02 | 2022

MAX PLANCK *Research*

SOCIETY
On the fringes of the rule of law

ARTIFICIAL INTELLIGENCE
Machine teaching

ASTRONOMY
A look at a cosmic donut

ORDERED CHAOS

IMAGE: IMAGO / WESTEND61

2

Who is actually threatening whom here? The young shark seems to have changed from the hunter to the hunted. In doing so, it will simply learn about the advantages that a shoal offers the smaller fish: the crowds of prey confuse the attacker, and the reaction of the shoal is always one fin beat ahead.

EDITORIAL

Dear Reader,

In many modern societies, individuality is very important – going your own way, even sometimes swimming against the tide. Life in a swarm is quite different: each member must keep a permanent eye on its neighbors and adapt its movements to the behavior of the others, otherwise the swarm will dissolve. Swarms exist in cells, in animals, and also in us humans. For many people, they are emblematic of disorder and chaos. But the individual swarm members actually follow strict rules. Researchers have now identified the most important ones: do what the others are doing and don't get too close to them.

Swarms seem to function as if by magic. They have no leaders. No one determines where they will go. Rather, individuals organize themselves. One example is the swarm-like associations of immune cells that overwhelm pathogens in the body. Messenger substances attract more and more cells. But how do swarms dissolve again? Researchers at the Max Planck Institute of Immunobiology and Epigenetics in Freiburg have now discovered the relevant signaling processes.

Huge schools of fish in the oceans are an impressive natural spectacle. At the Max Planck Institute of Animal Behavior in Constance, state-of-the-art technology is being used to analyze what keeps a swarm together and what advantages it offers. Fish-like swimming robots demonstrate how energy can be saved when swimming together.

However, there are also inherent dangers in so many individuals coming together, as shown by the crowd disasters at the Love Parade in Duisburg in 2010 or the Hajj pilgrimage in Mecca in 2015. Contrary to common belief, such tragic incidents are not caused by recklessness or religious fanaticism – the course of events follows the laws of physics. How to reduce the risk of such disasters is a topic at the Max Planck Institute for Human Development in Berlin.

Swarms are thus a multifaceted phenomenon and an increasingly relevant object for research. We hope you will get a real buzz out of reading our focus articles and the entire issue will provide you with a swarm of information!

Happy reading,

Your editorial team

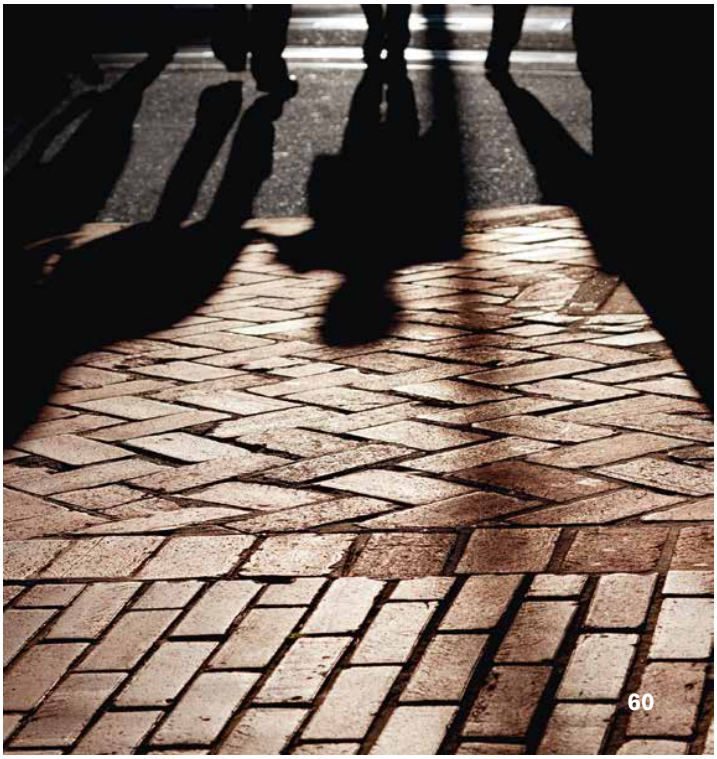

PHOTO CREDITS: MUHANNAD FALA'AH/GETTY IMAGES (TOP LEFT); ANNA ZIEGLER (TOP RIGHT); HYDRA MARINE SCIENCES GMBH (BOTTOM LEFT); ISTOCK/TNTEMERSON (BOTTOM RIGHT)

CONTENT

ON THE
SCENT TRAIL

PHOTO: ANNA SCHROLL FOR MPG

ON LOCATION

Banning perfume in the workplace – isn't this going a bit too far? Well, in order to study insects' sense of smell, even more precautions are also necessary. This is because some insects have such an extremely delicate 'nose' that they can even detect individual molecules of an odorant in the air. Bill Hansson and his team at the Max Planck Institute for Chemical Ecology want to understand how the sense of smell has evolved. One of their favorite subjects is the tobacco hawkmoth *Manduca sexta*. Its 'nose' is its large and very mobile feelers or antennae. The moths use these to find their mates, sources of nectar, and the plants on which the females lay their eggs with absolute precision.

How do they do it? Do animals have to learn this behavior? And which structures in the brain are involved and how? To find out, researchers have a state-of-the-art wind tunnel at their disposal. The system produces up to 800 liters of fully-conditioned air per second, the temperature can be regulated in the range of 15 to 30 degrees Celsius, and the humidity from 20 to 90 percent. The air used for this is always freshly drawn in and processed. Lighting is provided by a luminous ceiling of LEDs that can simulate day and night light.

Tobacco hawkmoths are predominantly nocturnal so the experiment shown here takes place under red light, which the animals cannot see. The moth starts from a transport tray and at the other end of the tunnel is a tobacco plant. Wind enters behind the plant in the direction of the moth. It carries the plant's natural scents or other scents placed there and allows the moth's behavior to be closely observed and recorded.

NEW PRESIDENT CHOSEN FOR THE MAX PLANCK SOCIETY

PHOTO: MPI FOR MULTIDISCIPLINARY SCIENCES

President-elect: Patrick Cramer will head the Max Planck Society starting in June 2023.

In June, the Senate of the Max Planck Society selected Patrick Cramer as the future MPG President for the term 2023 to 2029. The 53-year-old chemist and molecular biologist is Managing Director at the Max Planck Institute for Multidisciplinary Sciences in Göttingen. He will take over his new position in June 2023 from Martin Stratmann, who has headed the Max Planck Society for eight years. Patrick Cramer has been a Scientific Member of the Max Planck Society since 2014. Previously, he had held a professorship in biochemistry at the Ludwig-Maximilians-Universität in Munich for thirteen years. During this time, he served as Director of the Munich Gene Center and Dean of the Faculty of Chemistry and Pharmacy, among other positions. Cramer earned his doctorate at the European Molecular Biology Laboratory (EMBL) in Grenoble, France. From 1999 to 2001, he conducted research at Stanford University in the U.S. with Roger Kornberg, who was later awarded the Nobel Prize. Cramer enjoys great acclaim as a scientist and has won a number of scientific awards, including the Gottfried Wilhelm Leibniz Prize in 2006, the Ernst Jung Prize in Medicine in 2009, and the Louis Jeantet Prize in Medicine in 2021. Patrick Cramer is active in several national and international committees. His experience in science policy includes his chairmanship of the Council of the European Molecular Biology Laboratory.

www.mpg.de/18845304

PHOTO: EDOARDO CERIANI / UNSPLASH

Stand with Ukraine: the Max Planck Society supports staff from the war-torn country.

AID PACKAGE FOR UKRAINE

Looking to support Ukrainian scientists, the Max Planck Society has set up a special fund for an initial sum of one million euros. The goal of the fund is to finance follow-up contracts for temporarily employed Ukrainian staff at the Max Planck Institutes as well as to establish scholarships to accommodate further refugee guest researchers and early career researchers from Ukraine. Institutes can apply for these funds as needed. A number of Max Planck Institutes have already expanded their guest program with their own funds and are offering additional fellowships for the coming months. In addition, the Max Planck Society has established contact with the Ukrainian Academy of Sciences in order to support research in Ukraine in the medium and long term. One possibility would be to set up partner groups in Germany for former Ukrainian postdocs.

www.mpg.de/18477267

DISTINGUISHED ★

FRANK EISENHAUER

Frank Eisenhauer of the Max Planck Institute for Extraterrestrial Physics has been awarded the Gruber Cosmology Prize for developing instruments that have gathered evidence for the existence of a black hole at the center of our Milky Way. In the Gravity Experiment in 2018, researchers observed various phenomena near Sagittarius A*, a supermassive and invisible object at the center of our Milky Way. With the help of Frank Eisenhauer's technical innovations, the Gravity team found that the motions of stars and gas near the galactic center were consistent with theoretical predictions of a black hole.

PHOTO: ESO / M. ZAMANI

IN BRIEF

PHOTO: THOMAS BRUCKNER/MPI FOR THE SCIENCE OF HUMAN HISTORY

Reoriented: at the Max Planck Institute for the Science of Human History, the focus in the future will be on geoanthropology.

GEOANTHROPOLOGY COMES TO JENA

To reflect its scientific reorientation, the Max Planck Institute for the Science of Human History in Jena is changing its name to the Max Planck Institute for Geoanthropology. The Senate of the Max Planck Society decided on this name change in June. The scientific concept was largely developed by Jürgen Renn, Director at the Max Planck Institute for the History of Science in Berlin. He will also advance the concept's implementation as Director at the Institute. It will be the site of future research into the interrelationships between the geosphere and man-made systems. The Institute combines research areas from all three scientific sections of the Max Planck Society. One central subject, for example, is human-ecosystem dynamics, bringing together data and expertise from climate research, biodiversity research, and the social sciences. Examples of inter- and transdisciplinary research projects include the study of urbanization, world nutrition, and global flows of materials, energy, and information. The core questions range from the deep past to the distant future and include the question of how humanity has driven the emergence of the Anthropocene and in what ways it can still positively influence its course. ***www.mpg.de/18857834***

PARTNERING WITH AMAZON AND GOOGLE

At the end of May, Amazon and the Max Planck Society agreed on scientific collaboration. The goal of the joint Science Hub is to advance research into artificial intelligence, particularly in issues of causality, computer vision, and machine learning. Amazon is already providing nearly 700,000 euros in the first year to support the financing and implementation of research projects as well as the education and training of talented doctoral students. In addition, researchers from the Max Planck Society are being given the opportunity to work at Amazon part time, thereby gaining deeper insights into application-related research issues. The cooperation is planned for an initial period of five years. The Max Planck Institute for Informatics in Saarbrücken and Google have another partnership, and are now expanding their collaboration. In early June, they jointly founded the Saarbrücken Research Center for Visual Computing, Interaction, and Artificial Intelligence (VIA). The center will conduct basic research in frontier areas of computer graphics, computer vision, and human-machine interaction at the intersection of artificial intelligence and machine learning. The VIA will be headed by Christian Theobalt, Director at the Max Planck Institute for Informatics.

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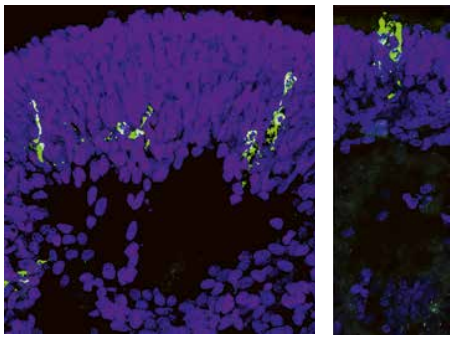

IMAGE: MPI FOR MOLECULAR BIOMEDICINE/ YOTAM MENUCHIN-LASOWSKI

Using immunofluorescence (green), the researchers detected SARS-CoV-2-infected cells in the retinal organoid.

THERE IS MORE TO SARS-COV-2 THAN MEETS THE EYE

SARS-CoV-2 is a multi-organ virus that affects various tissues of the human body. Autopsies of patients who died from Covid-19 have detected the virus in the retina. In addition, visual disturbances occasionally occur during or following infection with the coronavirus. However, it was unclear which retinal structures were affected and whether the damage might only be an indirect consequence of the virus. In an attempt to clarify this question, researchers at the Max Planck Institute for Molecular Biomedicine and the Westfälische Wilhelms-Universität Münster have studied the effects of Sars-CoV-2 infection on the retina in laboratory experiments. As a model, they used retinal organoids that can be grown from reprogrammed human stem cells. In the experiments, researchers showed that SARS-CoV-2 actually infected these organoids and replicated in them. The virus primarily affected retinal ganglion cells, but light sensory cells were affected as well. Retinal pathologies should therefore be monitored more closely as a possible consequence of "Long Covid". ***www.mpg.de/18453648***

ON A COLLISION COURSE

Wind and solar energy are crucial in the fight against the climate crisis, but birds and other flying animals risk death from collisions with wind turbine blades. Wind farm operators could limit the impact of turbines on wildlife by considering the collision risk to birds early in the planning process. Researchers at the Max Planck Institute of Animal Behavior in Constance, Germany, and the University of East Anglia in England have now presented the necessary data. The team has identified hotspots in Europe where birds are particularly at risk from wind turbines and power lines: the western Mediterranean coast of France, southern Spain, the Moroccan coast and the Strait of Gibraltar, eastern Romania, the Sinai Peninsula, and the Baltic coast of Germany. The authors say that the construction of new wind turbines and transmission power lines in these high-sensitivity areas should be minimized. In another study, black kites equipped with GPS transmitters were observed approaching wind turbines. The data showed that the birds do not fly directly up to the wind turbines but avoid the rotors once they are within one kilometer. This means that at least some of the birds recognize the danger and keep an appropriate safe distance.

www.mpg.de/18544955

Griffon vultures near wind turbines in southern Spain. In the Gibraltar region alone, more than a hundred of these birds die each year as well as dozens of short-toed eagles and kestrels.

PHOTO: ALEJANDRO ONRUBIA

HOT BREATH

Sexual arousal not only causes more blood flow to the genitals, but also an increased pulse and dilated pupils. But arousal can also be detected in breath, as a study by an international team involving researchers from the Max Planck Institute for Chemistry has now shown. According to the study, a characteristic signature of volatile molecules is found in the breath of sexually aroused people. The test subjects exhaled less isoprene and carbon dioxide, while the concentration of metabolites that can be assigned to certain neurotransmitters, such as the happiness hormone dopamine, increased. The researchers made this discovery when they showed twelve men and twelve women different film clips, including an erotic film, at the Research Laboratory on Human Sexuality, or SexLab for short, at the University of Porto. While the test subjects watched, the researchers measured their sexual arousal by determining the temperature of their genitals and analyzed their breath for more than one hundred volatile organic compounds. The researchers hope their discovery will help better diagnose sexual dysfunction in the future.

www.mpg.de/18577820

ALARM SYSTEM AGAINST HARDWARE ATTACKS

Radio waves could protect computers, as well as card readers, against attacks on their hardware. As a research team from the Max Planck Institute for Security and Privacy and the Ruhr University in Bochum has shown, the signal from one antenna in a device generates a characteristic electromagnetic pattern that is received by a second antenna. If an attacker taps the device with a wire or needle, for example, the radio wave pattern changes and blows the whistle on the tampering. Until now, only individual, particularly important components have been wrapped in a wired film that emits an electrical signal in the event of damage. How well the new radio wave alarm system responds depends on the thickness of the object that is inserted into a device and also on the location and depth of penetration. The technology reliably detected a needle 0.3 millimeters thick, for example, when it was pushed one centimeter deep into a computer case.

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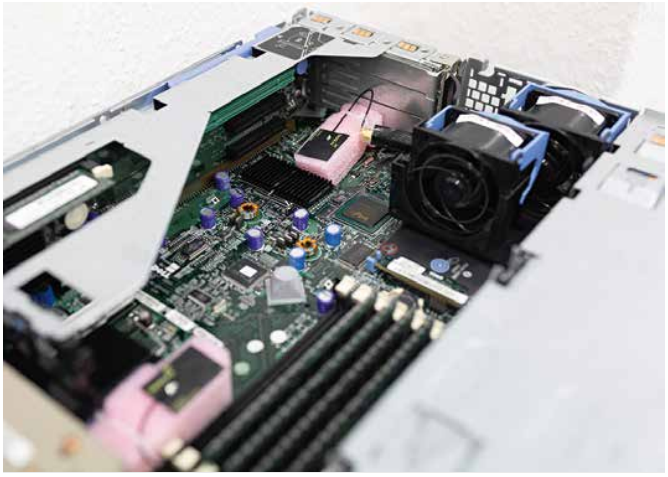

PHOTO: MICHAEL SCHWETTMANN

Radio monitoring: two antennas (pink) for electromagnetic signals can detect hardware attacks on a circuit board.

12 %

of the world's land surface is covered by biological crusts.

HARD LIFE

Living in arid regions is hard – often literally. This is because in a quarter of the world's areas where plants grow sparsely, bacteria, fungi, mosses, lichens, and algae form biological crusts. These stable layers cover about 12 percent of the world's land surface, but they are projected to decrease by 25 to 40 percent by 2070 due to climate change and shifts in land use. A team from the Max Planck Institute for Chemistry has now investigated the importance of biocrusts for the climate and ecosystems and what their partial loss would mean. According to the study, biocrusts currently stabilize soils against erosion and reduce dust emissions in drylands by about 60 percent. Their decline is likely to raise more dust in the future, cooling the climate, because dust in the atmosphere reflects sunlight. The additional dust will slow global warming by about half as much as human-made dust emissions, which come mainly from burning fossil fuels and biomass. In addition, the stirred-up dust transports nutrients. These nutrients are lacking in the areas from where they are blown and act as fertilizer where they land. According to the researchers, this can also lead to the displacement of the original vegetation. In addition, microorganisms travel with the dust and colonize new habitats in this way. This can also spread pathogens that harm plants, animals, or humans.

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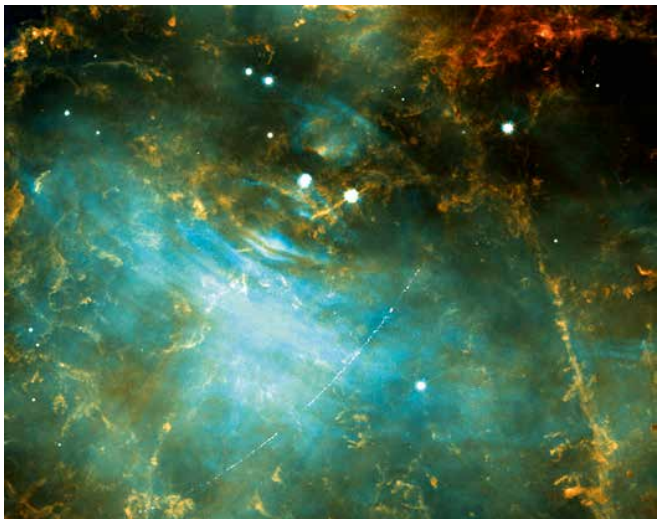

IMAGE: NASA/ESA/HUBBLE, M. THÉVENOT

Cosmic motion profile: in this Hubble photo taken on December 5, 2005, asteroid 2001 SE101 is passing in front of the Crab Nebula

ASTEROIDS FROM THE HUBBLE ARCHIVE

Using a sophisticated combination of human and artificial intelligence, researchers led by the Max Planck Institute for Extraterrestrial Physics have sifted through the archive data that most observations with the Hubble Space Telescope automatically filter out as noise or interference. In their cosmic detective work, some 11,500 volunteers searched the images for traces of asteroids, which appeared as more or less short streaks due to the typical exposure times of half an hour. In the process, they managed 1488 hits. The scientists used these layman classifications to train an automated machine learning algorithm to search for additional asteroid trails in the remaining archive data. This resulted in 900 additional discoveries. After the cleanup, a total of 1701 trails remained. Of these, a third could be identified as objects listed in the Minor Planet Center – the largest database of solar system objects. The majority, 1031 trails, come from small celestial bodies that were apparently unknown until now.

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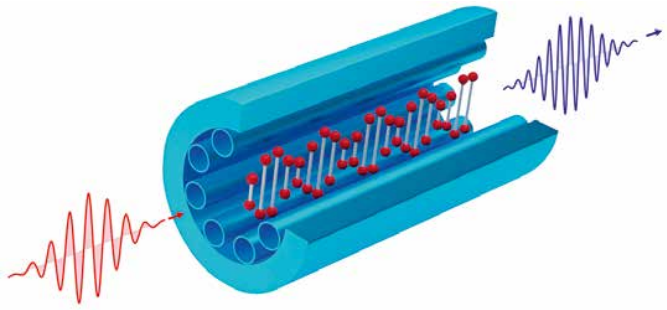
Hydrogen molecules (red) placed in collective vibration in a photonic crystal fiber change the frequency and thus the color of a photon (red and blue waves). The entanglement with a second photon is preserved.



GRAPHIC: NICOLAS JOLY / MPI FOR THE SCIENCE OF LIGHT

PLAY OF COLORS WITH PHOTONS

Quantum information could enable more secure communication and speed up some computer calculations. But before it can fulfill these promises, physics must come to terms with one of its drawbacks: many quantum states are extremely delicate, especially the entangled states where two or more particles behave as one. Entanglement is a central element of both quantum cryptography and quantum computing. Now, a team from the Max Planck Institute for the Science of Light has found a way to dramatically change the color of a photon from two entangled light particles without destroying the entanglement. This is a prerequisite for optical devices operating at different frequencies to exchange photons in a quantum internet, for example. To achieve the drastic frequency jump, the researchers inject hydrogen gas into the hollow core of a photonic crystal fiber – that is, a glass fiber in which fine channels are arranged regularly in parallel to the core and which conducts light in a particularly loss-free manner. Using a method called stimulated Raman scattering, the researchers excite the molecules of hydrogen gas to vibrate collectively. Now, when the photon of an entangled pair passes the molecules oscillating in time, it absorbs energy from them. By choosing the color of the entangled photons, the gas, and the pressure in the fiber, researchers can very efficiently control the color that the photon will take over a broad spectrum.

www.mpg.de/0120222en

PHOTO: SHUTTERSTOCK

Not so negative anymore: if we actively suppress a memory and then recall it again, the images appear less vividly than before.

