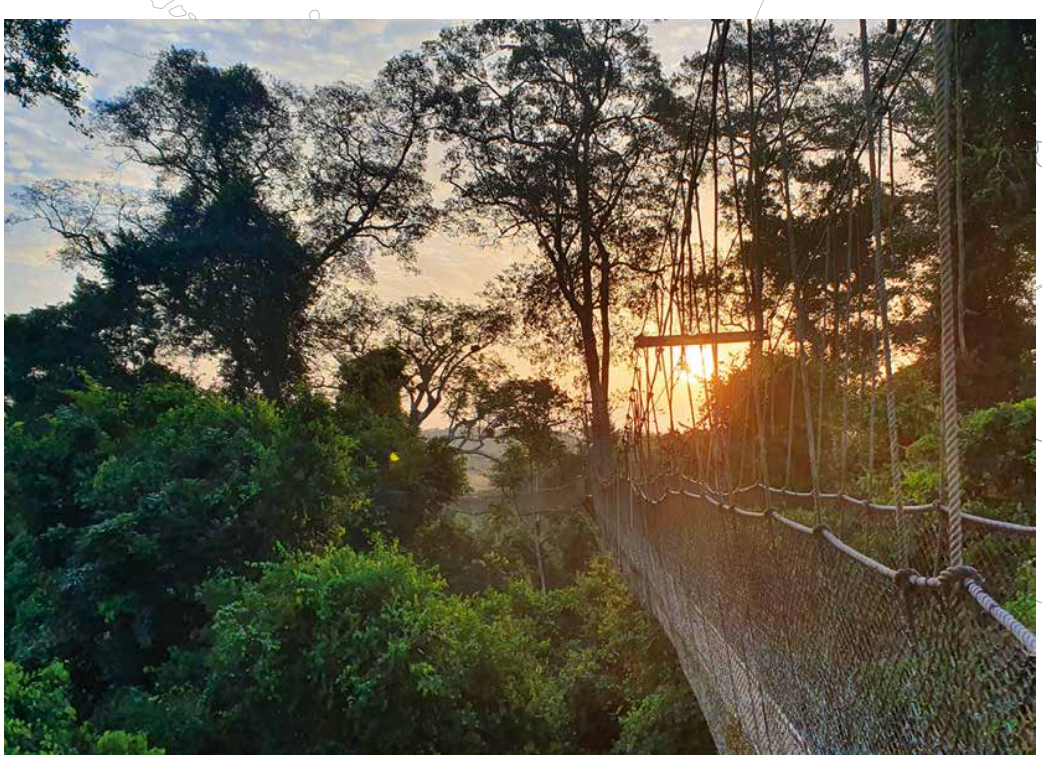

PHOTO: ANNA PROSS

Sunrise over the tree canopy: the suspension bridge along the treetop trail in the Kakum National Park north of Cape Coast is up to 45 meters high. The researchers chose it as the ideal spot from which to observe nightingales and many other animals.

Max Planck scientists collaborate with partners in over 120 countries. Here they write about their personal experiences and impressions. Anna Proß of the Max Planck Institute for Ornithology researched the vocal behavior of nightingales in Ghana. Here, she talks about her encounters with venomous snakes, her new fondness for plantains, and she reveals how ornithologists are making the most of the COVID-19 pandemic.

My research concerns the question as to how communication works and which neuronal processes it involves; to that end, I study the vocal behavior of male nightingales. The male birds attempt to out-sing one another, usually with the aim of defending their territories or attracting a female. Depending on their age, the males can have up to 200 different phrases in their repertoires, which they can also combine in any order. They can also adapt their songs spontaneously to match an opponent's vocalizations. In terms of this ability, they are similar to humans; after all, we have no problem with reacting spontaneously in the course of a conversation.

Nightingales are one of the migratory bird species; they breed in Germany during the spring, for example in Brandenburg, and then fly to warmer climes, including Ghana, in the fall. Having already studied their vocal behavior during the breeding season, I then wanted to investigate how they communicate in winter. So I set off for Accra in early November, accompanied by the head of my research group, Daniela Vallentin, and another doctoral researcher.

The early bird catches the worm – to paraphrase and apply this proverb to my research stay, it would have to be worded: "the early researcher hears the nightingale." We often had to leave at four o'clock in the morning to be at the target location by sunrise, as the birds are particularly active at dawn. Our chosen destinations were national parks, which are usually frequented by tourists. But due to the COVID-19 pandemic, the parks were almost deserted, which meant that we could lie in wait at our leisure.