BEST FORGOTTEN

Many people have negative experiences in their lives that they would prefer not to be reminded of. Nevertheless, there are always moments when memories come up unintentionally – often triggered by objects that are otherwise quite harmless: a rubber boot reminds you of a flood, a sneaker reminds you of a car accident, a teddy bear reminds you of an injured child. However, earlier studies had concluded that if a person actively pushes the emerging images out of their consciousness, the associated scenes are more difficult to recall later. They are forgotten. Until now, however, it was unclear what happens to the memory as a result or how the process is reflected in the brain. Researchers at the Max Planck Institute for Human Cognitive and Brain Sciences have pursued these questions in a study. They found that suppressing a memory reduces the neuronal reactivation of scene information both globally throughout the brain and locally in the parahippocampal cortex, which plays an important role in memory. By controlling one's thoughts, it is apparently indeed possible to permanently weaken one's memories.

www.mpg.de/18683205

WEAKER DEFENSE IN OLD AGE

The immune system must constantly respond to and memorize attacks from new pathogens in order to protect against the next infection. This is accomplished with the help of B cells that build up a store of information and produce a large number of antibodies that directly recognize the pathogens. As we age, however, the immune system works progressively worse – a process that we also find in fish. A research team from the Max Planck Institute for Biology of Aging in Cologne has found that older killifish have different types as well as a lower diversity of antibodies in their blood than young ones. This could contribute to a general deterioration of immune defenses.

www.mpg.de/18474159/0325

PHOTO: HAKAN NURAL/UNSPLASH

MISCONCEPTIONS LOWER VACCINATION RATES

Raising vaccination readiness in the fight against Covid: the study by an international team, including the Max Planck Institute for Tax Law and Public Finance shows how this could be achieved. In January 2021, the researchers surveyed several thousand physicians about their attitudes toward vaccination against Covid. About 90 percent said they trust vaccination and plan to get vaccinated themselves. This proportion was vastly underestimated by the general population: in surveys, about 50 percent of lay people assumed that, at most, half of the medical profession was positive about vaccination. Those who were then told the actual numbers not only changed their perception of the doctors' opinion but also increased their willingness to be vaccinated themselves: education lowered the number of unvaccinated by 15 to 20 percent. One reason for the distorted perception among the population, according to the researchers, is that minority opinions are given disproportionate weight in the media. For this reason, in debates on controversial topics, it should always be communicated how widespread individual views are.

www.mpg.de/18755942/0601

A matter of trust: those who believe that the medical profession trusts Covid vaccination are more likely to get vaccinated themselves than those who assume that there are many vaccination skeptics among physicians.

BONES BUILT LIKE PRESTRESSED CONCRETE

What engineers discovered only about 100 years ago has been used by nature for as long as vertebrates have existed. Just as steel wires under strain increase the fracture resistance of prestressed concrete, bones also become particularly hard and strong when their collagen fibers are prestressed by embedded mineral nanoparticles and they transfer this stress to the particles. A team from the Max Planck Institute of Colloids and Interfaces has observed that it is not only hydroxyapatite (which forms the mineral component of bone) that creates a prestress in collagen fibers but other minerals with different crystal structures as well. In addition, the researchers have for the first time followed live, so to speak, how the stress builds up in the collagen and mineral particles when they precipitate within the protein fibers. The findings could be used to develop collagen-based hybrid materials for medical applications, among other things.

www.mpg.de/18569011

IMAGE: MPI OF COLLOIDS AND INTERFACES

Toughened by mineral particles: scanning electron microscopy shows that nanocrystals of strontium carbonate have become embedded within the collagen fibers of a tendon.

A TOOTH FOR A TOOTH

Who eats whom often depends on body size. Potential prey can therefore escape their predators in the long term by growing larger in the course of evolution – a path that whales, for example, may have taken as protection against killer whales and great white sharks. As an international research team led by the Max Planck Institute for Evolutionary Anthropology in Leipzig has now shown, however, size does not always offer an advantage in the food chain. The researchers used zinc isotope analysis to compare the diet of the great white shark with that of the megalodon (Otodus megalodon). This megatooth shark lived 23 to 3.6 million years ago and reached a length of up to twenty meters. According to the findings, the positions of the megalodon and the much smaller great white shark (six meters long) in the food chain overlapped. This means that when the first great white sharks emerged about five million years ago, both species must have frequently hunted the same prey – even though the megalodon was more than three times larger. The findings support the theory that the great white shark competed with the megalodon for food and thus may have contributed to the giant toothed shark's extinction. ***www.mpg.de/18712873/0527***

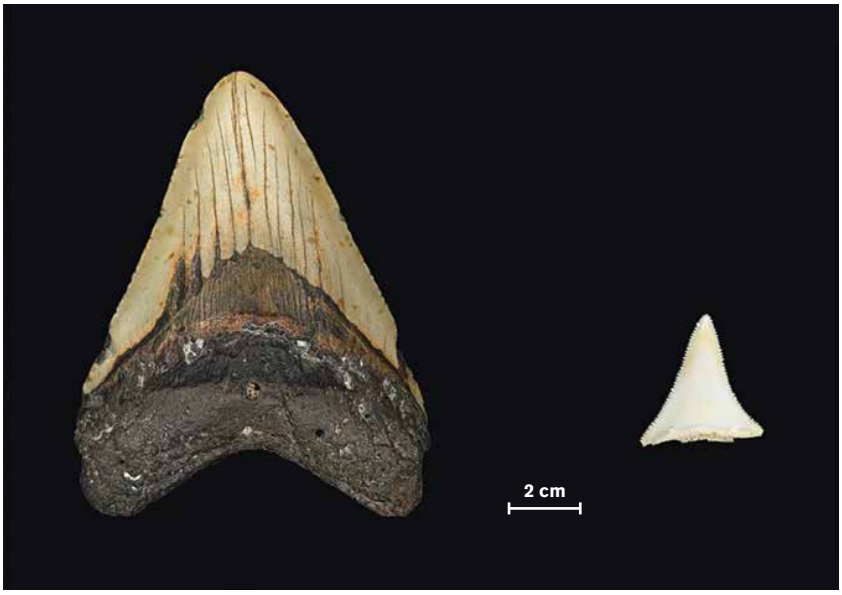


IMAGE: MPI FOR EVOLUTIONARY ANTHROPOLOGY

Clear difference: tooth of an extinct giant toothed shark Megalodon (left) and a great white shark (right). The composition of different zinc isotopes in the enamel crown of the teeth tells researchers what the animals fed on.

PHOTO: LIRAN SAMUNI, TAÏ CHIMPANZEE PROJECT

Communication in chimpanzees: the researchers identified hundreds of different vocal sequences that follow each other according to certain rules.

PLEASE USE COMPLETE SENTENCES

The gift of combining words according to rules is considered a unique feature of human language. Researchers at the Max Planck Institutes for Evolutionary Anthropology and Human Cognitive and Brain Sciences have now found clues as to where this extraordinary ability comes from. They studied the vocal communication of great apes and recorded thousands of vocalizations of chimpanzees living in the wild in Taï National Park in the Ivory Coast. As it turns out, the animals produce hundreds of different vocal sequences containing up to ten different call types. The order of calls in these sequences follows certain rules. This shows that vocal communication among chimpanzees is far more complex and structured than previously thought. The researchers will now investigate whether there are similarities to human language structures and whether chimpanzees use these sequences to increase the range of topics, they can communicate about.

www.mpg.de/18653265

A PRAGMATIC APPROACH TO HELPING REFUGEES

Europe is currently experiencing the largest movement of refugees since the Second World War. However, unlike 2015, when many people from Syria and Afghanistan sought shelter in Europe, there are currently no demands to turn back refugees at the border. How does the situation today differ from then? And what lessons can we learn from this for the future? Our author Dana Schmalz searched for the answers to these questions.

In the immediate aftermath of Russia's attack on Ukraine in February 2022, many Ukrainians fled the country, arriving in neighboring European states. Meanwhile, as of the beginning of June 2022, more than six million people have fled Ukraine, and even more have sought safety within the country's borders. In many respects, the reception of Ukrainian refugees in the European Union differed from other groups of refugees. This text looks at these differences and situates them within general questions of refugee law.

To begin with, there is a legal and practical difference with regard to entering the European Union: Ukrainian citizens are allowed to stay in the Schengen area for ninety days without a visa, meaning that a passport is generally all that is required to cross the border. Accommodation and reception beyond this initial period have to be organized but, unlike for other asylum seekers, crossing the border itself is unproblematic. This is in marked contrast to the otherwise vehement disputes concerning entry and expulsion. In some cases, refugees are being turned back from other countries in clear violation of the law, for example, in the Aegean Sea. In other cases, the legality is in dispute such as in the recent rulings by the European Court of Human Rights on the prohibition of collective expulsion

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VIEW POINT

DANA SCHMALZ

Dana Schmalz regularly writes about current developments in the European border regime and is particularly concerned with issues at the intersection of international law and legal theory. She received her doctorate from the University of Frankfurt and, after several sojourns in New York, is now a consultant at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg. Since October 2021, she has also held the Professorship for International Law at the University of Jena. Her book Refugees, Democracy and the Law. Political Rights at the Margins of the State was published by Routledge in 2020.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

in which the Court opted for a surprisingly narrow interpretation. These cases concerned pushbacks to Morocco in the border zone of the Spanish exclave of Melilla and collective expulsions at the border between North Macedonia and Greece.

THE COMMON EUROPEAN ASYLUM SYSTEM HAS BEEN IN CRISIS FOR YEARS

Moreover, there is widespread unanimity that those fleeing Ukraine should be admitted and aided quickly. Ukraine's direct neighbors – the EU member states Poland, Slovakia, and Romania as well as Moldova – took a generous approach and allowed even those to enter who could not present a passport. Within a few days, civil society initiatives were formed to organize accommodation and provide material support in addition to government measures. It was not the existence of civil society initiatives that was exceptional but the harmonious interplay of those activities and government measures. The Common European Asylum System has been in crisis for years now, especially the sharing of responsibility between the member states within the Dublin system is the object of continuous disputes, and reform efforts have failed so far.

The reception of persons from Ukraine, on the other hand, has been pragmatic. For the first time ever, the member states of the European Union activated the Temporary Protection Directive (TPD). It provides that those protected receive a right of residence for twelve months, which can be extended to a total of up to three years. They also receive a work permit, financial support, and accommodation. The Temporary Protected Status does not exclude the right to apply for asylum but does provide access to certain rights without the lengthy and uncertain asylum process.

Member States have some room for maneuver when it comes to applying the Directive, and some issues – such as how to deal with asylum applications, how long the protection lasts, or who it applies to – may also still be up for discussion. Nevertheless, it can already be said without a doubt that the reception of Ukrainian refugees differs significantly from that of Syrian, Afghan, or Eritrean refugees in recent years. As we have seen, there are legal reasons for this. These include the aforementioned visa exemption scheme and the fact that Ukrainian refugees can flee directly to European states, while many others seeking protection come via other states – often because they are prevented from flying. This is due to carrier sanctions, a measure designed to dissuade airlines from allowing people without visas to board, making entry by this route impossible for most asylum seekers.

However, the treatment of refugees from Ukraine also reflects political decisions and a social mood. The legitimacy of that different approach has been fiercely debated: Is the higher willingness to receive refugees due to the political circumstances of the war in Ukraine? Is geographical proximity the decisive factor? Is there a sense of cultural similarity at play? Or does this difference in treatment reflect the role of racism in perceptions of war and in attitudes toward refugees, as some commentors have criticized?

To begin with, the question of whether differential treatment is legitimate must be distinguished from individual incidents of direct discrimination at the borders. For example, there were some reports of students from African states fleeing Ukraine being detained at the Polish border. There is no question that this is unacceptable. This follows from the simple application of the existing law. In addition, the Geneva Refugee Convention also explicitly prohibits discrimination.

A DEBATE ON PERCEPTIONS OF DISPLACEMENT IS BENEFICIAL

When it comes to the scope of protection under the TPD, member states adopt specific rules. In this regard, Germany decided that only Ukrainian nationals who had resided in Ukraine before February 24, 2022, and third-country nationals, who enjoyed international protection in Ukraine or otherwise cannot return to their home states, are eligible for protection. Other individuals who previously lived in Ukraine, but are able to return to their home states, do not receive protection in Germany, at least not under the TPD. While this decision may be politically contentious, it does not constitute discrimination, since no unequal treatment takes place. The situations are different because third-country nationals can seek refuge elsewhere – namely in their home state.

The fact that the admission of Ukrainians refugees is politically supported to a much greater extent cannot be judged from a legal perspective. However, it can constitute a reason to stress that the reach of responsibility is implicitly negotiated through the interpretation of legal criteria. The dependence on prior understandings was visible, for instance, in a case on humanitarian visas in which the European Court of Human Rights had to interpret the criterion of sovereignty under Article 1 of the European Convention on Human Rights. The issue was whether the Convention applies to a visa decision at all, i.e. whether the consequences of issuing or refusing a visa should be examined in light of its human rights implications. The court ruled against this. Such an interpretation is guided by the wording, context, plausibility, and previous rulings – but there are always

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underlying ideas of proximity and responsibility. In this respect, a public debate on the different perceptions of war and displacement is beneficial, since assumptions on who is owed protection are spelled out and challenged. Rather than relativizing the current willingness to admit refugees, it can provide a basis for broader empathy and engagement. Such a concrete universalism takes special connections and the role of proximity seriously but looks beyond them.

If we now look at what the treatment of Ukrainian refugees tells us about the European asylum system more generally, two points are noteworthy: firstly, the role of individual procedures, and secondly, the distribution of responsibility and freedom of movement in the European Union.

The admission of refugees under the TPD represents a temporary departure from the individual process. The history of the protection of refugees has been defined by alternating perspectives regarding groups and individuals. While the protection of the politically persecuted was strongly oriented toward individual cases, the protection of refugees was initially primarily directed at groups. Until the Geneva Refugee Convention of 1951, there was no abstract definition of a refugee; their admission was coordinated on the basis of groups according to the situation. On the one hand, individual procedures are a significant achievement: they are the only way to ensure that the rights of each and every individual are actually protected. In this respect, the tendency to move away from individual procedures is problematic, for example, through increased screening – that is, rough assessments based on nationality, as proposed in the draft reforms of the Common European Asylum System. On the other hand, the focus on individual procedures and the ideal image of the individually persecuted person can lead to group movements being perceived as exceptional and downright "catastrophic".

THE PROTECTION OF REFUGEES WAS INITIALLY PRIMARILY DIRECTED AT GROUPS

The notion of migration as an entirely individual concept contradicts the reality of refugee movements, which, in the past as well as today, often involve groups.

In this respect, it is important to realize that individual rights and collective migration exist side by side. The TPD offers an example of how lengthy procedures can be avoided pragmatically without barring the way to an individual assessment.

Another noteworthy aspect of the application of the TPD is that there is no overarching system of responsibility. The distribution of people with protection status in the EU is based on where they register. Since Ukrainian citizens are allowed to move around within the EU without a visa, the place of registration and, consequently, jurisdiction depend on their choice. The contrast with the debates on sharing responsibility in the Common European Asylum System could not be starker: there is strong opposition here, especially with regard to the question of responsibility. The Dublin Regulation mostly stipulates that the state of first entry into the EU is the responsible state; those states at the EU's external borders consider this distribution unfair. Some landlocked states like Germany, on the other hand, are the de facto destination of many asylum seekers, and these states treat secondary migration in the EU as a significant problem. So while many asylum seekers are spread across the EU, there is considerable opposition to a free choice model. The current application of the TPD now offers a first experience with just such a model – and has worked without major difficulties so far.

EXPERIENCE SHOWS THAT THE INTERESTS OF THOSE SEEKING PROTECTION AND STATES OFTEN COINCIDE

It remains to be seen whether responsibility for people with protection status under the TPD will become an even more contentious issue in the months and years to come. The Directive mentions responsibility sharing in Recital 20 and states that "[p]rovision should be made for a solidarity mechanism." Germany had already pushed for distribution according to quotas, but the Commission opposed this. Instead, a solidarity platform exists that bundles information and coordinates resources such as medical care or housing. In any case, the current self-distribution shows how such a system can work and what factors are involved when it comes to selection: primarily geographic proximity to the country of origin as well as family and other contacts.

This shows that the interests of those seeking protection and states often coincide: namely, perspectives with regard to integration, social inclusion, and access to the labor market. This paints a hopeful picture when it comes to shaping the European Asylum System: much is possible if migration is not treated as a threat and admission is organized pragmatically.

←

WIND POWER, BUT DONE RIGHT

For Germany to reach climate neutrality by the middle of this century, renewable sources need to generate a whole lot more power than the roughly 500 terawatt hours that they produce today. After all, electricity will also need to replace the fossil fuels that are currently still in use for heat generation, transport, and industrial production. Besides the question of where to build photovoltaic systems and wind turbines, this expansion should also consider the power that the various forms of renewable energies can generate – especially wind power.

POWER GENERATION BY RENEWABLES

Potential power supply

by renewables in Germany

8,600 GW
Photovoltaics

390 GW
Wind

260 GW
Biomass

15 GW
Geothermal

5 GW
Water

Energy requirements

2021

3,390 TWh/year = 387 GW
of which roughly 80 percent is imported

To produce the 387 gigawatts needed to meet all of Germany's energy needs, current photovoltaic systems would cover around 4.5 percent of the country while wind turbines could provide a maximum of 390 gigawatts throughout Germany. Even today, the electricity supplied by wind power and photovoltaics is often cheaper than that produced using lignite.

Costs (€ cent / kWh)

2018

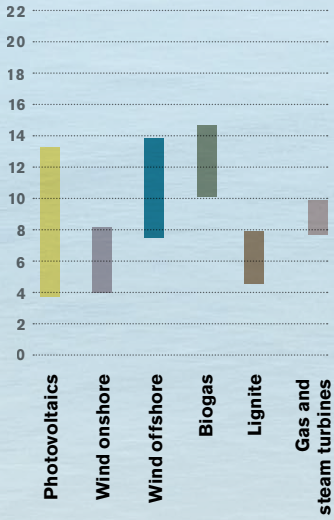


CHART: GCO BASED ON A TEMPLATE BY FRAUNHOFER ISE

MANY TURBINES SLOW DOWN THE WIND

As turbines draw energy from the wind and create a slipstream, they are usually erected at a distance of four to six rotor diameters (around 600 to 800 meters) from each other to allow additional energy to be supplied from above. But there are limitations: as the number of wind turbines in a region increases, the atmosphere is less able to balance the losses and the power of the wind decreases. This effect could reduce the electricity yield for the planned onshore expansion in some regions and will be an important factor in the targeted expansion in the North Sea.

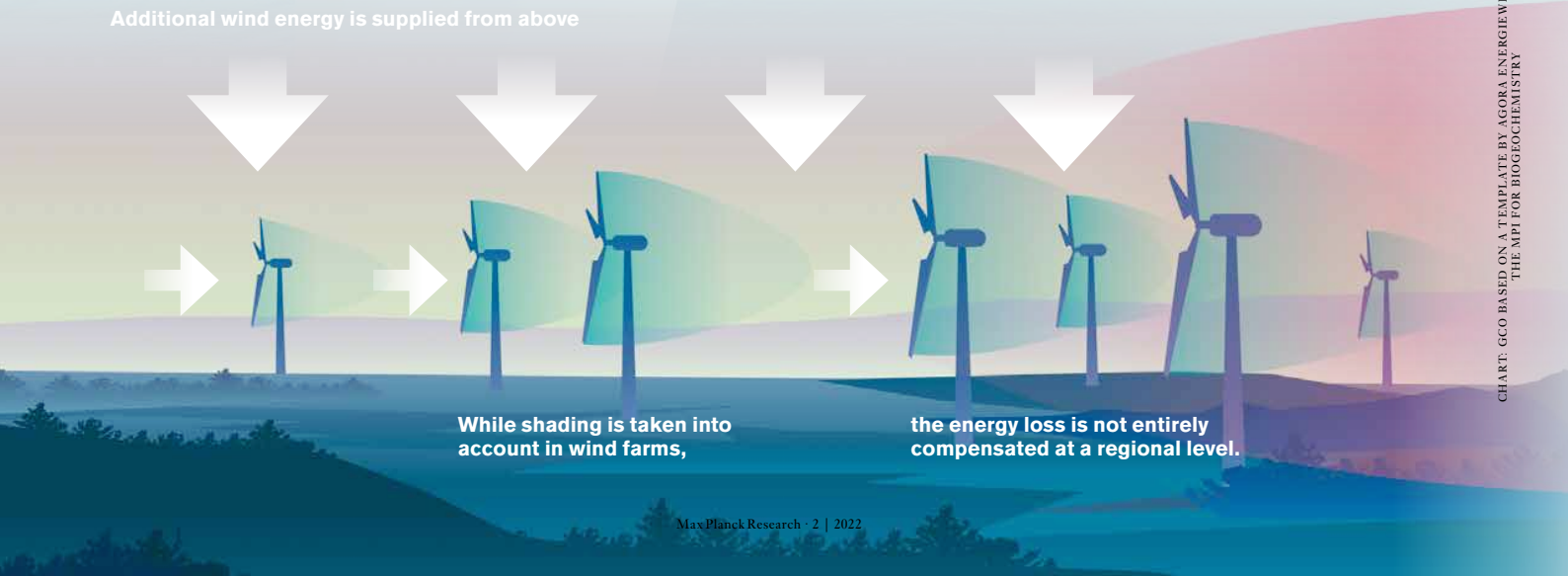
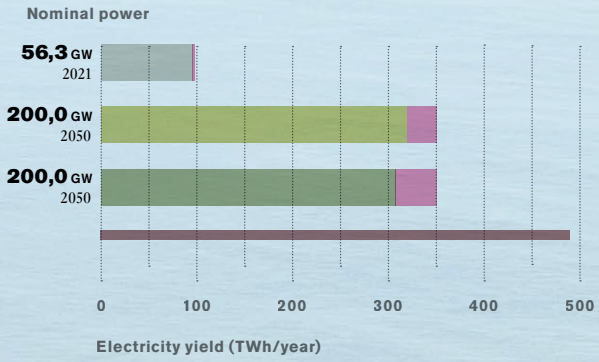


CHART: GCO BASED ON A TEMPLATE BY AGORA ENERGIEWENDE AND THE MPI FOR BIOGEOCHEMISTRY

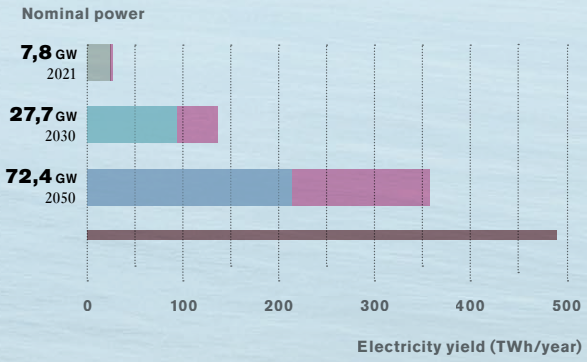
WIND POWER NEEDS SPACE

In 2021, onshore wind turbines with a nominal power output of 56 gigawatts were installed; this could increase to 200 gigawatts by 2050. According to the calculations by researchers at the Max Planck Institute for Biogeochemistry, the electricity yield will be reduced by 8 percent due to a fall in wind energy if the turbines are proportionately distributed throughout the country (scenario A). In this case, a large number of new turbines would be erected in the southern federal states. If turbines are erected proportional to the turbines currently in place (scenario B), primarily in the northern federal states, the yield will decline by over 10 percent. The area available for wind turbines in the North Sea is much smaller than the German land mass, yet it is expected to account for the production of 70 gigawatts, one-third of the targeted onshore power, by 2050. This leads to a calculated yield reduction of 40 percent, which would significantly increase the costs of electricity production.

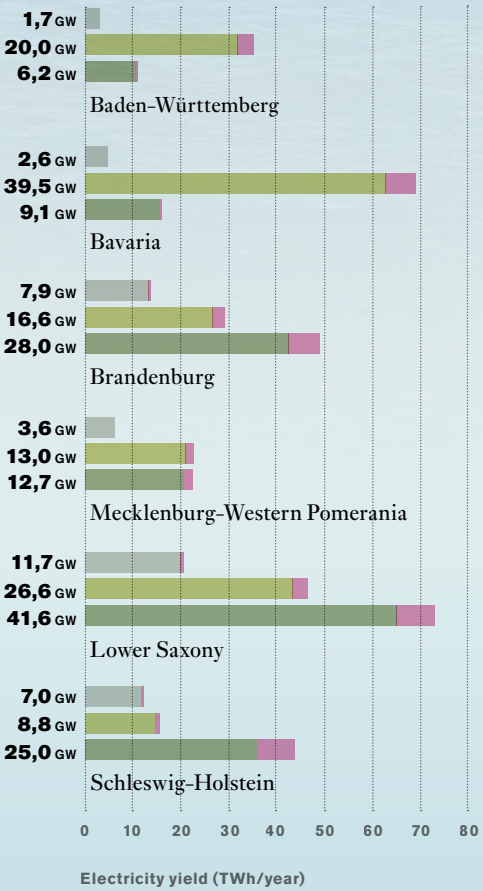
Onshore electricity yield

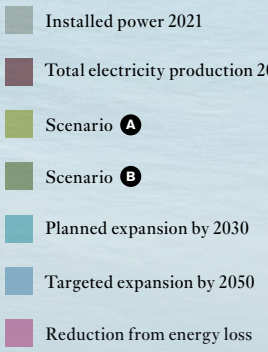


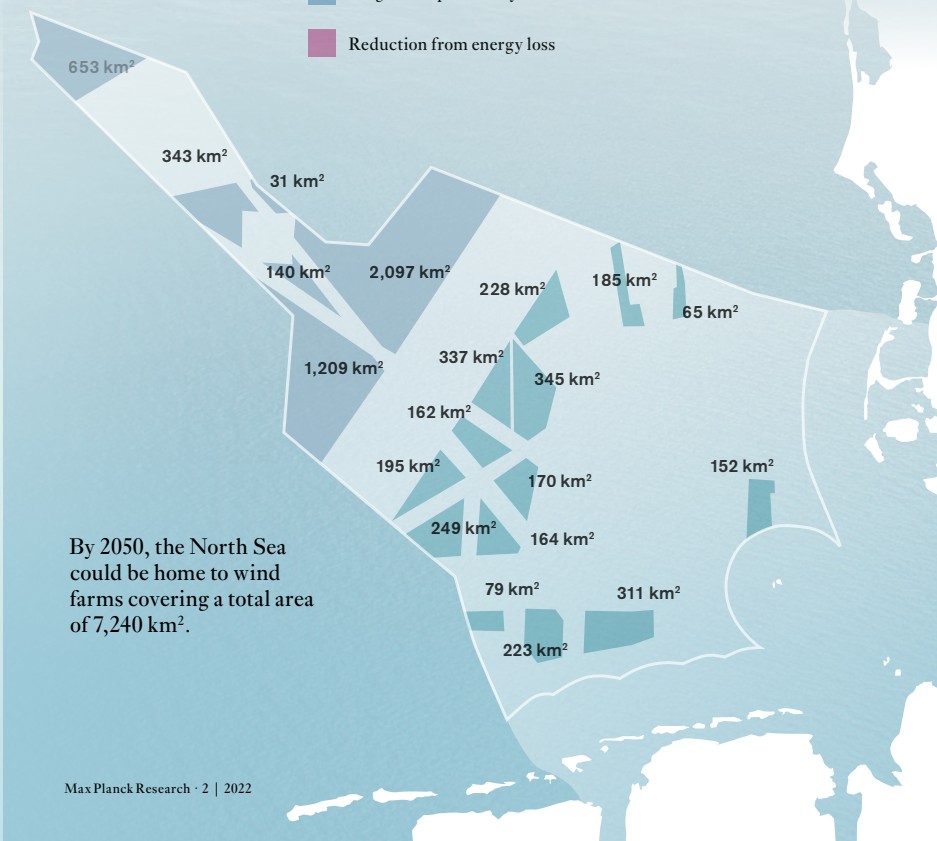
Offshore electricity yield



Northern and southern federal states







By 2050, the North Sea could be home to wind farms covering a total area of 7,240 km².

CHART OF WIND FARMS ON THE NORTH SEA: GCO BASED ON A TEMPLATE BY THE MPI FOR BIOGEOCHEMISTRY

FOCUS

ORGANIZED CHAOS

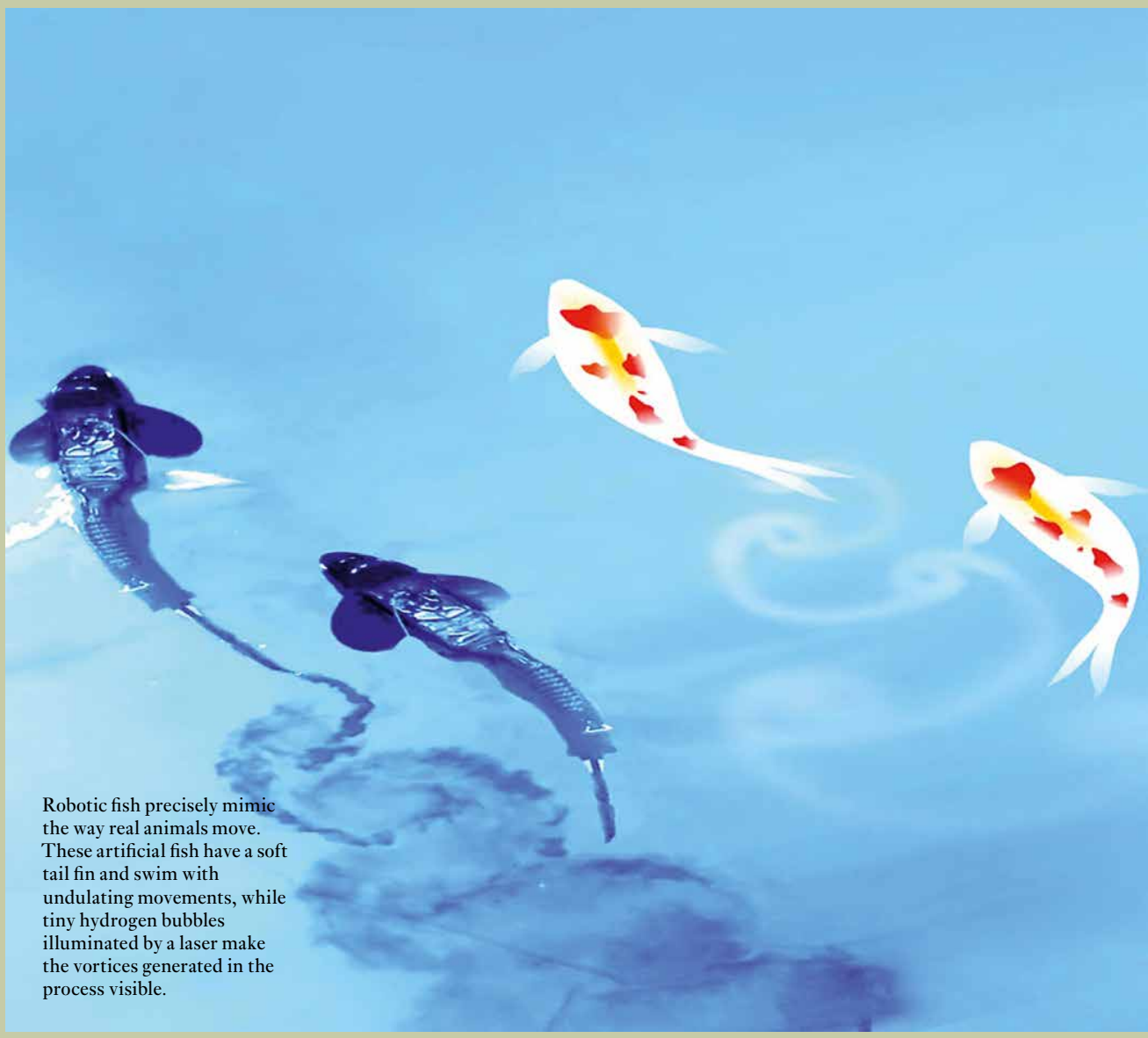


PHOTO: LIANG LI / MPI OF ANIMAL BEHAVIOR

Robotic fish precisely mimic the way real animals move. These artificial fish have a soft tail fin and swim with undulating movements, while tiny hydrogen bubbles illuminated by a laser make the vortices generated in the process visible.

SCHOOL VORTEX

TEXT: HARALD RÖSCH

Iain Couzin, a researcher at the Max Planck Institute of Animal Behavior in Constance, and his team want to discover the rules that schools of fish follow as well as the advantages of life in the collective. Cutting-edge technology is helping the researchers to find order amid the chaos.

PHOTO: IMAGO IMAGES/IMAGEBROKER/H.X.REINHARD

In Iain Couzin's laboratory, schools of sunbleak fish swim around tanks of several thousand liters. In the dense, seething mass of fish bodies flitting back and forth, the human eye struggles to follow any individual fish for longer than a few seconds, but thanks to modern, high-performance cameras, automatic image-based tracking, and motion analysis, the researchers working with Iain Couzin are nevertheless able to observe, and even identify, each fish. The apparent chaos within the school is confusing not only to the human eye; for predators, too, it is hard to focus on one specific animal. Although a school like this is easier to find than one single fish, and therefore draws the attention of predators more readily, the sheer quantity of fish offers safety.

Seeing, smelling, and feeling more

Protection is one of the reasons why fish travel through the ocean in often enormous schools. The school not only confuses attackers, but is also more reactive to their environment because thousands of eyes, noses, and pressure sensors can see, smell, and feel more! The first fish in the school to perceive a predator alerts its neighbors by fleeing, setting off a chain reaction. The information travels at lightning speed, and this informational advantage means a school can react up to 15 times faster to an attack than an individual. Large predatory fish aim to prevent this, and the researchers have discovered that some of these animals swim into the school in a row, one behind the other, when they attack in order to divide it up. Prey is then easier to catch in the resulting small groups.

Living in a school also helps with the perception of local differences or gradual changes in salinity, light, or temperature. By living together in a group, the school acquires collective knowledge about its environment and can react to this – knowledge that individual animals do not have. Furthermore, the scientists have discovered that by schooling, an individual can save energy, compared to when swimming alone, because they can recover energy from the water vortices created by the

In good company: sunbleak perfectly demonstrate the advantages of living in a school. The fish, which are around five centimeters long, usually live in still or gently flowing water – for example, in ponds, flooded gravel pits, or swampy ditches.

fin strokes of their neighbors, thus making collective swimming more efficient. Researchers had long suspected as much, but Couzin and his team provided the most conclusive evidence to date in 2020. To do so, they engineered biomimetic artificial fish and measured their energy consumption as they swam collectively in a countercurrent pool. Tiny hydrogen bubbles that lit up under laser light revealed the vortices that each fish creates as it swims and that spread backward. The secret to saving energy lies in the synchronization of the tail beats: "The fish swimming behind has to coordinate the beat of its tail fin with that of the animal swimming in front, and this – depending on the distance to the fish in front – results in an optimal phase shift. If the robotic fish swim side-by-side, for example, then their tail fins ideally need to beat synchronously," explains Couzin.

But do real fish behave that way too? The researchers developed a hydrodynamic model that predicts precisely, for example, how two fish swimming together should coordinate their tail beats to do so. And indeed, the animals swim in such a way that they optimally utilize the vortex of their partner, allowing them to save around five percent of the energy they put into swimming. "That's a big deal when you think that locomotion requires a large proportion of the fish's energy," says Couzin. But not only that: if necessary, the animals can then also decide not to save energy, but rather utilize the energy of the vortex to increase their propulsion. This allows trailing fish to speed up more quickly. However, a fish should not be too small if it wishes to benefit energetically from its neighbors. For very small fish, the viscosity of the water is too high. "For them, the water is like honey – they can't make any lasting vortices in it."

"A school can remember things that a particular animal may never have experienced itself."

IAIN COUZIN

With the technologies available today, it has so far only been possible to analyze the interaction of two individuals. Things start to get extremely complicated as soon as a third one is added – let alone a whole school. It is therefore also not yet clear how efficient swimming and defensive behavior against predators influence each other. Does one of the two predominate, or do fish compromise between the two requirements? The behavior of animals in a school appears so perfectly coordinated that you cannot help but suspect there are highly complicated rules that keep the school together, but Couzin and his team have dispelled this misconception. "Animals that live in large groups like this follow relatively simple and effective rules; they don't need to exchange information actively with each other at all. It is enough to react to the movements of their neighbors." Fish swimming very close together, there-

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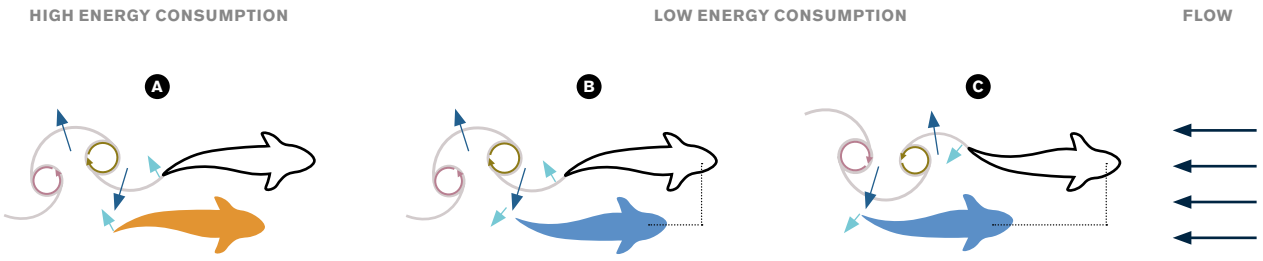

If the force arrows of swimming movements (light blue) and vortices (dark blue) point in different directions, swimming together consumes more energy (A). To save energy, therefore, a fish needs to synchronize its movements with the animal swimming in front so that its vortices assist its own movements (B). If the distance is greater, the tail fin must beat with a greater time lag (C).

GRAPHIC: LI, L., NAGY, M., GRAVING, J.M. ET AL. VORTEX PHASE MATCHING AS A STRATEGY FOR SCHOOLING IN ROBOTS AND IN FISH. NAT COMMUN 11, 5408 (2020)

fore, repel each other and thus avoid collisions, while individuals located further away are drawn towards the others. These are the rules that govern the direction the fish swim in. "Always stay close to the other members of the school, but don't get too close to them – then you automatically swim in the same direction as them."

Couzin and his team have also discovered that, contrary to conventional wisdom, the middle of a school is often not the best position to have at all. The animals swimming at the front and the sides get information from other members of the school on the one hand, but at the same time, they have direct access to information about occurrences outside of the group, such as the appearance of a predator. The worst place is at the back, which leads to the animals there constantly attempting to leave this risky position and therefore remaining permanently on the move.

The researchers have also found out that fish follow the majority principle – even though they themselves cannot count. If ten fish swim to the right and eight to the left, then the school generally opts to go right. Surprisingly, some mammals behave in a similar way. Together with Couzin's colleagues Meg Crofoot and Ariana Strandburg-Peshkin, the researchers have equipped a herd of free-ranging baboons in Kenya with GPS transmitters and used them to determine the position of each individual animal over a period of weeks. Evaluation of the data revealed that the direction the animals choose to travel depends on the angle at which two leading baboons move away from each other. If the angle is less than 90 degrees, then the following animals compromise and head for the middle. If, however, the angle is greater than 90 degrees, the baboons take the direction preferred by the majority of group members. The dominant animal can only follow suit *(Max Planck Research 02/21).*

SUMMARY

Life in a school offers a host of benefits for fish: it protects them from predators, among other things, saves energy as they swim, and improves perception.

Schools of fish form according to simple rules: individuals who seek proximity to one another but simultaneously always maintain a minimum distance all swim in the same direction and therefore stay together. They thus form a school.

A school is more than the sum of its individuals. It can acquire collective intelligence that the individual animal does not have.

The individuals in many fish schools do not know each other; they are usually not related and do not form lasting relationships. Previously, it was assumed that fish within a school are entirely anonymous and egalitarian. However, the findings of Iain Couzin and his team challenge these notions. The researchers have developed machine learning algorithms that can identify individual fish even when they look completely the same to us humans. The research shows that, surprisingly, schools are not uniform in structure, but exhibit previously unknown internal structures. The fact that a school is a self-organizing system does not, therefore, mean that all individuals have the same influence on its behavior. Despite a lack of any obvious hierarchy, the analysis reveals some individuals are more important than others. Fish at the edge of the school are the first to react to changes, for example, to an attacker, and thus dictate the group's direction of motion for several seconds. Some individuals, meanwhile, swim faster than others and, as a result, can lead the school for longer periods, for example, when searching for food. Such individual differences have hardly been studied so far, yet they give structure to a seemingly uniform group and have a massive influence on its behavior.

PHOTO: INES JANAS FOR MPG

The wisdom of the many: Angela Albi, Eduardo Sampaio, Kajal Kumari, Iain Couzin, and Lior Lebovich (left to right) enjoy discussing their ideas on school behavior collectively.

Making better decisions together

Together with colleagues from the Universities of Konstanz and Cambridge, Couzin used sticklebacks to study the influence of individual differences on group behavior. The researchers analyzed the behavioral patterns of multiple individuals in various environments. Then they placed the fish together in groups and observed how the animals found and utilized sources of food. The results show that the individuals that spent more time close to members of the same species were slower, more likely to stay in the center of the group, and also tended to follow other fish. A group consisting primarily of such individuals held together more closely but moved about less and with poorer coordination. Meanwhile, groups of individuals less concerned with proximity to members of the same species held together more poorly but swam faster. This raises the question of "personalities" in fish. Why do some swim faster than others? Are they braver? Are some of them perhaps more altruistic, while others are clearly more concerned with their own advantage and exploit their neighbors in the school? "Personally, I'm less inclined to talk about 'personalities' in fish, because I think this kind of term is not very helpful for describing relatively simple differences. Ultimately, we still don't know whether an individual swims faster because it is braver or because it is simply bigger or stronger," says Couzin. Regardless of how one might describe the differences among the members of the school, a few small variations are enough to influence decision-making, both of an individual and an entire school.

A large number of interconnected units that share information with each other and can thus make better decisions as a collective – isn't that reminiscent of how the brain works? "That's right. Our experiments with schooling fish have shown that it is not only the brain of the fish that processes information but also the school as a whole. How reliably the school reacts to an attacker, for example, depends not on the sensitivity of the individual fishes but rather on their position in relation to, and distance from, one another: they need to see each other as well as possible to be able to pass on information optimally. Nerve cells in our brains follow the same principle," says Iain Couzin. If the connection between the individuals or the nerve cells changes, then this also affects the flow of information between them, and this can lead to changes in the behavior of the entire system. According to the researchers, fish in a school can thus react earlier to dangers without increasing the risk of false alarms. In contrast, overly sensitive fish or neurons that react to even the smallest sign of danger would trigger mass false alarms.

In this way, schools of fish and other groups of animals develop abilities not possessed by individual animals. The school is therefore more than the sum of its parts

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– and this, too, is an analogy to the brain and likewise constitutes the basis of the "wisdom of the many" often cited in connection with the internet. The knowledge of the individuals – some of which is subject to errors – all adds up to a fairly accurate reflection of reality. "This means a school can develop a collective memory and remember things that a particular animal may not have experienced itself," explains Couzin. This kind of "collective mind" is also known from state-forming animals such as ants and bees, but unlike these insects, the fish in a school are only rarely related to each other. Therefore, evolution cannot optimize the school itself, but only its individuals.

It is well known, however, that the wisdom of the many is not infinite. Iain Couzin and his former doctoral researcher Albert Kao, who has recently started leading his own research team in Boston, have demonstrated that the informational advantage brought by life in a school declines again above a group size of fifteen to twenty individuals. Why, then, do some species form schools of many thousands of individuals? "Contrary to how it may seem at first glance, many large groups are not uniformly structured, but are rather heterogeneous, meaning that they include subgroups. Large herds of elephants, for example, consist of different families and clans," says Couzin. These kinds of group structures can prevent the flow of information from breaking down.

School code cracked

Thanks to the analytical tools they developed, the researchers are able to reveal piece by piece how fish coordinate their behavior in the school. This also provides indications of how humans might apply these rules to effectively coordinate swarms of autonomous vehicles such as drones. "I believe we have finally cracked the code, and it tells us that the rules developed by nature are probably just as good as those created by humans, but much simpler and more robust.