If you hang around national parks in order to see birds at dawn, you'll see other wildlife through your binoculars as well. For example, in addition to all kinds of colorful birds, we saw antelopes and monkeys. The ceiling in one cave was covered with bats, and we once spotted a group of crocodiles from a safe distance. But the most dangerous encounter we had was with a snake. We were walking through the rainforest when we heard something rustling in the bush. And then we saw it – a Green Mamba, one of the most venomous snakes in West Africa – and it was just two meters away! But the Mamba seemed to have at least as much respect for us as we had for it,

POST FROM

GHANA

because the snake fled before our guide could even react.

Our research stay was barely affected by the COVID-19 pandemic, as we were traveling in remote locations and avoided large crowds. At our hotels, we were often the only guests, which is why the operators focused all their attention on us. One time we were treated to a traditional drum concert while we savored an amazing fish dinner.

All in all, the trip was a culinary revelation. I was especially fond of plantains, which have a similar consistency to potatoes and – whether they are boiled, roasted, or deep-fried – are included in nearly every meal. I've already looked into where I can buy them in Munich and have every intent to include them in my own recipes. Apart from that, there are many soups and stews in Ghana, which are delicious, but often very spicy. For snacks, you can find a huge selection of fresh fruits all over the place, like pineapples, papayas, and coconuts.

At one point we stopped in a remote village at the edge of a cocoa plantation, where the residents gave us a warm welcome and took the opportunity to give us a tour of the plantation. It was harvest time, so we learned how to open the cocoa pods, which are about 30 centimeters long, how to separate the individual beans from the jelly-like pulp and how to dry them. Of course, we were also allowed to taste them.

This encounter is just one example of the amazing hospitality to which we were repeatedly treated throughout our time in Ghana. In addition to its fascinating scenery, dazzling flora and fauna and numerous culinary delights, there are lots of other good reasons to visit the country. One thing's for certain: I'll be returning to Ghana as soon as I possibly can.

PHOTO: DR. SUSANNE SELTMANN/ MPI FOR ORNITHOLOGY

Anna Proß

28, studied biology at the TU Braunschweig and neurobiology and behavioral science at the FU Berlin, where she began her PhD studies under the supervision of Daniela Vallentin in March 2018, after which she followed her PhD supervisor to the Max Planck Institute for Ornithology in Seewiesen in early 2019. The biologist is interested in the vocal behavior of nightingales and studies their underlying neuronal processes.

"A RACE WE MUST WIN"

When he took part in the Vendée Globe, 39-year-old Boris Herrmann created a real sailing sensation: on January 28th, the Hamburg native reached the finishing port in Les Sables-d'Olonne, France, after more than 80 days on the world's oceans. Many people were on the edge of their seats when Boris Herrmann collided with a fishing boat shortly before the end of the race – narrowly missing out on a place on the winner's podium and finishing fifth. And he performed a great service to science.

PHOTO: YVAN ZEDDA

Under full sail: Boris Herrmann regularly sent data on the CO_2 content of the sea surface via satellite.

Peter Landschützer from the MPI for Meteorology also followed the race with excitement: Boris Herrmann regularly sent the climate researcher measurement data on the CO_2 content of the sea surface via satellite. Peter Landschützer is researching the carbon cycle in the ocean and reveals in an interview why the solo sailor took the time to do this despite lack of sleep during the world's toughest regatta.

Mr Landschützer, was Boris Herrmann's data collection successful?

Yes, it all worked out well, although at this point I don't have the most recent data yet. In the heat of the moment, transmitting data wasn't the top priority for Boris. But I have received all data until January 5th, when Boris had just sailed around Cape Horn. We have already uploaded 60,000 to 80,000 data points to SOCAT, which stands for "Surface Ocean CO_2 Atlas". This is the most comprehensive database on the CO_2 content of the surface of the world's oceans and coastal waters.

PHOTO: MPI FOR METEOROLOGY

Peter Landschützer

How did Boris actually come to take samples for you?

We met in 2018. It was Boris who proposed a collaboration to me a short time later. He is passionate about climate research. So the words "A race we must win" on his sail not only stand for his sporting success, but also for his fight against climate change. Together we then developed the idea of carrying the OceanPack – a lightweight sensor that measures CO_2 – on Boris' yacht.

Can you already derive initial findings from the data?