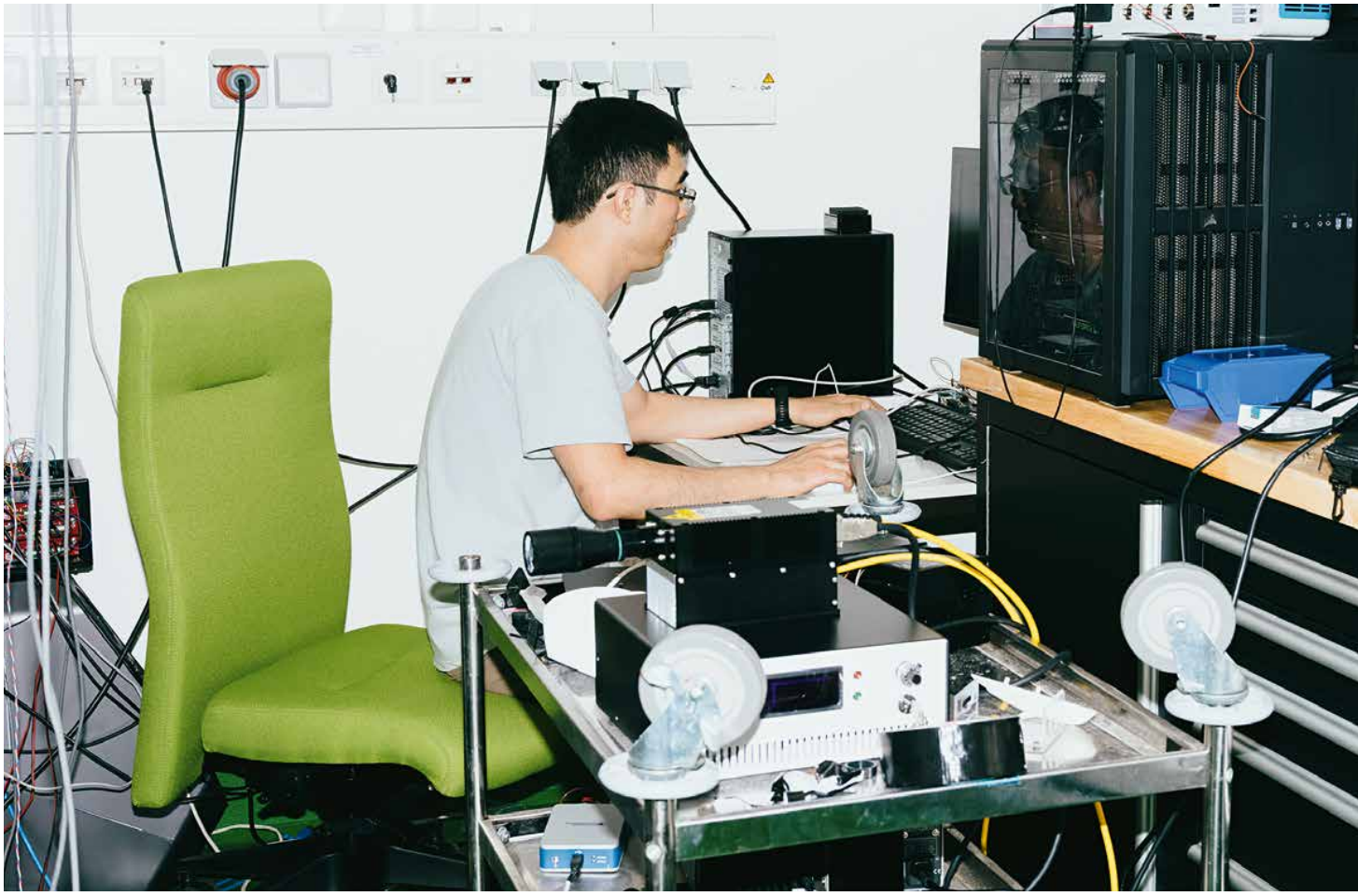


PHOTO: INES JANAS FOR MPG

PHOTO: INES JANAS FOR MPG

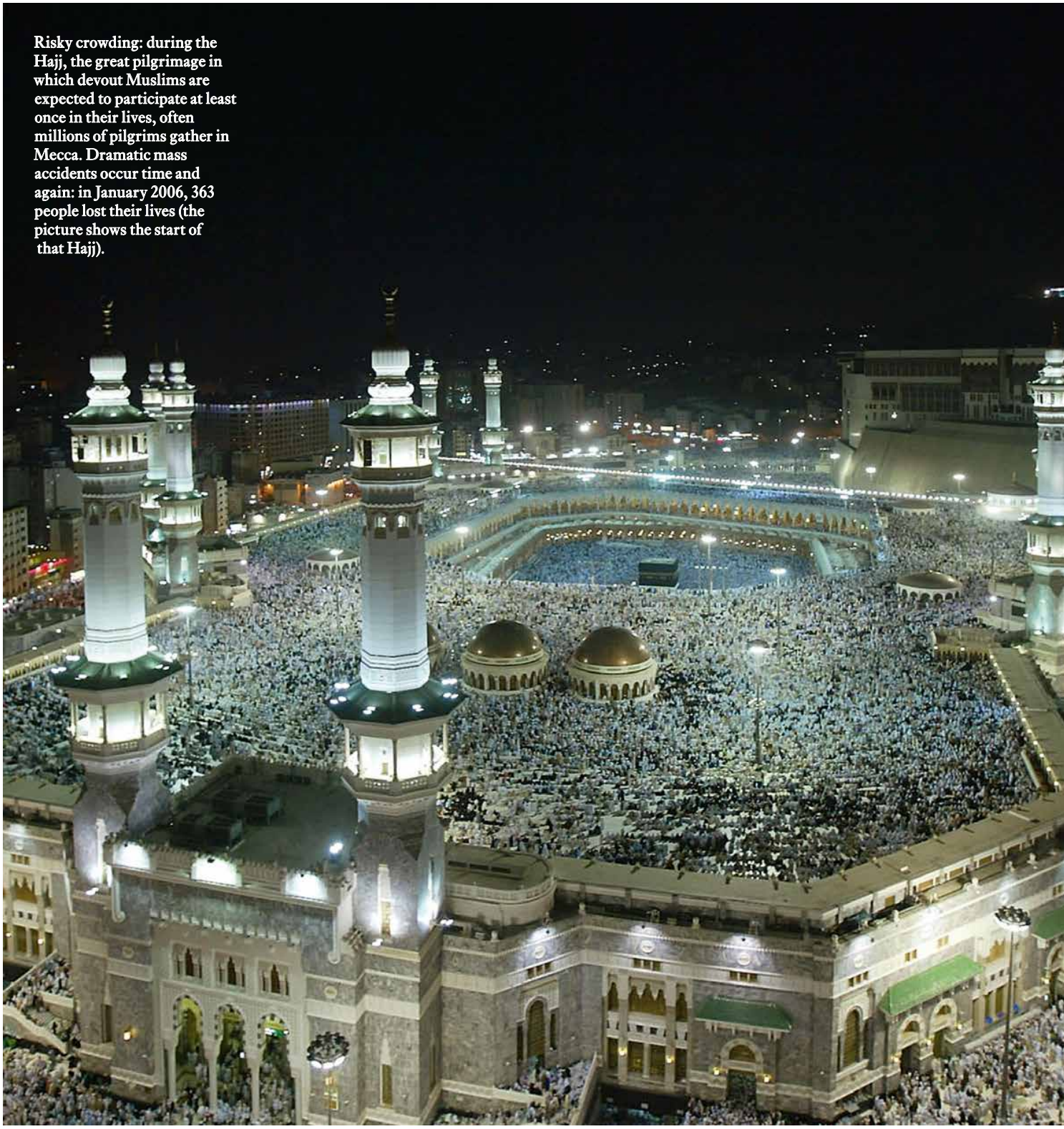
The way to save: flow experiments with robotic fish show that energy consumption drops when they swim together.

Our studies of fish could therefore soon have an impact on our day-to-day lives." What is not yet clear is whether schools of fish also exhibit such structures. Couzin and his team aim to close this knowledge gap and hope their latest development will help: software based on artificial intelligence that is able to track the movements of each individual fish in a school. "We don't have to mark the animals in advance. Our algorithm can identify each individual and measure its route – something that will revolutionize research into collective animal behavior," says Couzin. Schools of fish have been roaming the world's oceans for millions of years – defying predators and environmental changes. Recently, however, a new player has appeared on the scene that doesn't play by the rules: Homo sapiens. In the face of fishing trawlers with nets that are often kilometers long, even huge schools offer no protection – quite the contrary, as they attract the fishing fleets all the more. Many fish stocks have therefore collapsed.

What holds the school together at its core: Project Leader Liang Li uses sophisticated technology to reveal the rules according to which fish coordinate their collective behavior.

The numbers of other animals that form groups have also plummeted: birds, large mammals, insects. What this means for the survival of these species cannot yet be foreseen. There may, for example, be a threshold value below which there are no longer enough individuals to form a school, meaning a species could then become extinct, even though there are still many thousand individuals remaining. "Research into animal collectives thus helps with species conservation," says Iain Couzin. Whether schools of fish will still be swimming through the world's oceans in the future is therefore highly uncertain. It is certainly to be desired – and not only because, in coming together, they perfectly symbolize the power of the small and defenseless.

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



Risky crowding: during the Hajj, the great pilgrimage in which devout Muslims are expected to participate at least once in their lives, often millions of pilgrims gather in Mecca. Dramatic mass accidents occur time and again: in January 2006, 363 people lost their lives (the picture shows the start of that Hajj).

PHOTO: MUHANNAD FALA'AH/GETTY IMAGES

NINE PER SQUARE METER

TEXT: MARTIN TSCHECHNE

How do individuals orient themselves in a crowd? How does hate spread on the internet? And what does one have to do with the other? At the Max Planck Institute for Human Development in Berlin, Mehdi Moussaid studies people in motion and explains why this sometimes leads to disaster.

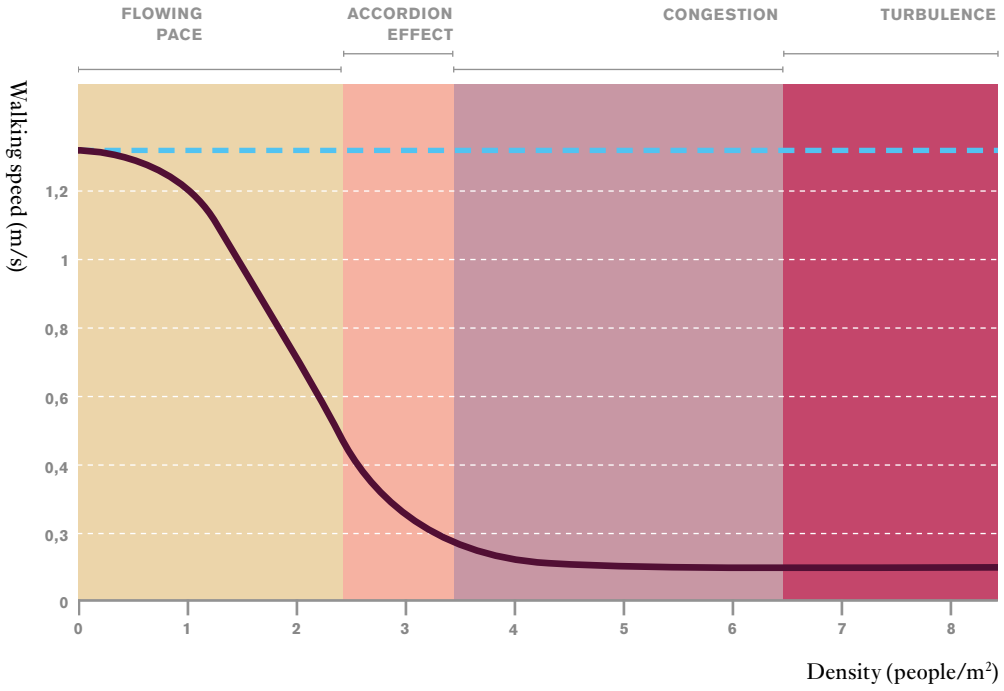
It was a moment when human existence passed into another state. Quite literally. In which it transcended the boundaries of its own corporeality and disintegrated into the flow of the masses. A moment when all hell broke loose.

January 12, 2006. Like every year, more than two million devout Muslims from all over the world made their way to Mecca to symbolically stone Satan and circle the Kaaba, the black shrine in the courtyard of the Great Mosque, seven times. And like every year, pilgrims pushed their way across bridges and through wide corridors towards the holy place, densely packed and hardly able to move on their own. There have repeatedly been deaths – in bad years, several hundred, or even more than one thousand, who succumbed to the masses and were trampled to death. Or those who simply suffocated in the crowd. The Saudi overseers of the ritual were at a loss to find a solution. Someone had to figure out exactly how such disasters occur. And how they can be prevented.

So it came to pass that Anders Johansson, a Swedish engineer and physicist, was able to film for the first time how the mass of pilgrims surged back and forth between the walls of the access roads like an ocean during a hurricane. How it surged up into wave crests, crashed against walls, and buried anyone who wasn't lucky enough to be squeezed out on top. No football stadium or rock concert has anywhere near as many people crowding into one place as the Hajj, the annual pilgrimage to Mecca. By the end of that ill-fated day in January 2006, 363 people had lost their lives.

Mehdi Moussaid has the horrific scenes displayed on his screen. Shrugging, he admits that it is first-class research material. He was still a student when he joined the research team led by Johansson and Dirk Helbing, a physicist and sociologist teaching in Zurich. Moussaid is now 40. And as bad luck would have it: on 24 July 2010, only a few days after he defended his doctoral thesis on the origin of turbulence in crowds at the University of Toulouse, 21 participants of the Love Parade in Duisburg were crushed and trampled to death, and 652 others were injured, some seriously. "With six or seven people per square meter," says Moussaid, "the critical limit is reached and exceeded." In Mecca, there were sometimes nine people per square meter.

He clicks another image onto his screen: bright red grape tomatoes in a wooden frame. Pretty to look at. In time lapse, increasingly more tomatoes are added. It gets increasingly tighter until the first fruits burst and red juice oozes out of them. What began harmlessly ends in disaster. The parallels are abundantly clear. The people in the mass are pushed and fall, every gap closes immediately, and every impulse is passed on and builds up to a powerful surge. "We tend to blame such events on personal shortcomings," says Moussaid. "Youthful recklessness, religious fanaticism, alcohol, and drugs. All nonsense! What happens here follows the laws of hydrodynamics, fluid mechanics, and me-



The denser, the slower: the number of people per square meter determines how fast someone can move. Even with one or two people per square meter, people have to avoid each other and the pace slows down. If the crowd becomes denser, the so-called accordion effect develops, for the only way to move is stop-and-go. If the crowd becomes even tighter, people have to move with the crowd. It becomes dangerous when people are so close that even small movements can cause turbulence.

GRAPHIC: GCO ACCORDING TO MEHDI MOUSSAID/MPI FOR EDUCATIONAL RESEARCH

Grape tomatoes as a model: a tomato almost exactly reproduces the outline of a human body. On an area of 15 square meters, two to three people can stay at a corona distance of 1.5 meters (1). Even with two people per square meter, progress is slow (2). On the S-Bahn, when trains are canceled during rush hour, there are often five people per square meter (3). This crowding is not yet dangerous, as impacts are absorbed by the bodies. A density of eight people per square meter (4), on the other hand, can be life-threatening: at the 2010 Love Parade in Duisburg, 21 people died at this density.

PHOTOS: GCO ACCORDING TO MEHDI MOUSSAID/MPI FOR EDUCATIONAL RESEARCH

chanics alone. Pure physics. It's about formulas. As simple as that."

As an engineer, he came to the interface of disciplines: computer science. But after six months as a programmer and data analyst in the industry, the allure had faded. He wanted to do research. So he studied bees and ants, swarms of birds and insects, and fish at the Behavioral Research Laboratory in Toulouse, worked at the ETH in Zurich at the interface between physics and social sciences, and finally came to Berlin to the Max Planck Institute for Human Development. Director Ralph Hertwig is a psychologist. "I fit in well there," says Moussaid, laughing. "I'm not a specialist in psychology or even computer science or biology – but I am quite adept at moving between these subjects."

How can a school of fish turn in another direction at the same moment? And what is the dynamic of a wave of hate on the internet? How does information about a threat propagate through a phone chain? Like waves in a liquid. Sometimes he almost has to laugh at how far the laws of natural science determine the everyday life of a highly civilized society. But then he gets very serious at the thought of the possibilities of remote control this opens up. It's then about the subtle (and not so subtle) mechanisms of social influence and manipulation. What influence does another's confident demeanor have on one's own judgment? Or the conviction of a large majority? When do people flee their homes? How do people move through a narrow network of corridors? And what influences the choice of an escape route? According to Moussaid, the patterns are remarkably similar. The findings from one field can be transferred to another. The scientist speaks of fouloscopy (derived from the French "la foule" meaning "the crowd" or "the mass"): what the mass says about us.

Mass hysteria stems from imitation

In the shopping mall at Alexanderplatz in Berlin, there is a balcony that offers an unobstructed view of how streams of people meet and glide past each other quite easily and almost elegantly. Moussaid thought he had found an optimal place for his analysis of the highly complex, collectively coordinated patterns of movement right on his doorstep – until the security guards came and escorted him out along with his video camera. They spoke of data protection. Of the right to one's own image. As if he were targeting individuals.

So he developed an experimental set-up, a kind of computer game, in which he sends avatars, proxies simulated on the screen, into a crowd that can be varied at will. The virtual creatures look like wooden mannequins. At the click of a mouse, they can be navigated through winding corridors and narrow passages. Signposts light up, and others push their way forward. The living participants of his studies sit in the same room, each in front of their screens with the other players in sight. Some form of contact must be provided if interaction is to be observed. It's about validity.

As he found out, the jerky, yet fascinatingly synchronous change of direction of a school of herring is not that far removed from the behavior of people in larger groups. The movement of the closest neighbor is a very important stimulus. One knows where to go, and the others follow. Decisive behavior convinces others. Mass hysteria comes from imitation. Increased reward, punishment, a flashing red light, or time pressure creates stress; if the density increases, crowding in front of a narrow exit quickly turns to panic. And of course, the

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PHOTO: DAVID AUSSERHOFER FOR MPG

Committed communicator: Mehdi Moussaid works at the Max Planck Institute for Human Development. In his spare time, he produces YouTube videos in his native language, French, in which he clearly explains his research area.

SUMMARY

The movements of individuals in dense crowds conform to physical laws. Appropriate calculations can help control large gatherings and avoid mass disasters.

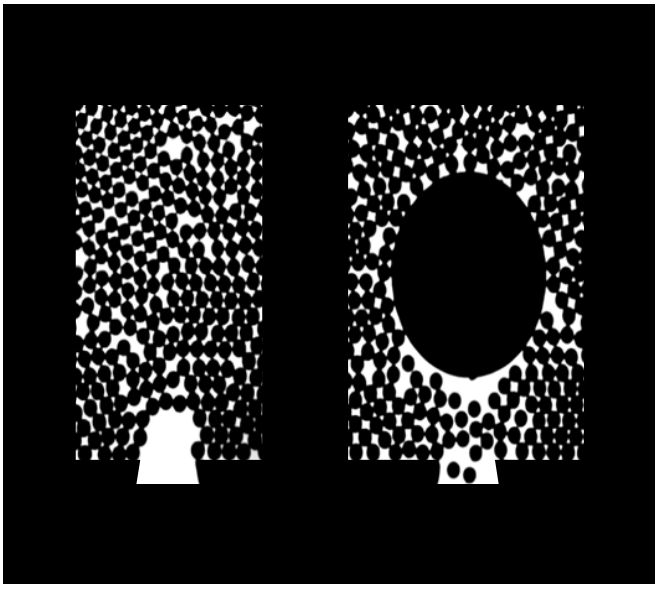
In less dense crowds, psychological factors play the essential role in the behavior of individuals and thus in the behavior of the crowd.

wider the gate, the quicker people are able to escape. Moussaid calls up another image on his screen. There are two funnels into which someone is pouring dry rice: on the right in a surging gush and on the left in a slow and steady flow. And while the grains flows unhindered into the bowl on the left, the grains clog the narrow bottom on the right.

A new film appears on the screen: sheep crowded in their pen in front of a narrow exit. And indeed, the more violently the animals are driven, the greater their fear and the more restless the flock becomes. And the longer it takes them to pass through the exit. "Pure physics," Moussaid says again, but who thinks about the zipper-merging process when deadly danger threatens from behind? He reels off the disasters that have all followed a similar pattern: Heysel in Belgium, Hillsborough in England, and the Jewish festival Lag BaOmer in 2021 in Israel with 39, 97, and 45 fatalities, respectively.

The trauma of terrorist attacks continues to have an impact

The terrorist attack in Paris in November 2015 should be noted as well, when around 1,500 people crowded into the Bataclan concert hall as Islamist terrorists opened fire inside, causing 90 fatalities. A further 40 perished and hundreds were injured during attacks elsewhere in the city, with no escape. And it is hard to imagine what



GRAPHIC: MEHDI MOUSSAID/MPI FOR HUMAN DEVELOPMENT

Helpful obstacle: a barrier just before the exit causes the crowd to divide, making it easier to flow out.

would have happened if the bombers had also stormed the Stade de France football stadium, where 80,000 spectators at the international match between France and Germany heard only the muffled bang of detonating explosive devices. The trauma of the terrorist attacks continues to have an impact today. Sometimes people take flight because they think they have recognized signs of a new attack and sometimes just because others are also running away.

Moussaid is a communicator. He not only determines his findings in concrete situations but also disseminates them that way. He tells stories, illustrates them in vivid and sometimes shocking images, searches for catchy analogies, and lectures with rousing enthusiasm. He writes popular books and articles, enjoys appearing on radio, produces audio books, and runs a YouTube channel in his native France with 300,000 followers. In all honesty: is he perhaps applying his findings on the power of persuasion to his own content?

The routing in Mecca was redesigned

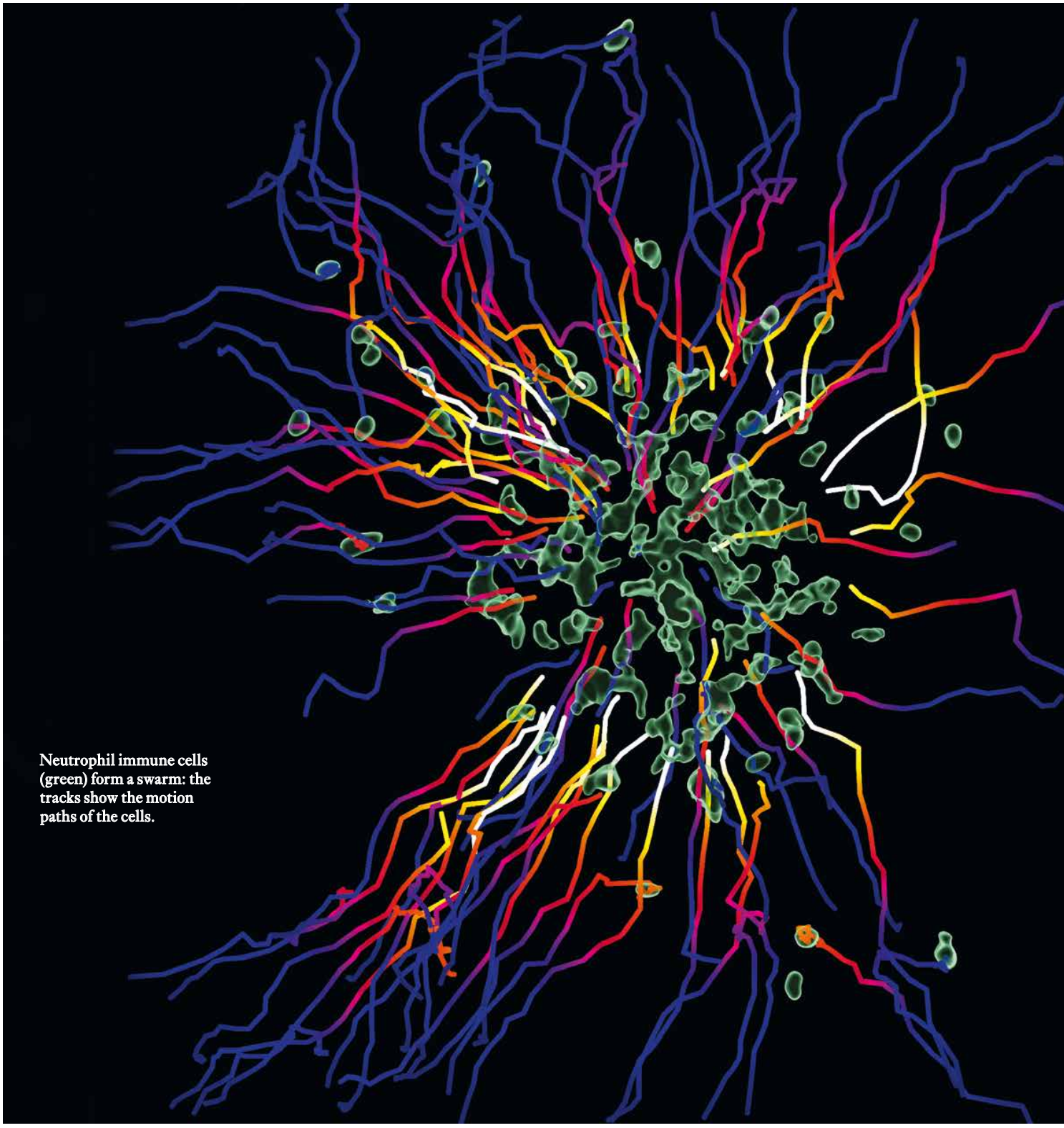
He laughs. His former teachers and colleagues now advise transportation planners and architects. The routing in Mecca was redesigned according to their specifications; a control center monitors the flow rate and density of the stream of pilgrims, and one-way streets divide it up. Bottlenecks in front of which the faithful had piled up like the grains of rice in a funnel were removed. The specialists curb inflow to mass events by opening and closing time windows. They limit access or, seemingly paradoxically, place an obstacle in front of a narrow exit. This obstacle acts like a kind of wave breaker in front of which the flowing mass divides and can then slip out more easily. The principle is similar to the formula used to design a wing to keep an airplane in the air. It is also helpful in preventing disasters.

Moussaid is now entering a research field in which events follow not only the laws of physics but also those of cognition and adaptive rationality, i.e., with fewer than three, four, or five people per square meter. "It's quite fascinating," he confirms as he points to the wooden figures in his virtual mazes. "The sheer number of people determines which scientific discipline provides the best explanations and predictions." Whether they block each other in the crowd or are free to decide for themselves how to behave. Whether they put their own interests before those of the group or give way to each other because they make quicker headway. Collective intelligence – even if someone shouts "Fire!" from behind. Density (also perceived or anticipated density) restricts any freedom of movement.

Did Napoleon really force the inhabitants of the countries he subjugated to swerve to the right side of the road when they encountered each other – so that they would not be able to swiftly draw their swords with their right hands and strike immediately? The person approaching could also be a soldier of the occupying power. "Nice story," says Moussaid, laughing again. "But, unfortunately, only a myth. And one that's hard to dispel." In fact, he says, the heuristic of swerving right or left is the result of a learning process in the social environment. There is a general consensus on which side people should swerve to. Quite simply because collisions cannot be avoided any other way. The rules of the road have some influence – but not a compelling one. It has been verified and proven many times that most people in Central Europe have the impulse to swerve to the right when in doubt. This can be seen nicely in the short film clip from the shopping mall at Alexanderplatz.

For almost 10 years, it seemed that the analysis and correction of the flow of pilgrims to Mecca had ended a chain of fateful misfortunes. Until September 24, 2015. On that day, a glitch in the process caused a panic unlike any seen before. Well over 2,000 people were killed. Was it because, as the Iranian press later claimed, Saudi Crown Prince Mohammed bin Salman had a barrier erected in order to make a convenient path for himself through the crowds? Moussaid is skeptical. For him, any attempt at prediction and prevention eventually reaches a limit. "Such events have many causes," he says. "Usually too many to even identify."

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



Neutrophil immune cells (green) form a swarm: the tracks show the motion paths of the cells.

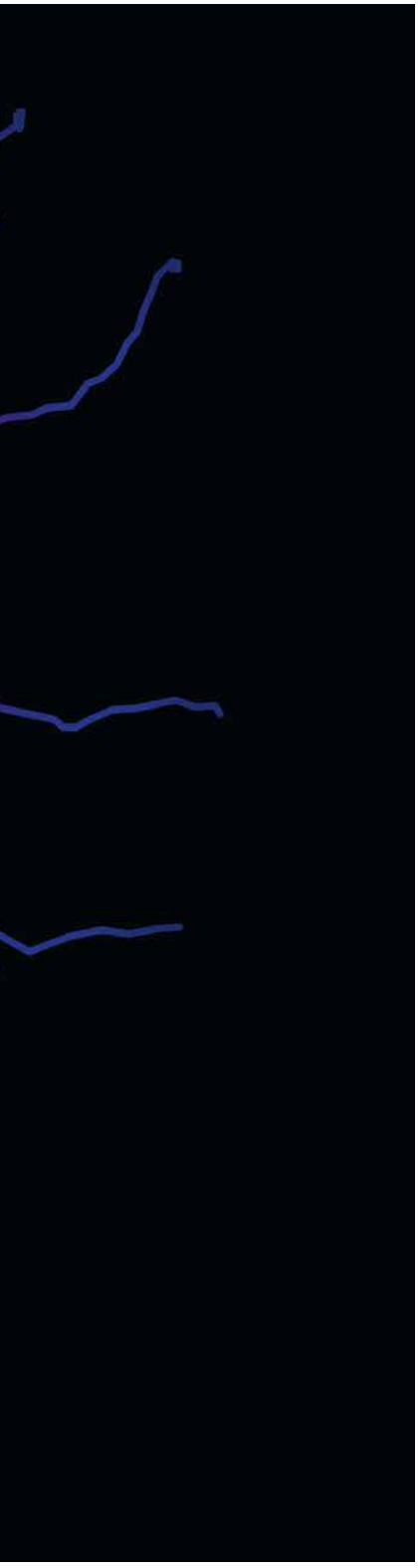


PHOTO: TIM LÄMMERMANN/MPI OF IMMUNOBIOLOGY AND EPIGENETICS

ATTRACTANTS FOR THE COLLECTIVE

TEXT: TIM LÄMMERMANN & HARALD RÖSCH

Max Planck scientist Tim Lämmermann is investigating how immune cells hunt pathogens in swarms. The cells exhibit a behavior that biologists will also be familiar with from an insect – the Asian honey bee.

PHOTO: LENA GIOVANAZZI FOR MPG

Katharina Glaser working on her doctoral thesis in Tim Lämmermann's lab. Here, she is isolating neutrophil granulocytes.

In a battle between females, the Asian honey bee doesn't stand a chance against a hornet. Yet the bee will be able to stand its ground against the intruder – if it calls upon its sisters for help. If an attacking hornet injures a bee, pheromones are released that alert the other female workers in the hive. Large numbers of them rush in and form an impenetrable ball around the hornet with their bodies. The temperature rises so much inside this ball that the hornet is literally "cooked" and dies from overheating.

Although at first glance, immune cells may seem to have little in common with bees, they behave quite similarly when defending. In particular, cells of the innate immune response use the same tactics when they encounter pathogens. Guided by various alert and messenger substances, they converge on the intruders from all directions. Unlike the bees, however, these cells do not kill the intruders by overheating them. Rather, they shield the pathogens off from the surrounding healthy tissue and render them harmless using their chemical weapons. "It is a fascinating finding that the swarm behavior of immune cells and insects follows similar rules to some extent – even though they are completely different entities of life," says Tim Lämmermann.

Hunters and guardians of the immune system

Lämmermann and his team at the Max Planck Institute of Immunobiology and Epigenetics in Freiburg, Germany, are concentrating on so-called neutrophil granulocytes. These immune cells (which are also simply referred to as neutrophils) are created in the bone marrow and patrol throughout the entire body in the blood. As guardians and hunters, they form an important part of the innate immune system and are among the first to be on the scene of inflammation or an infection. Thanks to their flexible form, they move forward like amoebas, slipping through the walls of blood vessels and even dense tissue. By means of molecular sensors on their surface, the neutrophils detect alerts from injured or damaged cells. Intruders such as bacteria, parasites and fungi are killed off by means of antimicrobial substances.

Fifteen years ago, researchers used special microscopy to observe remarkable behavior of neutrophils in different organs of mice: as soon as the scientists induced inflammation or pathogens infected the tissue, these immune cells converged from every direction. They be-

"The swarm behavior of immune cells and insects follows similar rules to a certain extent."

TIM LÄMMERMANN

haved like a swarm and attacked the pathogens in a coordinated way. "Even then, it was obvious that the cells were coordinating with each other, although it was not yet known how they were doing it," recalls Lämmermann. Lämmermann arrived at the topic of swarming immune cells in a roundabout way. After earning his doctorate, the scientist, who carried out research at the National Institutes of Health in the USA initially focused on macrophages. These innate immune cells also hunt down pathogens and eliminate them. "It quickly became apparent that macrophages are 20 to 100 times slower than neutrophils, which made the experiments time-consuming and tedious. Given the snail's pace of the macrophages, my visa would have expired long before I had even presented the initial findings," relates Lämmermann with a wink. Looking through the microscope, however, something else caught the researcher's eye. Apart from the lame macrophages, he noticed that there were also neutrophils constantly flitting through the image. "Compared to the sluggish macrophages, it was a real seething mass. As a result, I quickly switched to neutrophils – a decision that's turned out to be dead right." Fascinated by this behavior, Lämmermann henceforth devoted himself to researching the swarming behavior of these immune cells. Since then, he and his team have gained important insights into how the cells congregate in a swarm and how this disperses again. The latter is crucial for ensuring that the immune response does not go too far.

Together with researchers from other institutions, Lämmermann has identified different phases of the swarm formation. Shortly after an injury, a few neutrophils in the immediate vicinity change their pattern of movement and migrate to the site of the inflammatory response in a targeted manner. This first wave is followed by a second wave of cells from more distant regions of the body. The neutrophils are attracted by a mixture of substances released by damaged or dying cells, which they sense with the aid of around thirty receptors on the cell surface. The researchers have discovered that just one single dying cell is often enough to summon the neutrophils. However, it is not yet understood in detail which alert substances from the location of the tissue damage or dead cells attract the neutrophils in this early phase.

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PHOTO: LENA GIOVANAZZI FOR MPG

With the aid of a stereoscopic microscope, which provides a three-dimensional view, researchers can prepare tissue samples for further examination.

According to Lämmermann's findings, a messenger substance is essential for the neutrophils to subsequently be able to get together in a swarm – that substance being leukotriene B4, or LTB4 for short. Activated neutrophils give off this substance externally, but can also sense it themselves thanks to special receptors. They register changes in the LTB4 concentration in the surroundings and migrate towards increasing concentrations. More neutrophils release more leukotriene B4, attracting even more cells. In this way, neutrophils form impressive swarms in which, in some cases, several hundred cells come together at a location where tissue is damaged. "So neutrophils are not complete loners. They communicate with each other when they form a swarm and thus act as a collective," explains Lämmermann. At the inflammation site, the neutrophils then literally "clutch" each other and form an impenetrable cluster. In doing so, they shield the inflammation site from the surroundings and can thus prevent bacteria, fungi and parasites from spreading in the body. They can then effectively take action against the encircled pathogens.

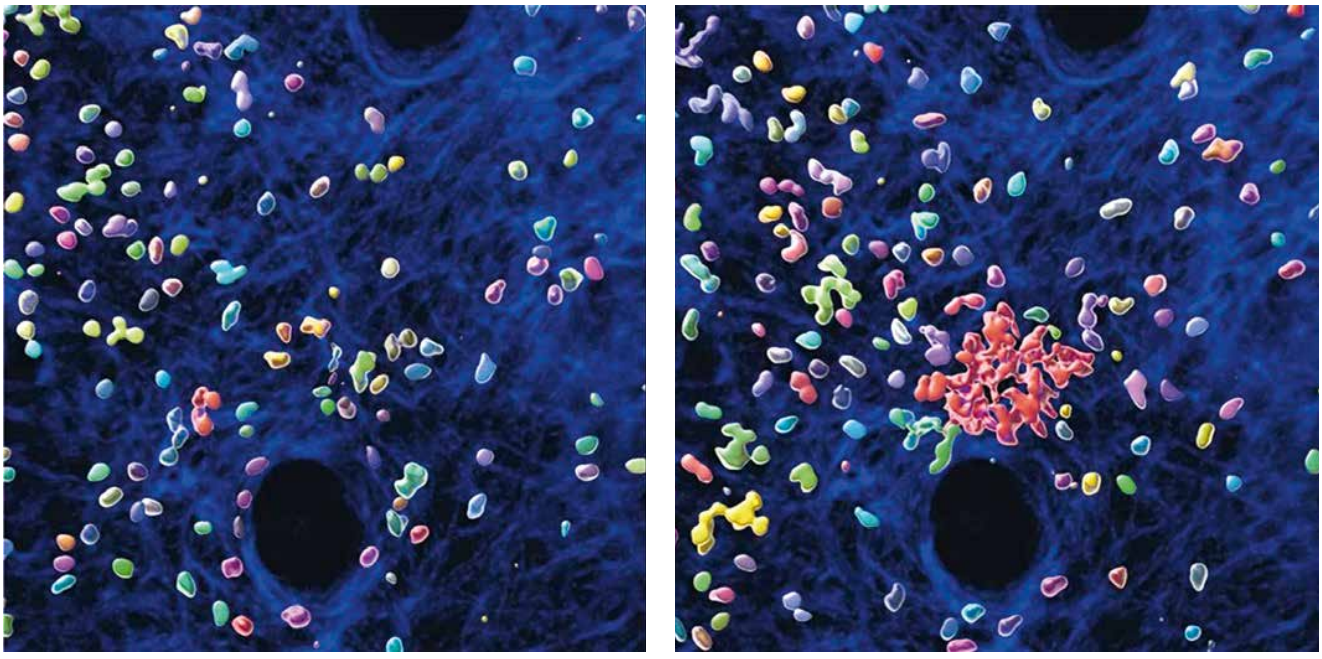
Always follow the attractants

In addition to LTB4, neutrophils also produce the messenger substance CXCL2. This substance, belonging to the chemokine family, also has a swarming effect for these cells. The attractants LTB4 and CXCL2 and the alert substances released by an inflammatory response are, therefore, among the key elements that hold the swarm together. "A swarm of neutrophils follows a simple positive feedback principle," says Lämmermann: "The individual cells move towards the increasing attractant concentration. In this way, even a small group can attract more and more cells and gradually become a swarm." If multiple places in the tissue are "burning", then several adjacent swarms form that sometimes compete for members. The larger ones are at an advantage and simply swallow the smaller collectives.

"The behavior of the neutrophils is reminiscent of the response of Asian honey bees to a hornet attack."

TIM LÄMMERMANN

Focus of inflammation in the skin of a mouse: individual neutrophils, illustrated here in different colors, attract more cells and thus trigger the formation of a swarm (red). There were 30 minutes between the photo on the left and the photo on the far right.



"Consequently, the neutrophils do not need a central authority to direct them; rather, they form a self-organizing system. In many respects, the neutrophil collectives perfectly resemble swarms of certain insect species or even the group behavior of slime molds," says Lämmermann. "According to our findings, however, individual neutrophils do not maintain distance from their neighbors in the swarm, like fish or birds," the scientist adds. After a certain time, the neutrophil swarms disperse again. This serves to prevent the cells from causing damage when they destroy scaffold proteins in their local cluster and literally "eat" holes in the tissue. An immune response that goes too far is often observed in cases of severe inflammation and could be one of the causes of lung damage with severe cases of COVID-19. So the body must balance out the activity of the neutrophils very carefully. In recent years, Tim Lämmermann and his team have, therefore, been increasingly preoccupied with the question of what actually stops the growth of a neutrophil swarm. The researchers' findings show that the cells can even control this behavior themselves and therefore create an optimal balance between the search and destroy phases in the battle against pathogens. "We have observed that, over time, swarming neutrophils become insensitive to their own attractants such as leukotriene B4 – that is, to those signals with which they originally initiated the swarm," Lämmermann explains.

SUMMARY

Some immune cells form swarms of several hundred cells on the hunt for pathogens. In doing so, the cells release substances that attract more cells.

The cell swarms are self-organizing systems that follow a positive feedback principle: the higher the concentration of the attractant, the stronger the attraction.

Over time, the sensitivity of the immune cells to their own attractant decreases. Thus, the swarm can disperse again as soon as the immune response is finished.

This finding came as a surprise because it had previously been believed that messenger substances and signals from other cell types in the tissue would inactivate the neutrophils again and disperse the swarm. Instead, the neutrophil scavenger cells possess a molecular brake that they themselves use to stop their movement as soon as they sense very high concentrations of the accumulating attractants. The brake goes by the name of "G protein-coupled receptor kinase 2" – a protein that ensures that the cells no longer react to the attractant at high concentrations. "This protein causes the attractant signals sensed by the receptors on the cell surface to no longer be transmitted to the cell interior after a certain point," explains Lämmermann. Therefore, neutrophils without this brake continue to react to the attractants, rush around relentlessly in the tissue and thus search an excessively large area for inflammation. As a result, they are unable to combat the pathogens that usually grow at single locations effectively. "Instead of searching around tirelessly, it is far more effective to surround and seal off a focus of infection in the swarm," says Lämmermann.

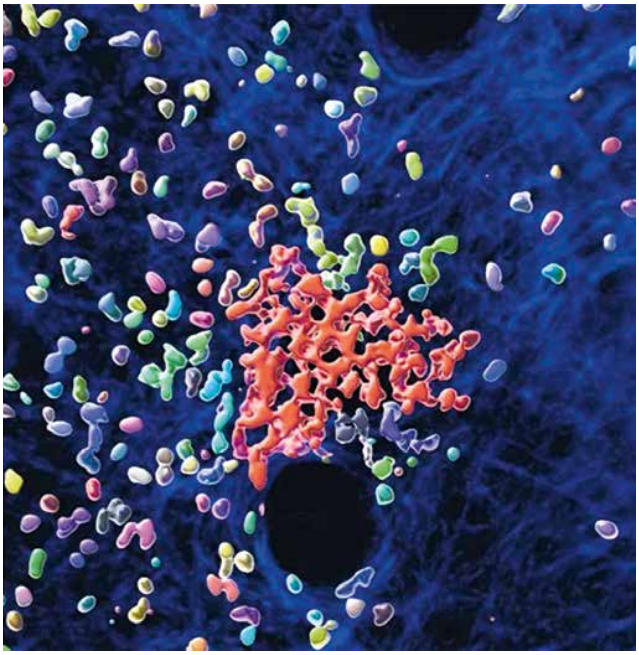


IMAGE: TIM LÄMMERMANN/MPI OF IMMUNOBIOLOGY AND EPIGENETICS

The researchers have thus uncovered an important aspect of the immune defense against bacteria. Their findings provide important stimuli for research into the collective behavior of other cell groups right up to the swarm behavior of higher organisms. "The behavior of neutrophils is actually reminiscent of the response of Asian honey bees to a hornet attack. These bees also behave in a swarm-like way as soon as they smell the substances given off by an injured member of the same species," says Lämmermann. Pheromones emitted by the workers alert other creatures, which then follow the increasing concentration of pheromones and surround the intruder. The hot bee ball resembles the clusters of neutrophils that bring together the antibacterial arsenal of many individual cells in one place. And like the immune cells, the bees do not need a leader; they smell what needs to be done and then simply organize themselves. *www.mpg.de/podcasts/schwarm (in German)*

Two years ago, a new department opened at the Max Planck Institute for Astronomy in Heidelberg in which researchers study the atmospheres of extrasolar planets. Its young director, Laura Kreidberg, has made a name for herself with some of the first observations of these worlds and is one of the lucky ones who will get to observe with the new James Webb Space Telescope.

TEXT: THOMAS BÜHRKE

To be appointed the new director at a renowned Max Planck Institute is a great honor. But in the middle of a Covid lockdown, such a turn of events can be an unexpected challenge. That's what happened to Laura Kreidberg when she wanted to move to Heidelberg in June 2020. "The most difficult thing of all was the preparation," says the young American, "but fortunately we received a lot of help from the institute during this time."

The head of the travel office viewed apartments for them, and the managing director wrote a formal document in which he justified Kreidberg's travel on one of the few transatlantic flights that were currently in service. "It was exhausting, but we made it!" By "we," the scientist also means her husband, who soon found a job at a startup in Germany thanks to his specialty in data science. The job happened to be in Berlin, but this was not a problem as working from home had become standard due to the Covid pandemic. At the time of her appointment, Laura Kreidberg was just thirty years old, making her one of the youngest directors in the history of the Max Planck Society. Her research field of Atmospheric Physics of Exoplanets seamlessly connects to the Planet and Star Formation department, where a focus on the discovery and investigation of extrasolar planets has been established for a long time. Since the spectacular discovery of the first planet orbiting a distant star in 1995, hardly any other field in astronomical research has developed as rapidly as this one. To date, around 5000 exoplanets are known.

The diversity of these bodies, some of which are very exotic, surprised the experts: there are gas planets with temperatures above 1000 degrees, some of which are so close to their central sun that they are literally evaporating; others are made of rock and may be similar to Earth. What these distant worlds are like, what temperature exist on them, or whether they have an atmosphere that can perhaps allow the emergence of life – these are the questions that fascinate Laura Kreidberg, and led her to study astronomy in the first place. Unlike many of her colleagues, it was not the fascination of staring at the night sky through a telescope that got her

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VISIT TO

LAURA KREIDBERG

PHOTO: ANNA ZIEGLER FOR MPG

Difficult shadow play: when a small celestial body passes in front of the sun that it orbits, it covers a tiny part of its surface. The existence of such an exoplanet can be inferred from the resulting decrease in stellar brightness. Laura Kreidberg, director at the Max Planck Institute for Astronomy, studies the geological properties and atmospheres of these objects.

started. "In fact, to this day, I've hardly ever looked through a telescope," she confesses, and she is not very familiar with the constellations either. "When someone asks me to show them where this or that planet that I've been studying is in the sky, I can only shrug my shoulders."

The researcher grew up in the mid-sized city of Reno in the U.S. state of Nevada, which is best known for its casinos. However, its proximity to the Sierra Nevada and Lake Tahoe makes it great for hiking – a passion that Kreidberg still indulges in today. In high school, she became interested in physics because the subject "didn't require as much memorization as, say, biology." Every now and again, she participated in Science Bowls, a competition for young scientists.

Then she learned that someone had studied the atmosphere of an exoplanet for the first time. This was her personal light-bulb moment. "Studying the composition of the atmosphere and the climate on a distant planet places the highest demands on observational techniques and I was fascinated by this," she recalls. "It was clear to me that this was something I could work on for the rest of my career."

For her doctoral research, Kreidberg pounced on the topic, using the Hubble Space Telescope to observe a planet orbiting a star 48 light-years away called Gliese 1214. This type of planet is referred to as a super-Earth, which has no analog in our solar system. Gliese 1214 b is seven times heavier and almost three times larger than Earth, but smaller than Neptune. Astronomers had already tried to analyze

"We've even seen planets orbiting two stars, like Tatooine in *Star Wars*."

There were no scientists in her family, but as a child, she was inspired to ask really big questions by reading her father's popular science books on astronomy. "I remember asking my mom where the edge of the universe was," she says. She was also immensely fascinated by the books of Stephen Hawking and Brian Greene, as they opened up a view of a universe that was as mysterious as it was immeasurable. No sooner had she gotten bored and frustrated by her physics classes – which focused on old, long-solved problems – when another coincidence steered her toward astronomy. She became aware of the work of Nate Silver – a journalist who used statistical methods to analyze the results of baseball games and later applied the technique to presidential elections. "I found that you can also use these methods to address many questions in astronomy," says Kreidberg. "I applied them in my undergraduate research, which was about black hole masses."

the atmosphere of Gliese 1214 b – without getting any clear results. One assumption was that the atmosphere consists mainly of water vapor, which would mean that the planet could also be covered largely or entirely by water – an ocean planet, in other words. However, the new observational data from Kreidberg and colleagues largely ruled out this scenario. The conclusion was that the atmosphere must be covered by dense clouds.

This was followed by observations of other exoplanets, which revealed their diversity time and again. In our solar system, there are the inner, terrestrial rocky planets and then, beyond the asteroid belt, the gas giants. Most other solar systems do not look like this. There are many planets that orbit so close to their central stars that their atmospheres evaporate or the rocks melt into lava. In the case of extremely hot gaseous planets, it was possible to detect clouds composed mainly of metals such as iron, magnesium, chromium, and vanadium.