One finding that is not new, but which has been confirmed by the measurement data, is that the ocean – with a few exceptions – has less CO_2 than the atmosphere. The ocean therefore absorbs CO_2 from the atmosphere in most regions. This makes the ocean an important factor in our climate system. Particularly valuable for us are the samples Boris took from such remote places as the Southern Ocean. There was hardly any data on this before. I was a bit surprised that the CO_2 content in the Southern Ocean fluctuates so much.

What is the reason for this?

In the Southern Ocean, different water masses meet: water from the subtropics, but also deep water that is driven to the surface by the wind. These are separated by strong fronts, through which Boris sailed. If we want to understand CO_2 uptake in the ocean, we also need to understand how these fronts change dynamically. This confirms that we need more observations. Because CO_2 in the ocean cannot be measured by satellite, we are also unable to model such strong dynamics satisfactorily.

Did you and Boris keep in touch during the race?

Yes, we connected via WhatsApp from time to time. We had to coordinate so that I could submit everything to the SOCAT database in time: when can Boris send the data? How much time do I need to look at and check the data? We received some compliments from other scientists about our data. I immediately passed them on to Boris – also as motivation for the last days before he reached the finishing line.

What happens now?

It will be weeks, if not months, before the first studies of the Vendée Globe data are available. However, the first scientific evaluations of Boris' data from recent years have already been incorporated into the global carbon budget. These are estimates of CO_2 fluxes – on land, in the ocean, in the atmosphere.

What do you think: will Boris stay "on board" and continue collecting data for climate research?

Well, we have achieved our first big goal, the Vendée Globe. We now have to sit down together and plan further steps. Of course, I hope that Boris will continue to collect data for us in the future, for example in other races such as the Ocean Race in 2022. Perhaps we will also win over other sailors for our research who will be infected by Boris' enthusiasm.

Interview: Petra Maaß

COMMUNITY NEWS

COOPERATION WITH AFRICA

Max Planck researchers have been actively conducting research in Africa for a long time. Now the Max Planck Society is exploring to what extent it can better support African scientists on the ground. The first Africa Round Table (ART) was held on December 15th, 2020 – initially only virtually due to the pandemic.

The MPI for Evolutionary Anthropology maintains field stations for behavioral research on great apes in the Congo and the Ivory Coast. Teams from the MPI for Animal Behavior are traveling through Kruger National Park to record animal movements there with GPS transmitters. The MPI for Psycholinguistics is investigating linguistic diversity in different regions of Africa. And with H.E.S.S. in Namibia or the Square Kilometre Array (SKA) in South Africa, huge measuring instruments for astronomy have been created with the cooperation of Max Planck Institutes.

"I myself have been carrying out research in Africa since 1991," says Bill Hansson, who is now chair of the "Africa Round Table". "Africa has continued to develop as a great research environment and to produce great researchers. And I think what is needed now is that we start engaging in genuinely equitable partnerships with African researchers."

Africa's population is young – half of its billion-plus inhabitants are under 19. And even if the young Africa of smartphones and solar cells has not yet quite conquered established politics, it continues to shape and develop societies. "We want to open up opportunities," says Hansson.

As a first step, the Max Planck Society wants to establish low-threshold measures, such as lectures and mentorships. There will also be a special partner group program (link to partner group page) and mobility grants for African scientists who want to work temporarily in Germany at an MPI. "An important aspect must be to provide returning junior scientists with the right opportunities to develop their careers at home with a view to strengthening Africa's science and innovation base," so Bill Hansson.

The bigger challenge, however, will be to establish a long-term scientific environment and adequate research conditions. How do you make a science system work? "While we should always be willing to learn from best practice around the world, we should not simply take our cue from European institutions like Max Planck or the CNRS," Hansson explains.

www.mpg.de/16384579

HIGHER PAY FOR DOCTORAL RESEARCHERS

A new development that has been prepared over a long period of time has finally come to fruition: the Gemeinsame Wissenschaftskonferenz (GWK) has granted the MPG its approval to apply the DFG's gold standard to doctoral candidates' remuneration. The novel contract details were published on December 14th, 2020 within the Organisationshandbuch (OHB).

Starting January 1st, 2021, all doctoral researchers with Max Planck contracts will be remunerated in accordance with the DFG funding rates. Both ongoing and new contracts will be subject to this renewal. If signatures of contracts are delayed, for example due to the necessity to work from home resulting from COVID-19, the regulation and payment will be applied retroactively. Additionally, Institutes may also define higher base salaries to account for discipline-specific salaries. Untouched by the new regulations is the continuing possibility of individual recruitment boni.