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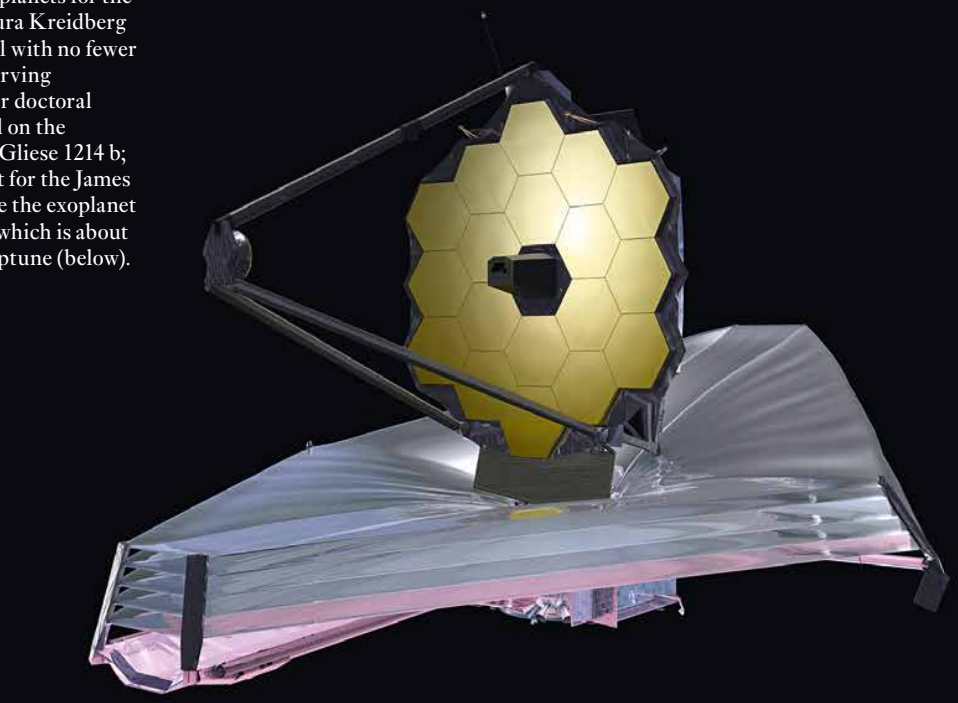
Alien worlds: using the James Webb Space Telescope, researchers will study the atmospheres of distant rocky planets for the first time. Laura Kreidberg was successful with no fewer than two observing proposals. Her doctoral thesis focused on the 'super-Earth' Gliese 1214 b; another target for the James Webb could be the exoplanet Gliese 436 b, which is about the size of Neptune (below).



Earth Gliese 1214 b Neptune Gliese 436 b

GRAPHICS: NASA, DEEP SPACE NETWORK (TOP); NASA, ESA, AND A. FEILD AND G. BACON (BOTTOM).

PHOTO: ANNA ZIEGLER FOR MPG

Dedicated teamwork: Laura Kreidberg places a lot of emphasis on communication in her department. Here she is holding a discussion with her doctoral student Evert Nasedkin.

"We've even seen planets orbiting two stars, like Tatooine in *Star Wars*," Kreidberg says. The zoo of exoplanets boasts a host of exotic specimens.

Laura Kreidberg made a name for herself with her doctoral thesis and other publications; she has also won several prizes. No wonder, then, that she soon had several attractive job offers to choose from – for example, at the renowned Harvard University. Ultimately, there were several reasons for her decision to become a director at the Max Planck Institute for Astronomy in Heidelberg. Here, she has the opportunity to build up her own research group over the long term with fixed funding. Seven of a total of fifteen approved positions have been filled, and she has already acquired additional positions through grants. This is advantageous, as it allows experts from all over the world and different disciplines to work under one roof: observers as well as theorists who can calculate complex atmospheric models. "Research on exoplanets is interdisciplinary," says Kreidberg.

Another important reason was easier access to large European observatories, especially the Very Large Telescope housed in the European Southern Observatory ESO in Chile. It is also set to be joined by what will then be the largest telescope on Earth, ESO's Extremely Large Telescope, by the end of this decade. This will have a concave mirror with a diameter of 39 meters, setting completely new standards in observational astronomy. The Max Planck Institute in Heidelberg is involved in the construction of an instrument that will record both images and spectra in the infrared range. "With support for instrumentation projects from the Max Planck Society, I have the opportunity to make observations with state-of-the-art facilities over a very long period of time," says Kreidberg.

But before this happens, the astronomer will observe with the new superstar on the scene: the James Webb Space Telescope. After years of delays and increasing costs, the ten-billion-dollar instrument finally entered space in December 2021 and reached its destination four weeks later – 1.5 million kilometers from Earth. There, in the deepest darkness, it is expected to surpass the capabilities of the Hubble telescope many times over. "It will be 10,000 times better," Kreidberg enthuses. The mirror, the wavelength coverage, and the spectral resolving power are each ten times better. "By observing in infrared light, we can access much cooler and, therefore, potentially habitable planets than before, and we can also more easily detect a wide range of molecules in the atmospheres of exoplanets."

However, the James Webb is an all-around instrument that is just as well suited for studying distant galaxies, black holes, or faint comets. Accordingly, there is high demand for observation time from researchers. For the 6000 hours available for the first observation cycle, a total of 1172 applications were received from scientists in 44 countries. Of the 266 proposals ultimately selected, one-third came from member states of the European Space Agency (ESA), which is involved with the new super telescope.

Laura Kreidberg emerged from this competition rather successfully: the international committee approved no fewer than two of her proposals. "I had actually written four proposals, which was a really busy time," she says. All details in the proposals had to be worked out to the nth degree. "For a month, I sat at home with my laptop filling out applications while my husband fed me ice cream." The work, and the ice cream bill, paid off. So far, atmospheres could only be detected on hot planets the size of Jupiter, which is why these celestial bodies are also called hot Jupiters. The James Webb Space Telescope is now expected to make the breakthrough and provide access to the atmospheres of smaller rocky planets. The problem in all cases is that the star is thousands of times brighter than the nearby planet and outshines it.

This is also the case with an exoplanet called Trappist-1 c, which Kreidberg chose for her observations with the space observatory. Forty light-years away, this rocky planet is only slightly larger than Earth but orbits its star at such a close distance that its temperature is similar to that of Venus. "This body is the coolest terrestrial planet we can detect heat from with JWST," the astronomer says. "We want to find out if it has an atmosphere."

The first step will be to do this in an indirect way because the star and planet themselves cannot be observed separately with James Webb. The brightness of the star and planet are measured together in the infrared range where the planet emits thermal radiation. As the planet passes behind the star, the heat emanating from its surface or atmosphere is blocked.

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The brightness of the planet can be determined from the change in the total brightness, and from this, its temperature can be derived. This process is strongly dependent on whether an atmosphere is present or not. Without an atmosphere, all the starlight hits one hemisphere and heats it very intensely. But if the planet is surrounded by a thick atmosphere, the gas envelope transports heat from the hot day side to the cooler night side balancing it out. The day side is not as hot with an atmosphere as it is without. Hence such a measurement provides an indirect indication of an atmosphere.

search for volcanic basalts, solidified magma surfaces, and granite – all indicators of crustal reprocessing and tectonics. "We also want to look for traces of sulfur dioxide as a result of volcanic outgassing."

One of the overarching goals of exoplanet atmosphere research is to detect biosignatures on Earth-like planets. Most commonly cited in this regard is the simultaneous presence of oxygen and methane. Normally, these gases react quickly with each other to form carbon dioxide and water. "So if we see the

"We want to look for traces of sulfur dioxide as a result of volcanic outgassing."

Should this observation indicate the existence of an atmosphere, Kreidberg will request a complementary measurement for the next round with the James Webb; this time with a spectrograph. As the planet passes in front of the star, some of the light passes through the planet's atmosphere whose molecules leave their fingerprints in a spectrum. "This allows us to determine, for example, whether the atmosphere contains water, methane, or carbon dioxide," she says.

As recording a spectrum is time-consuming, it makes sense to do this only when the previous brightness measurement has confirmed that an atmosphere exists in the first place. While planning her JWST observations, the astronomer discovered a fun fact about the telescope. The color filter she will use to observe TRAPPIST-1c is part of a filter wheel whose mechanics were developed and built by the Max Planck Institute. "Yet another reason to come here," says Kreidberg with a grin.

The second rocky planet she will observe, LHS 3844 b, is also slightly larger than Earth but has a temperature of +770 degrees and probably has no atmosphere. In this case, the aim is to understand the geological conditions of a terrestrial planet for the first time. Kreidberg plans to use the James Webb to

two gases at the same time, this means they are constantly being produced and replenished by something, and that something on Earth is life," the Max Planck director says. However, even the James Webb will probably fail in this task. Oxygen, in particular, leaves only a very weak spectroscopic signature. In addition, clouds in the atmosphere could make such observations difficult.

The question of what other biomarkers might exist is currently highly topical. We know, for example, that Earth's atmosphere contained hardly any oxygen until about 600 million years ago, but life did exist, albeit primitive life. This means that the atmosphere at that time had different biomarkers than the atmosphere today. Perhaps it will be possible to detect these on other planets in the years to come.

In any case, the scientist is convinced that life exists somewhere out there. Again, as with exoplanets, there could be much greater diversity than we imagine. "To search for signs of life in the atmospheres of distant planets, we need even better telescopes – and patience," says the astronomer, summing up. At NASA and ESA, the search for biomarkers is a top priority. Plans are already underway for next-generation space telescopes that could launch in the 2040s. "So, before I retire!" says Kreidberg, laughing.

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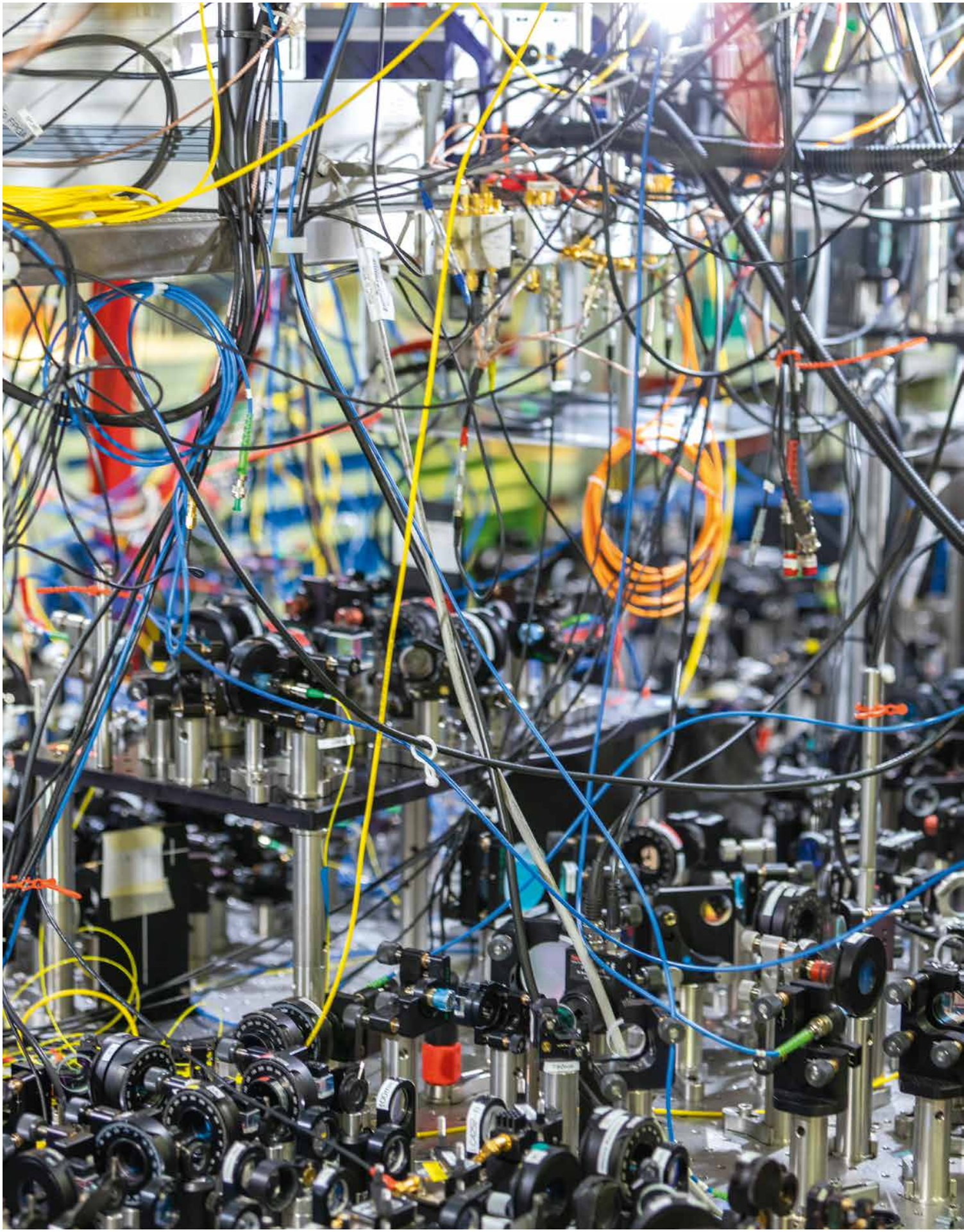

PHOTO: AXEL GRIESCH

DOUBLE TAKE

MAX PLANCK INSTITUTE OF QUANTUM OPTICS

The smaller the research object, the more complex the apparatus: this tangle of colorful fiber-optic and black power cables, lasers, numerous mirrors, and other optical instruments is needed to handle individual atoms. This allows two atoms (this page) to be positioned, manipulated, and imaged in a resonator: a tiny cavity between two mirrors. Atoms in resonators could serve as switching points in a quantum internet in which quantum information is exchanged in a spy-proof manner via fiber-optic cables.

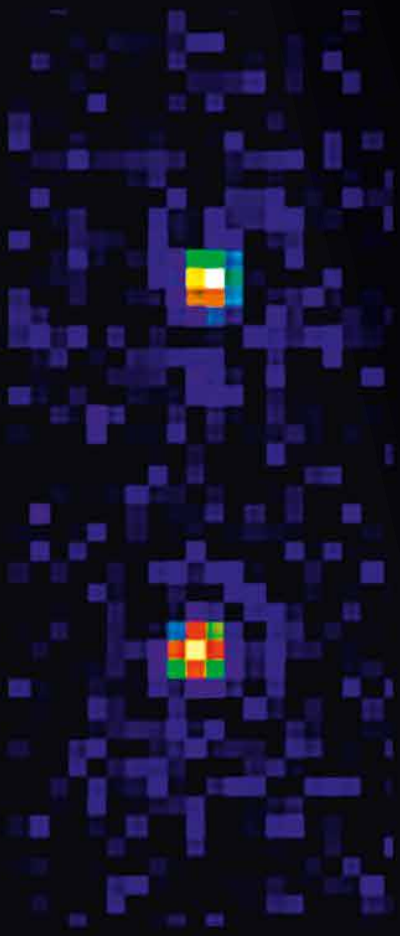

IMAGE: MPI OF QUANTUM OPTICS

LAND OF PLENTY IN THE MEDITERRANEAN SEA

TEXT: KLAUS WILHELM

At the Max Planck Institute for Marine Microbiology in Bremen, Marcel Kuypers' and Nicole Dubilier's departments are unraveling the mysteries of seagrass meadows. Their discoveries have been astonishing: microorganisms play a crucial role in the fitness, productivity, and element fluxes of plants, not just on land, but also in the sea.

If you enjoy swimming in the sea or walking along the shore, you might be familiar with seagrass as unpleasant debris: the long, gray-green leaves often wash ashore en masse in the fall and after storms. At the coast of the Baltic Sea, for example, a thick carpet of seagrass is part of the beach scene – just like the dredgers that remove the plant debris. On the other hand, researchers, are just beginning to understand the real value of these underwater meadows.

Seagrass meadows are common in the shallow, coastal regions of the temperate and tropical seas worldwide. They cover about 600,000 square kilometers, an area larger than France. They are the foundation for an ecosystem that is home to many animals including endangered species like sea turtles, seahorses, and manatees, and provide a safe nursery for several species of fish.

Seagrasses are flowering plants and, unlike algae, form true roots. These roots keep them firmly anchored in the seabed protecting the coasts from erosion. Seagrass meadows produce vast amounts of oxygen and, every year, take up millions of tons of carbon dioxide, which they store as 'blue carbon.'

These underwater meadows are thus not only of immense ecological importance, but they also play a key role in the global climate. Until recently, relatively little was known about the microorganisms associated with seagrass. In their joint work, scientists at the Max Planck Institute for Marine Microbiology in Bremen have now shed light on the matter. Their expeditions to the Mediterranean Sea provide astonishing new insights. In particular, the question of how carbon storage in the ocean actually occurs has not been unveiled so far. The "Symbiosis" department of the Max Planck Institute in Bremen, headed by Director Nicole Dubilier, has now revealed a mechanism. Several years ago, research group leader Manuel Liebeke analyzed the metabolome of gutless worms native to a seagrass meadow off Elba in the Mediterranean Sea. The metabolome includes all of an organism's or ecosystem's molecules that are somehow involved in metabolism – amino acids, sugars, fats, and many more. To everyone's amazement, the researcher detected enormous amounts of plant sugars in the worms. Where could they have come from?

"We suspected the sugars came from the seagrass," Liebeke says. To investigate the source, the researchers sampled water from the root environment of seagrasses at several locations – off the coast of Elba, but also in the Caribbean. "To sample interstitial water from different regions next to and below the seagrass, we penetrate the sediment with a thin metal lance and use a large syringe-type collector," the scientist described the procedure. The samples are then shipped frozen to the Bremen laboratory as quickly as possible for analysis. The crux: the salt in the seawater would interfere with the measurements of the metabolites in the sample.

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PHOTO: HYDRA MARINE SCIENCES GMBH

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BIOLOGY & MEDICINE

Playground for marine researchers: scientists from Bremen's Max Planck Institute for Marine Microbiology study seagrass beds of the species *Posidonia oceanica* off the coast of Elba.

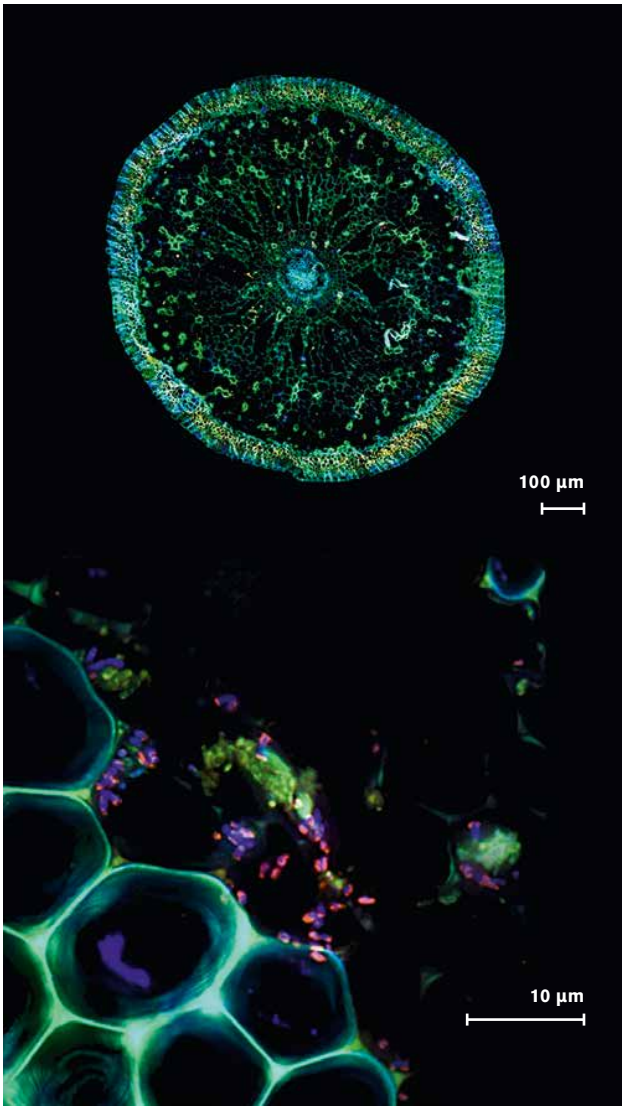

IMAGE: MPI FOR MARINE MICROBIOLOGY/DANIELA TIENKEN/SOEREN AHMERKAMP

Intimate partnership: microscopic images show a cross-section of a seagrass root (top) and a section of the root interior (bottom) showing the symbionts (in pink).

Dubilier's colleague at the time, Maggie Sogin, took the lead in developing a method to initially remove the troublesome salt. The sample is then transferred to a gas chromatograph coupled to a mass spectrometer that records the chemical compounds in the pore water sample. This snapshot reveals which molecules are present and in what quantities. "In our pore water samples, there was always a gigantic peak that came from the sugar sucrose," says Sogin, who now works at the University of California, Merced. Never before had such masses of sugar been detected in the sea: "It is eighty times more than what is usually found in seawater," explains Dubilier. To put it into perspective: the researchers estimate that globally there are one million tons of sucrose in the sediment beneath all the seagrass beds in the world's oceans – a massive amount of sugar.

An overflow valve for energy

Physiologically, the release of sugars by the seagrass is most likely a mechanism to manage excess energy – similar to an overflow valve. But how can so much sucrose accumulate in an ecosystem? In the largely oxygen-rich environments on land, legions of microorganisms immediately pounce on the sugar and break it down. Most of the sediment in the root zone of seagrass meadows – called the rhizosphere – is, however, free of oxygen. But there are enough specialists among the microbes that can also cope with this. It took a while for the scientists to come up with the solution to the riddle. An insight from their worm research proved helpful: one of their colleagues had discovered that microbial symbionts living in gutless worms can break down phenols – chemical substances found in red wine, dark chocolate, tea, and berries, and are known for their antibiotic properties. This put the Bremen team on the right track: could the seagrass be producing phenols that prevent bacteria from devouring the sugars? The researchers launched a series of experiments that clearly proved that the seagrass actually produces phenols and releases them into the sediment, along with the sugar! These substances prevent many species of bacteria from utilizing sucrose. However, some microorganisms have adapted to the low-oxygen but phenol-rich situation and can still use the sugar. Thanks to this ability, they live unrivaled in a land of plenty.

The team of the "Biogeochemistry" department, led by director Marcel Kuypers, has been researching seagrass beds for about ten years. Kuypers' coworker Wiebke Mohr and her colleagues recently found out why seagrass can thrive in the Mediterranean despite its low nutrient content: in its roots, it maintains a symbiosis with a bacterium that provides the plant with the nitrogen it needs. The habitat of many seagrasses is low in nutrients for much of the year. In its molecular form, nitrogen is abundant in the ocean, but seagrasses are unable to utilize it in this form. The reason the plants grow luscious is due to their microscopic helpers that fix the dissolved nitrogen gas within the roots and make it available to the plants in a usable form. Together with colleagues from Hydra Marine Sciences in Bühl and the Swiss Aquatic Research Institute Eawag, the Bremen team investi-

gated the organization of this intimate relationship between the seagrass and the bacterium. Until that point, the assumption was that the fixed nitrogen came from bacteria living in the sediment of the rhizosphere. "We've demonstrated that this relationship is much closer," Mohr says. "The bacteria live right there in the roots of the seagrass."

Nitrogen-fixing bacteria

This is the first time such a close symbiosis with nitrogen-fixing bacteria has been shown in seagrasses. Until now, it was only known from land plants: in particular, agriculturally important species such as legumes, wheat, and sugarcane receive nitrogen with the help of bacteria and in return provide them with carbohydrates and other nutrients. A very similar exchange of metabolites also takes place between the seagrass and its symbionts.

The bacteria that live in the plant roots are a new discovery. Mohr and her team named them *Celerinatantimonas neptuna*, after their host, the Neptune grass *(Posidonia oceanica)*. Relatives of *C. neptuna* have also been found in marine algae, such as kelp. "About a hundred million years ago, seagrasses colonized the sea from land. Back then, they probably adopted the bacteria from the large algae," suspects Mohr. "They copied the system that was highly successful on land. To survive in low-nutrient seawater, they acquired marine symbionts." The studies by the Bremen team bridge the entire ecosystem from seagrass productivity to the symbionts responsible for it in the root system. Research methods such as on-site oxygen measurements are revealing the productivity of the seagrass meadow. Special microscopy techniques such as fluorescence in situ hybridization (FISH) make it possible to color-code individual bacterial species and locate symbionts among the root cells of seagrasses. The bacteria's activity can be detected in the NanoSIMS, a state-of-the-art mass spectrometer. Genome and transcriptome analyses reveal the mechanisms likely to be important for host-symbiont interactions.

SUMMARY

Seagrasses produce vast amounts of sucrose, which they store in the sediment. This sugar forms a large carbon reservoir for otherwise climate-damaging carbon dioxide.

Seagrasses' roots house symbiotic bacteria that supply the plants with vital nitrogen.

Other microbes contribute to the production of methane – a greenhouse gas – in seagrass sediments. This methane is released even when the plants have already died

The study also provided evidence that the seagrass community maintains a seasonal rhythm – depending on the supply of nutrients in the coastal waters. In winter and spring, the nutrients available in the water and sediment are enough for the seagrasses. "The symbionts are then present sporadically in the roots of the plants but are probably not very active," Mohr says. In summer, when the sunlight increases, more and more algae grow and consume the nutrients. Then nitrogen also becomes scarce. At this stage, the symbionts take over and provide the seagrass with the nitrogen they need. This is how seagrasses can reach their largest growth in summer, when nutrients are most scarce in the environment.

Seagrass beds play an important role in the carbon cycle and, therefore, in the climate for two reasons: they are highly productive ecosystems and at the same time, a natural source of methane. As a PhD student in the "Greenhouse Gases" research group led by Jana Milucka, Sina Schorn is investigating the activity of methane-producing microorganisms including those in the seagrass beds of the Mediterranean Sea. Just like their land-based relatives, seagrasses form large peat deposits beneath the sediment surface during their growth. On land, peat releases large amounts of methane during the microbial decomposition of the organic material. The same happens underwater: methane, the simplest hydrocarbon, is also a greenhouse gas – and a far more potent one than carbon dioxide. In addition to protecting the climate, seagrass beds hence also have a climate-damaging impact that partially offsets the blue carbon effect. It was unclear for a long time, how the methane is formed. Schorn and her colleagues initially suspected that in seagrass beds, the gas is produced in the same way it is in terrestrial ecosystems. This made it all the more a surprise when the researchers took a closer look at the mechanisms of methane production: "In the sediments of seagrass beds, methane is produced only from a specific group of organic compounds," the microbiologist explains. These so-called methylated compounds are produced by the seagrass plant itself. Specialized microorganisms – the methanogenic archaea – then take care of the conversion to methane.

Methane from dead plant matter

The methylated compounds include betaine, for example – a molecule that helps seagrasses cope with the fluctuating salinity of seawater, and its breakdown products, such as methylamines. Because methanogenic microorganisms can use methylamines

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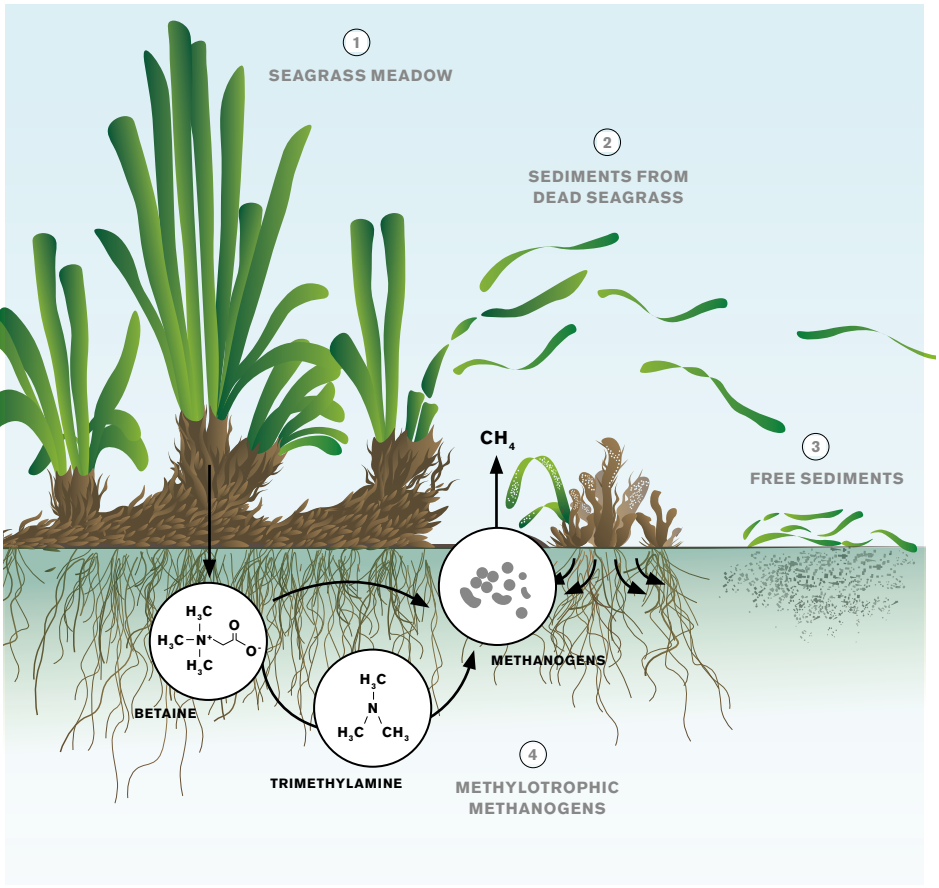

1) Neptune grass *(Posidonia oceanica)* produces a variety of methylated compounds that get broken down by microorganisms. Methane (CH_4) is produced in the process.

2) Plant parts in the sediments of dead seagrass beds release methylated compounds over long periods of time.

3) Detached seagrass leaves deposited on free sediments are also a source of methylated molecules.

4) A diverse community of microbes – called methylotrophic methanogens – lives in the sediment releasing methane directly from methylated compounds (such as betaine) or from their breakdown products (such as trimethylamine).

GRAPHIC: GCO, SCHORN, S., AHMERKAMP S. ET AL.. DIVERSE METHYLOTROPHIC METHANOGENIC ARCHAEA CAUSE HIGH METHANE EMISSIONS FROM SEAGRASS MEADOWS. PNAS, VOL. 119 | NO. 9, MARCH 1, 2022

directly, methane production in seagrass beds is highly efficient and methane is released very quickly. As if through a straw, the gas passes from the seabed, through the plant tissue, and into the water. Because seagrasses only grow in shallow marine areas, microorganisms have little opportunity to break down the methane before it escapes into the atmosphere. "Moreover, the methane literally gets washed out of the sediment by the force of the waves," says Milucka.

In the course of their study, the Bremen researchers sampled productive seagrass beds but also one that had already died. The latter revealed another surprise: "The rates of methane production there were similar to those in an intact seagrass meadow," Milucka explains. "The reason for this sustained methane release is probably that the methylated compounds persist in plant matter for a very long time." They were even still found in plant tissue that had died more than two decades ago.

Taken together, the Bremen scientists' findings show that seagrass beds play an important yet widely underestimated role in climate change. At the same time, the underwater meadows are under severe threat: as nearshore habitats, they are particularly affected by human-induced changes. Above all, they are affected by overfertilization of the oceans from agriculture and aquaculture. Large amounts of phosphorus and nitrogen lead to excessive algae growth: the seagrasses can no longer obtain sufficient light and die off. In addition, more and more recreational boats anchor on seagrass beds and holes torn into the vegetation often do not close again. At a growth rate of only a few centimeters per year, underwater meadows regenerate very slowly.

The greatest threat, however, is global warming: Neptune grass, for example, is very sensitive to heat. Just a few more degrees will induce physiological stress in the plants and increase their die-off rate. "We're currently experiencing a die-off of seagrass beds worldwide with devastating effects on coastlines," says Milucka. This is fatal for the climate for two reasons: "Our findings show that after the plants die, carbon dioxide is no longer sequestered from the atmosphere and stored in the sediment as blue carbon. On top of that, methane continues to be released."

Coastal regions as carbon reservoirs

The new findings make it clear that seagrass beds deserve far greater attention than they have received so far.

The Bremen-based scientists continue to work closely across multiple groups to improve our understanding of this fascinating habitat. Within the German Marine Research Alliance (DAM), the Max Planck Institute for Marine Microbiology is involved in a variety of projects focusing on coastal regions – by investigating, for example, how much carbon can be stored in seagrass meadows on German coasts. For this purpose, several institutions have joined forces in the sea4soCiety project.

Max Planck researchers Manuel Liebeke and Jana Geuer are involved in analyzing which carbonaceous substances the plants produce and release into the water: "We've already measured hundreds of different compounds," Liebeke says. Next, they aim to find out how stable these molecules are under stress, such as under strong UV light or at elevated temperatures. This is crucial for the fate of carbon: "The idea is to target coastal ecosystems that produce as many stable carbon compounds as possible over the long term," Liebeke explains. Reforestation of destroyed areas could also be conceivable if the coastal conditions allow it. With long-term planning, the Bremen researchers are also ensuring the future of their research on seagrass beds. To this end, a new research collaboration has just been launched in the western Mediterranean on the island of Mallorca. With half a million Euros funding from the Max Planck Society, the Portocolom lighthouse will serve as an outpost for Bremen's seagrass research in the future. Together with the Mediterranean Institute for Advanced Studies IMEDEA in Esporles, the German and Mallorquin scientists are planning long-term observations and detailed studies of the seagrasses and the habitat's many inhabitants. As the Max Planck Institute in Bremen has shown impressively, it's not just forests on land that count for climate protection – but also marine ecosystems such as underwater seagrass meadows.

←

GLOSSARY

ARCHAEA
Unicellular microorganisms without a nucleus. Along with bacteria and eukaryotes, they form a third domain of life within biology.

BLUE CARBON
The carbon stored in marine/coastal ecosystems.

RHIZOSPHERE
Region of the soil that is directly surrounding the plant roots.

SUCROSE
Disaccharide consisting of one molecule each of glucose and fructose.

PHOTO: ACHIM MULTHAUPT FOR MPG

Out of the sea and into the laboratory: Sina Schorn examines samples of Neptune grass *(Posidonia oceanica)* collected off the coast of Elba. Her doctoral thesis is researching methane-producing microorganisms in seagrass beds.

More light in the shadows: researchers are studying migrant communities in Germany in an effort to fathom the rules and norms they live by.

PHOTO: PICTURE ALLIANCE/DPA | ROLF VENNENBERND

ON THE FRINGES OF THE RULE OF LAW

TEXT: JEANNETTE GODDAR

In Germany's diverse society, law and order are not just overseen by the police and the courts. There are communities that have their own means of settling disputes: family clans with foreign roots, for instance, but also motorcycle gangs and so-called *Reichsbürger* (Reich citizens), who turn their back on the modern German state and long for a return of the days of empire. Hatem Elliesie of the Max Planck Institute for Social Anthropology in Halle and Clara Rigoni of the Max Planck Institute for the Study of Crime, Security, and Law are studying this phenomenon.

Back when he was working on his PhD, Elliesie embarked on an unusual journey in his investigation of the underpinnings of the law. As a lawyer as well as a scholar in the fields of Islamic and African studies, he traveled through a number of countries in the Horn of Africa, sometimes on foot. His aim was to find the treaty under which Italy declared modern Ethiopia a protectorate in 1889. The Italian version is well known. Elliesie was instead interested in the Amharic version of the document drafts. In discussions conducted in Amharic and Tigrinya over many cups of tea, the native Swabian finally hit pay dirt – and was able to demonstrate that key passages in the Amharic edition were worded completely differently than those in the Italian version on which Italy had relied.

That was a long time ago. However, it shows just how a lawyer with a PhD in Semitic studies found himself right at home at the Max Planck Institute for Social Anthropology in Halle surrounded by field researchers in the area of sociology. Since 2018, Elliesie has been leading a research group there under Marie-Claire Foblets, Director of the Department of Law and Anthropology, that is examining German law from a number of angles. It set up a project called "Conflict regulation in Germany´s plural society" with the aim of asking German civil servants about how people in immigrant communities resolve their problems and disputes: do they contact their nearest police station or go to court? Or do they instead appeal to councils of elders, heads of families, Islamic Hakam (justices of the peace), or even clan bosses?

Search for victims and witnesses

This phenomenon goes by a snappy name in the news: parallel justice. Why so controversial? The first objection is obvious: justice is exercised by the state, which, by its very nature, expects the term to apply only to its institutions. The second is more complex: "'Parallel' would imply that people go about their lives in completely separate worlds," explains Elliesie.

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PHOTO: PICTURE ALLIANCE/DPA | ROLF VENNENBERND

Clara Rigoni, Senior Researcher at the Max Planck Institute for the Study of Crime, Security, and Law, has spent more than ten years studying the relationship between immigrant communities and governmental authorities.

"But this happens only very rarely." Instead, he says, people decide on who to turn to on a case-by-case basis depending on what they want to achieve. Some dispute situations are also often split up into judicial and extra-judicial elements. "This is simply another type of so-called 'forum shopping'," says Elliesie. "It's really not all that unusual. Most of our everyday disputes are settled informally."

That view stands in direct contrast to a book that was the impetus for the research project. Its name is "Richter ohne Gesetz. Islamische Paralleljustiz gefährdet unseren Rechtsstaat" ("Judges Outside the Law: Islamic Parallel Justice is Threatening the Rule of Law in Germany"), written by Joachim Wagner, the long-time anchor of the NDR news show Panorama. A little more than ten years ago, the journalist and lawyer set out to interview judges, public prosecutors, and social workers, as well as Islamic organizations and Hakam. He paints a bleak picture: there are social settings in Germany that operate exclusively according to their own laws. Wagner claims that German judicial authorities have essentially capitulated to parallel justice, particularly Islamic variety. The book served as a wake-up call to the maximum effect: state governments all across the country commissioned studies. The German Judicial Academy and the State of Bremen created a continuing education course called "Recht ohne Gesetz, Justiz ohne Richter - Die Welt der 'Schattenjustiz'" ("Law without statutes, judiciary without judges – The world of 'shadow justice'"). Even Germany's largest state, North Rhine-Westphalia, got involved. In 2019, Mathias Rohe, a professor at Friedrich-Alexander-Universität Erlangen-Nürnberg who has spearheaded research in the translation of Islamic law into present-day Germany, was tasked with writing an expert opinion on family law. Moreover, the Max Planck Institute for Social Anthropology was asked to conduct a study on areas with relevance to criminal law. The latter was undertaken by Hatem Elliesie in collaboration with Clara Rigoni, a senior researcher at the Max Planck Institute for the Study of Crime, Security, and Law in Freiburg. For more than ten years, Rigoni has been studying the relationship between immigrant communities and governmental authorities in European countries. Together, Rigoni and Elliesie looked at what employees in the judicial administration and prosecutor's offices know about the phenomenon of "parallel justice", how they assess it, and how they deal with it.

It's a delicate matter when a government commissions research: just how unbiased will it be? "We were given contacts and access to records of witness examinations and court files. North Rhine-Westphalia had no influence on the results," says Elliesie. In collaboration with the Ministry of Justice and supported by the Ministry of the Interior – so the official wording – the Max Planck researchers conducted 40 interviews with judges, prosecutors, and investigators, reviewed more than 60 written questionnaires, and examined numerous court files. One key question interested them: were there cases where victims or witnesses refused to give any statement at all – or suddenly stopped cooperating at trial? "That is normally evidence of a settlement taking place outside the German judicial system," explains Rigoni. Follow-up questions included: What reasons played a role? Was the family involved? Were there indications of organized crime? Was money at stake? Extortion, intimidation, bribery?

Biker gangs and *Reichsbürger,* too

The discussions brought some surprising things to light: not many employees in the judicial administration and prosecutor's offices had confronted such situations. "Although we wrote to a lot of people, we didn't get many replies," says Rigoni. Even assuming that public prosecutors and judges are

sidestepped at times when disputes are settled out of court, there was no evidence that the practice is widespread. The cases that were reported involved very different groups, many more than those described by Joachim Wagner: for example, motorcycle gangs, such as the Hells Angels or the Banditos, or self-appointed *Reichsbürger.*

Lots of money at stake, pressure, or violence

Where the research group found evidence of and stories about out-of-court dispute resolution, they discovered that all of them had in common a "strongly felt sense of solidarity and loyalty obligations". There were three relevant contexts: first, groups characterized by family ties (often extended families); second, groups whose members feel closely bound by a shared national identity, including some immigrant communities and also, for example, Reichsbürger; and third, people who pursue common interests, such as motorcycle gangs.

And Islam? "In criminal law, religion plays hardly any role," says Rigoni. "We didn't hear of any group that exists solely because all of the members are Muslims." Even in cases in which Islam-aligned Hakam, i.e. the justices of the peace, were called upon, they mostly applied traditional rules from the country of origin. Rigoni points out that there are also Hakam who are paid for their work. But it is also true, she says, that the aim of "reconciliation", which sounds so peaceful, isn't always the best possible solution for all parties: "There can be a lot of money at stake, psychological pressure, physical violence, intimidation," says Rigoni.

IIn family law, by contrast, Mathias Rohe found social settings among the Muslim population where "religious beliefs are adhered to, especially in the area of marriage and divorce." But when examined more closely, here as well, the main focus is not on religion. Rather, as he states in his expert opinion, "mechanisms anchored in socio-cultural values" are employed. What does that mean? "Legal conceptions are based on three pillars," explains Elliesie. "On Islamic law – or on what people consider it to be – on customary law, and on German state law." Where these three areas collide, he says the following can normally be seen: "When a dispute arises between

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PHOTO: MPI FOR SOCIAL ANTHROPOLOGY, CARLO DIESTERBECK

Hatem Elliesie, a lawyer as well as a scholar in the fields of Islamic and African studies, leads a group at the Max Planck Institute for Social Anthropology that is studying dispute resolution in Germany's plural society.

Outside the law: some branches of the Hells Angels motorcycle gang are frequently targeted by investigators. The accusations range from weapons possession to extortion and drug dealing, even murder. During a sweeping police raid in 2017, the North Rhine-Westphalia State Criminal Investigation Department seized leather jackets and weapons of a group called Clan 81 Germany.

PHOTO: PICTURE ALLIANCE / DPA | ROLF VENNENBERND

the Imam's recommendation and what the heads of the families believe, the traditional conception of the law almost always prevails," he reports. The upshot: disputes are resolved in accordance with traditional values as understood in the communities and not by relying on the classical understanding of Sharia.

No right to work legally

Two PhD students and three postdocs are conducting research, expected to be concluded at the end of the year, on the norms and values that people live by in Germany's plural society. They are studying communities composed of people of Syrian, Chechen, Yazidi, and Afghan origin, as well as groups affiliated with the Mhallami, better known as Lebanese Kurds. They include the kinds of extended family associations called "clans", particularly in the area of organized crime. When Elliesie talks about them, he sheds light on the background of a life that is lived, at least in part, in self-created structures: "The Arabic-speaking Mhallami come from the region around Mardin in the south of Turkey", he explains. "In the 20th century, many of them emigrated to Lebanon. They weren't accepted there as citizens or given access to education." In the 1970s, to escape the Lebanese civil war, many Mhallami fled to Germany where history repeated itself in some respects: "Here as well, they remained marginalized. For decades, they were tolerated in terms of residency law, but they didn't have the right to pursue lawful work."

And how are the young researchers received in the communities that don't always have the best relationship with German authorities? "Amazingly well," says Elliesie. "If anonymity and data protection are safeguarded, people are very willing to describe their own views." Unfortunately, however, a lot of that may have to do with the choice of researchers: all five, who spent a year living among the communities examined, speak both German and the language of their community on account of their own origin. They know the social and cultural codes, meaning they can speak with community members on equal terms and at the same time also read their non-verbal communication. To this extent, the research project also tells a story about the growing – and necessary – diversity in science. Despite the often patriarchal structures that the researchers need to navigate, gender apparently does not play a role: Elliesie reports that one of the female researchers was even permitted to attend a meeting of the council of elders: "These meetings essentially resemble the proceedings before a German court. The council of elders relies on case files to decide on matters involving the community." The researchers are reluctant to make judgments. "We know hardly anything about how people structure their lives in this country. Just describing the situation is an enormously difficult task," says Elliesie. The findings are to be published in a joint book next year.

Cultural competence is needed

Elliesie and Rigoni presented their study – "Paralleljustiz in Nordrhein-Westfalen aus strafrechtlicher Sicht" ("Parallel Justice in North Rhine-Westphalia from a criminal law perspective") – in Düsseldorf last March. The study ends with a series of recommended actions whose aim is two-pronged: "On the one hand, the proposals are intended to facilitate the work of the judicial authorities and the police. On the other, they can help to give people unrestricted access to government agencies where this is lacking," explains Rigoni. The researchers recommend that evidence be collected at an early stage, for example, through videotaped witness examinations by the police that can later be admitted in court, but also that programs be set up to protect witnesses and victims, as well as those who have broken ties with the community. However, these steps would have to be tailored to fit the people as well as the cases, says Rigoni: "Where family disputes are involved, the approach is much different than with organized crime outside of blood relationships." They also urge that judicial authorities and the police be given greater advanced training while also making the communities concerned more familiar with German law.

The recommendations can be broken down into a simple formula: in a society where people with many different backgrounds live side by side, there needs to be a willingness not only to get acquainted with one another but also to learn to understand one another. "That can't happen without cultural competence," says Rigoni. As Elliesie puts it succinctly, "Communication is everything."

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SUMMARY

The kind of "Islamic parallel justice" often portrayed in the media does not exist in an institutionalized form.

Out-of-court dispute resolution occurs in some extended families and in certain groups bound by national identity or shared interests.

Traditional rules determine how the law is understood; disputes are sometimes resolved by resorting to violence, psychological pressure, or money.

The researchers recommend more educational outreach directed at immigrants on legal topics as well as programs to protect witnesses and victims and better advanced training for police and judicial authorities.