The new regulations will apply to all MPIs in Germany, as well as the Netherlands and Italy. The Institutes are expected to cover the increased costs for their own doctoral researchers from their local budgets, although according to Ilka Schießler-Gäbler of the Department for Human Resources Development and Opportunities, "current centrally funded Max Planck Research Groups (Competitive W2 Groups), which are in particular open-topic Max Planck Research Groups, Lise-Meitner Groups, Minerva Max Planck Research Groups, as well as Otto Hahn Groups, receive an annual grant of €7,500 per group. The same applies to the current so-called institute-bound Max Planck Research Groups. International Max Planck Research Groups will receive single, nonrecurring remuneration."

As the new PhDnet spokesperson for 2021, Lea Heckmann, explains, "The new contract regulations are a great step forward, as they will not only ease the financial situations of doctoral candidates but also bring greater equality to doctoral researchers' salaries, since they will reduce the section- and gender-specific pay gaps – a discrepancy which was also reflected within the last PhDnet surveys." The former PhDnet spokesperson Lindsey Bultema, was also enthusiastic: "We're very pleased that this milestone of improvement in the doctoral candidates' situation has now been achieved, and we're thankful to the many generations of PhDnet steering committees who have pushed this project forward, as well as to the MPG Administrative Headquarters General Administration and the General Secretary Rüdiger Willems for spearheading this progress."

FIVE QUESTIONS

ON THE USE OF ARTIFICIAL INTELLIGENCE IN PHARMACEUTICAL RESEARCH

FOR PETER NUSSBAUMER

Proteins consist of a chain of different amino acids, which can fold into complex three-dimensional structures. Based on the sequence of amino acids, Google subsidiary DeepMind's AlphaFold software is able to predict this 3D structure with high accuracy.

Mr. Nussbaumer, will this new software revolutionize the development of new drugs?

PETER NUSSBAUMER Without a doubt, this program represents a milestone in protein analysis. However, many different research disciplines contribute to the development of novel drugs. Of course, technical progress in one field benefits the entire development process, yet it is only one piece of the puzzle, so I'm not expecting a revolution.

How could AlphaFold advance the development of new drugs?

We could, for instance, use AlphaFold to obtain a new spatial structure of a protein involved in a specific disease. If it has a structural similarity to another protein whose function is already known, we could then potentially use that knowledge to infer the role of the disease-related protein. However, we also have to keep in mind what AlphaFold cannot do; for example, it can neither predict the ways in which proteins change over time, how their structure is affected upon binding to other proteins or drugs, nor the orientation of side chains. The software also does not tell us where and how a molecule binds to a protein, which is particularly crucial for the development of new drugs.

What is the current role of artificial intelligence in the development of new drugs?

Among other things, the answer to that depends on how one defines artificial intelligence. The computational power of modern computers, neural networks and machine learning have long been aiding us in pharmaceutical research. We also refer to this as "computational chemistry." Examples of this include making structural comparisons between known and unknown proteins or the use and evaluation of the vast amount of data generated during preclinical research. Computational chemistry is also extremely useful for interpreting gene activity patterns and predicting target proteins for drug development. Artificial intelligence will certainly become more important going forward, but we shouldn't expect miracles from it.

Will the LDC be using AlphaFold?

I don't know whether DeepMind will make the software available to us and at what price, but, at this point, I suspect that the costs would exceed the benefits to us. Perhaps the algorithm may be made public, thus becoming "open source" software.

Do you think that DeepMind may move into drug development?

I'm not privy to Google's plans, but, as I said, there's more to developing new drugs than a sophisticated program for the 3D analysis of proteins. Even so, I wouldn't provide our data to the company. In my view, the question at this moment is more about whether DeepMind will eventually offer structural analysis as a paid service. So far, research groups have provided free access to the structural data from their studies.

Interview: Harald Rösch

Peter Nussbaumer is Managing Director of the Lead Discovery Center in Dortmund (LDC), which is a spin-off of Max Planck Innovation; LDC is dedicated to the development of new drugs.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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- Institute / research center
- Sub-institute / external branch
- Other research establishments
- Associated research organizations

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- Nijmegen

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- Rome
- Florence

USA
- Jupiter, Florida

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- Manaus

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