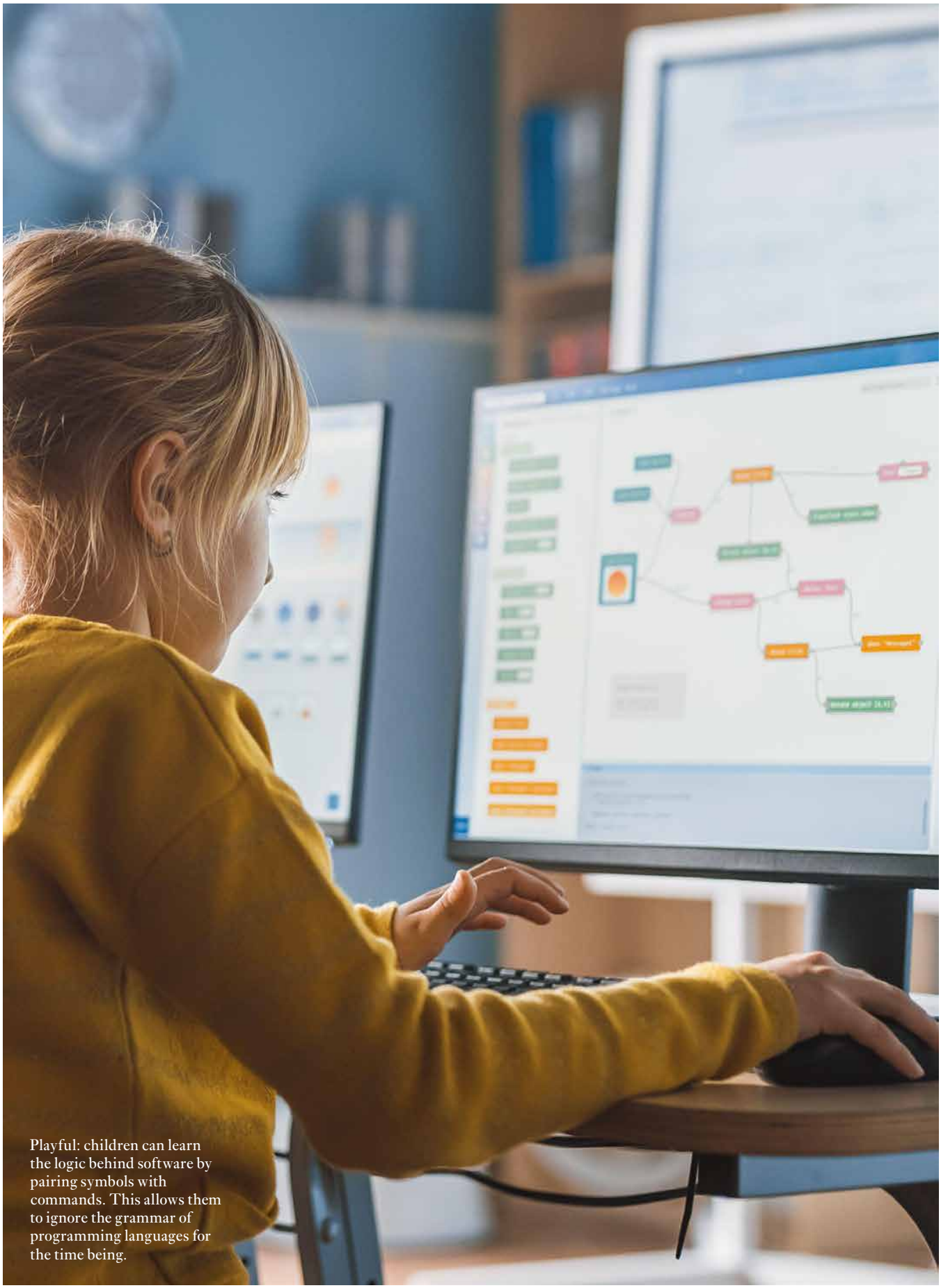

PHOTO: ALEKSEI GORODENKOV / ALAMY STOCK PHOTO

Playful: children can learn the logic behind software by pairing symbols with commands. This allows them to ignore the grammar of programming languages for the time being.

MACHINE TEACHING

TEXT: THOMAS BRANDSTETTER

Artificial intelligence has the power to support people in an ever-increasing number of areas – including education. Researchers at the Max Planck Institute for Software Systems are working under Adish Singla's leadership to find methods to help children learn how to program. These algorithms can, however, also be used in other areas.

Intelligent machines are about to transform society. Not only do they outperform us in chess and Go, but they also translate texts, can assist in making medical diagnoses, and drive our cars. Rather than simply carrying out the commands of their human creators step by step like earlier computer programs, this artificial intelligence learns new skills by analyzing vast amounts of data on its own. In keeping with this concept, the machines are now set to make the step from machine learning to machine teaching and will also be used as intelligent tools in the classroom. This would mean that students could soon be learning how to program machines from the machines themselves.

Beginners usually start out learning programming in a fun way with simple picture elements. Millions of children have already written their first programs in this way through initiatives such as Hour of Code. Researchers at the Max Planck Institute for Software Systems are now going one step further. "We aim to improve children's learning experiences with software that employs artificial intelligence to help learners when they get stuck," says Adish Singla, who is the head of the Machine Teaching group.

Software like this could change school education significantly: "In the classroom of the future, human and digital teachers will work hand in hand," says Maria Wirzberger, professor of teaching and learning with intelligent systems at the University of Stuttgart. However, digital systems can only ever be used to supplement normal classroom activities; they are in no way intended to push human teachers aside. Only humans are capable of truly connecting with students and responding to them intuitively – software is not capable of that. "But software that is designed to provide support can help cover the times when the teacher can't be present," Wirzberger says. For instance, the digital assistant would be able to pitch in during periods of self-directed learning and distribute tasks to learners that are tailored to their needs. It's unlikely that a single teacher would be able to prepare twenty different worksheets for twenty students. "An AI-based system is able to do this very well based on the children's ability profiles," explains Wirzberger. But humans should stay in charge and intervene when specific problems arise. Ultimately, this frees up more resources for providing individual support – both for the weaker students and for the particularly talented ones who can be set extra tasks by the software.

The president of the German Teachers' Association, Heinz-Peter Meidinger, holds a similar opinion. "It all depends on the teacher," he stresses. The teacher is the greatest source of motivation for the students. In a society that is, or will be, increasingly shaped by digitalization and AI, it is also extremely important that these topics are also addressed in schools. "This is both in terms of a teaching subject in which the effects are explored but also as a teaching medium," Meidinger says. Nevertheless, he does not see artificial intelligence as the ultimate solution to all the current problems of the school system, such

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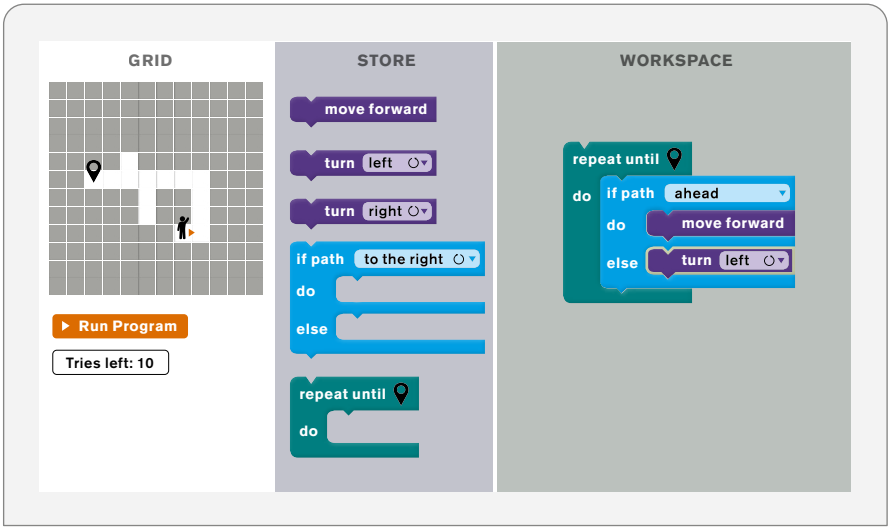
as the shortage of teachers, educational injustice, inclusion, and integration. "In my experience, piling too much expectation onto such new developments always ultimately leads to disappointment."

Meidinger also sees potential for AI in the classroom primarily based on its ability to adapt the difficulty of tasks to the learners' needs. However, he believed that it is also important to realize that this will lead students to different levels of proficiency. "I am very supportive of personalized support for talent, and AI could provide an opportunity to take particularly gifted students deeper into subject areas than has been possible to date," Meidinger says. "At the same time, however, there will also be those who, despite artificial intelligence, will have a much lower level of progress." Ultimately, individual support also always leads to a greater range of abilities. "At the end of the day, we still have a school system that operates based on grades, qualifications, and graduation certificates," Meidinger points out. "So it has to be incorporated appropriately."



GRAPHIC: GCO ACCORDING TO WWW.TEACHING-BLOCKS-HINTS.CC

Block programming: in this task from the Hour of Code initiative, students must correctly string together commands to guide a figure along the white path to a destination. If they encounter difficulties in doing so, a program from the Max Planck Institute for Software Systems provides them with tips and presents them with further tasks tailored to their comprehension needs.

SUMMARY

Algorithms can be used in programming classes to create tasks tailored to individual learners and help them find solutions. This involves setting sub-tasks that specifically aim to improve students' understanding of the steps they are struggling with.

The approach can also be extended to other subjects, such as mathematics, where open-ended conceptual problems need to be solved.

The software will be able to support teachers, but not replace them. Teachers will continue to be the main motivators and will need to intervene in particularly difficult cases. Machine learning methods will, however, provide them with more time to provide individual support.

AI holds a virtual tutorial

Learning to program is particularly well suited to the use of AI in the classroom. One typical exercise for young beginners involves guiding a figure on the screen along a specific path to a destination. This requires precise instructions on how far the figure should move straight ahead on the chessboard pattern behind it, for example, and which direction it should then take. Educators prefer to use block-based, visual programming techniques to introduce children to problems like this. This saves beginners the trouble and frustration that difficult-to-understand written commands and subtleties in syntax (such as the difference between square brackets and curly brackets) can cause. Instead, the children arrange predefined blocks that have short instructions and pictures in a row, enabling them to intuitively instruct the figure to do what they want it to. A typical example of this would be an instruction to keep taking a step forward as long as the path continues in that direction. If the path eventually turns left or right, then another command is required. This allows children to focus their full attention on the logic underpinning the problem and playfully develop an approach to computer-based thinking.

Adish Singla and his team in the "Machine Teaching" research group at the Max Planck Institute for Software Systems in Saarbrücken are continuing to develop exercises like this with artificial intelligence. In 2020, the researchers presented an algorithm that automatically generates exercise tasks using machine learning methods. "Once a student has solved a problem and moved the figure to the target location, we give them another, similar task that they can then use to reinforce what they've learned," says Adish Singla.

Singla's research team is meanwhile working on an AI-powered virtual tutoring system that will also provide children with direct help in solving a particular task. The system will recognize that a student is struggling with the task and try to help them by providing hints. The earlier version of the software simply corrects errors, presenting the correct solution right away, so that the student can continue

working from that point. That is already a great help when it is needed – but it can be even better.

"What we're working on today is much more advanced," says Singla. "The software now helps children with personalized multiple-choice quizzes when they get stuck." In other words, the algorithm develops a small subtask on its own and offers several possible solutions to the problem in order to help the learner get up to speed. It's as if the artificial intelligence were to say, "Think a bit more about this part!" which prompts the child to take action themselves and stay in control. "This is much more motivating than simply fixing a mistake," explains Adish Singla. The challenge for the software, however, lies in being able to identify the simplest task that will allow the child to understand the concept that is causing them difficulty.

Everyone can evaluate the software

"It's not easy to automatically create an appropriate quiz," Singla says. After all, he says, that is a small programming task of its own. While there is theoretically a multitude of possibilities for developing a sub-task like this, only a few of them also have meaningful, interesting solutions that can be used to clarify the unclear programming concept. "One key aspect of our current work is to be able to automatically figure out which misconception underlies the mistake," Singla says. This is the only way the software will be able to help learners correct their misconceptions on their own. Singla and his team are focusing their work on the underlying functionalities of the software. By incorporating AI, they want to make it possible for students to work with it even when no one is around to help them.

Although they are limiting their current work to programming instruction, the methods being developed by the researchers can be applied more broadly, for example, in mathematics. "Essentially, we are trying to develop AI that can help students solve open-ended conceptual problems," Singla says. After all, he says, it is particularly challenging for both the learners and the artificial intelligence when there is no predetermined approach to solving a task. "It's also important for the software to motivate learners and keep them engaged," says Maria Wirzberger. Small, human-like figures that provide clues or important feedback can help with this. "Playful elements can also provide motivation, such as when mathematical puzzles have to be solved in order to find treasure," says Wirzberger. Only when all these aspects come together can a piece of educational software be successful.

The German Teachers' Association, however, would like to see empirical research support the use of AI-supported learning software in Germany, for example, by testing the new methods in model schools. "In the end, the only thing that counts is improving children's education and learning success," says President Heinz-Peter Meidinger. And if it works well, the new technology should then of course be used across the board. Such an approach reflects the spirit of the researchers. That's why Adish Singla's team is already releasing the software online so that everyone can try it out and help evaluate it. This way, the machine assistants will be gradually prepared for their use in the classroom. ***www.teaching-blocks-hints.cc***

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Georgios Tzannetos, Adish Singla, and Ahana Ghosh (from left) discussing how they can enhance the software that supports students by using artificial intelligence.

PHOTO: MATS KARLSSON FOR MPG

Cool computer: the Finnish–German company IQM is developing quantum computers that use superconducting circuits known as Squids to compute. These are cooled with such a cryostat to temperatures close to absolute zero, which is minus 459.67 degrees Fahrenheit.

PHOTO: ADOBE STOCK/BARTEK WRÓBLEWSKI

QUANTUM COMPUTING'S LEAPS AND BOUNDS

TEXT: ROLAND WENGENMAYR

With the expectation that they will be able to solve problems that stump even today's best computers, both governments and private financiers are investing heavily in the development of quantum computers. The team led by Ignacio Cirac, a Director at the Max Planck Institute of Quantum Optics in Garching, is researching what computers will actually be able to do in the years to come. As the research reveals, not all hopes are likely to be fulfilled so soon.

Ignacio Cirac should actually have reason to be enthusiastic. The Director at the Max Planck Institute of Quantum Optics in Garching near Munich is a pioneer in the development of quantum computers. With the aid of quantum physics, these computers will be able to process some tasks, for example, in logistics or the development of new drugs and materials, much faster than today's computers. This hope is driving state institutions to enter a practical bidding war when it comes to their funding of quantum technology – and especially quantum computing. The German government has earmarked two billion euros for this area from 2021 to 2025, the U.S. government has also pledged about a billion dollars over four years, and the EU Commission has invested about the same amount in a flagship program that will run for ten years. However, China is outdoing them all by spending ten billion euros in one swoop on an institute for quantum information science. In addition to numerous startups, large companies such as Google and IBM are also competing in the race to create the first quantum computers – and they accompany every advance with a certain amount of media furor. The companies and their investors are putting hundreds of millions of euros into developing quantum computers.

So Ignacio Cirac's research field is clearly booming – a fact that not only inspires enthusiasm in the physicist, but also a certain anxiety. Like many of his colleagues who are well versed in the field of quantum information, he fears this hype about quantum information technologies could soon turn into disinterest should there be a lack of success. "The field is not only being driven by researchers but now also by investors," says Cirac. But, he says, they might not have enough patience. Given the enormous technical challenges, Cirac expects at least another ten-year, if not a twenty- to thirty-year wait before truly application-ready universal quantum computers will hit the scene. "But the hype won't last that long," he stresses, "and in the end, when quantum computing isn't ready in time, we scientists will get the blame." The great vision of the future is universal, i.e., freely programmable, quantum computers. They are the counterpart of digital computers. In a similar manner to digital bits, they calculate with

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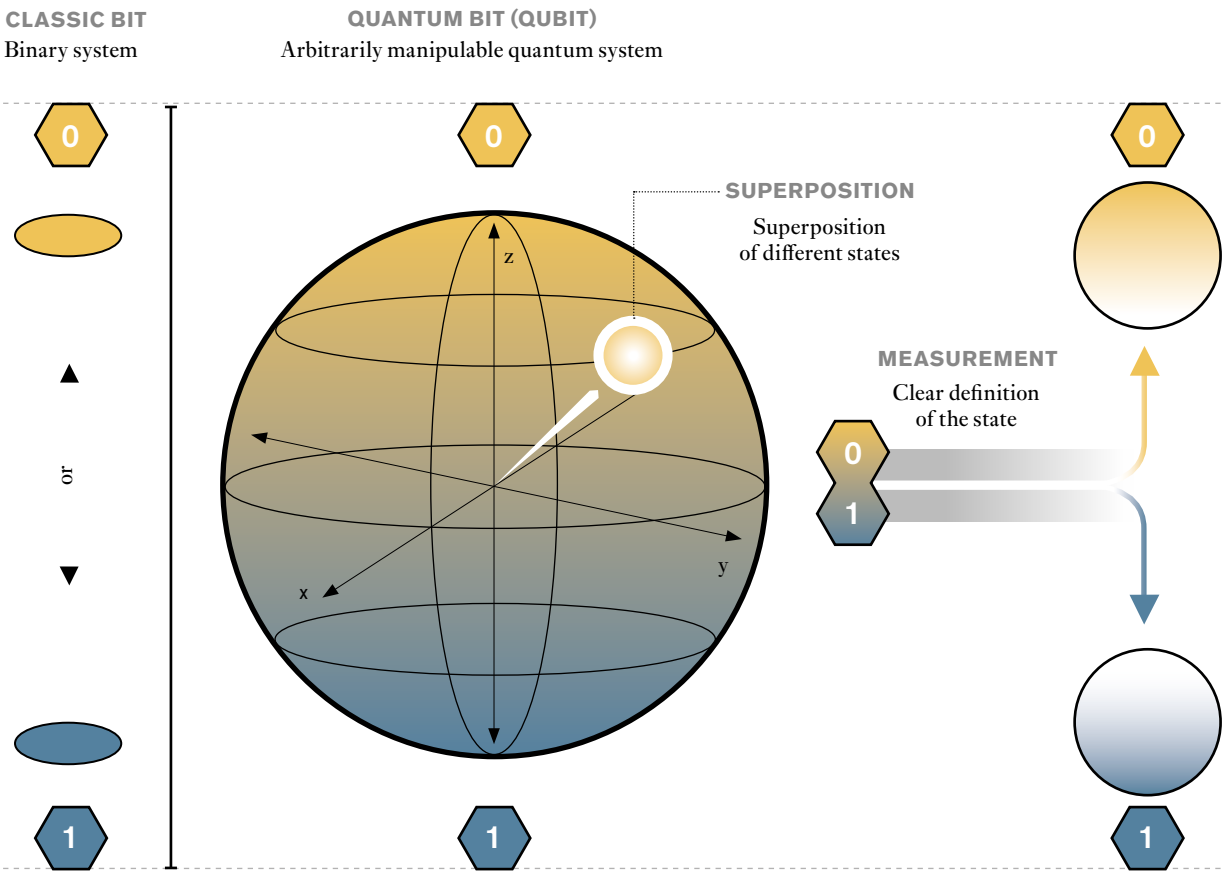

GRAPHIC: GCO AS PER VOLKSWAGEN AKTIENGESELLSCHAFT 2019

Ambiguous bit: unlike a classical bit, a quantum bit can also assume superpositions of the states 0 and 1, which can be represented by the coordinates x, y, and z on a sphere and occur with a certain probability during a measurement. Since this means that quantum computers can test different solutions in parallel, they should be able to handle some tasks faster than classical computers.

quantum bits or qubits for short. When it comes to certain tasks, their computational power stems from the rules of the quantum world: unlike a digital bit, a qubit cannot just assume either the states 0 or 1 but can also be in a superposition of both states. In addition, multiple qubits can also be superpositions which are called entangled states. This entanglement forms the arithmetic unit of a quantum computer.

There could be many applications for a universal quantum computer. "One typical example is the traveling salesman problem," says Cirac. The traveling salesman has to visit a certain number of cities and wants to calculate the shortest route. "Now, how does the computing time required by a digital computer for this grow with the number of cities?" the physicist asks, and immediately comes up with the answer: "It grows exponentially!" This is typical of such combinatorial problems, he says, and they manifest themselves in a variety of ways with one example existing in the technology that makes computing times on conventional computers explode. And not only that: the memory required for computing can snowball.

We've all seen how something can explode exponentially during the Covid pandemic. This is illustrated by the

legend of how chess was invented. Enthusiastic about the new game, the king wants to give the inventor a reward of his own choice. The inventor who, unlike the king, is mathematically gifted, thinks about this and then wishes for rice according to the following rule: for the first square of the chessboard, one grain of rice, for the second two grains, and then for each subsequent square, always double the number. Mathematically, this results in the number 2^{64}-1 for 64 squares on the board, which looks harmless as a power in this form but is in fact immense. The king would have to give the chess game inventor a quantity of rice equivalent to around two thousand times the world's current annual production.

Such an exponential explosion also makes solving tasks from fields of physics and chemistry difficult – but quantum computers could handle these quite soon. One example is when it comes to specifically developing new active medical ingredients or new materials, such as practical materials that conduct electricity without resistance. If you want to calculate the properties of chemical reactions of molecules and materials as precisely as possible, you inevitably have to take quantum properties into account. Or to put it more precisely: the complex interaction of electrons. Even a present-day supercomputer cannot calculate the behavior of such a quantum many-body system. Hence, programs used for material development, for example, use highly simplified approximation models. Their predictive power is correspondingly underdeveloped. In principle, quantum computing can enable much more precise material design. The underlying idea goes back to the American physics Nobel Prize winner Richard Feynman. The idea states that if you want to precisely calculate a quantum system, you must take an adapted second quantum system that is suitable as an adequate substitute. But unlike the hardly accessible object of study, such as the electron collective in a superconductor, this second quantum system must be easily controllable from the outside in the same manner as a computational device. This is exactly what a quantum computer excels at, namely as a quantum simulator.

Simulators for physics research

If you compare this to the history of classical computers, quantum simulators are the counterpart of analog computers. These were highly specialized computers that simulated, for example, the aerodynamic properties of an aircraft under development. Unlike digital computers, which process information in portions as bits, analog computers continuously reproduced a particular system, for example, mechanically or electronically. Analog computers had their golden age when digital computers were not yet so powerful. Today, in the early stages of quantum computing, the situation is similar. For a while now, quantum simulators have been becoming increasingly interesting for tackling at least basic physics research questions. For example, this is being researched by Immanuel Bloch's group. He is also a Director at the Max Planck Institute of Quantum Optics with whom Cirac's team is also collaborating.

As much separates the quantum simulator, which is available today or will at least be in the near future, from the universally programmable quantum computer as does an old analog computer from today's PC. Cirac's team is, therefore, pursuing a dual strategy. Some of the algorithms being developed by the Garching-based researchers will only be able to run on powerful, error-corrected universal quantum computers in the distant future. The rest should be usable as soon as possible on the already available quantum computers with relatively few qubits and demonstrate the first advantages, in particular in quantum simulation. "We want to show that you can already do something useful on quantum computers that you can't do on classical computers," Cirac says, "for example, predict the properties of some new materials." To achieve this, he is also cooperating with Google Research.

Several physical systems are competing in the quantum computer hardware race. Immanuel Bloch's group, for example, uses ultracold atoms as qubits; these are trapped in a spatial lattice of laser beams and controlled by laser light. Google, on the other hand, is developing chips that use tiny superconducting circuits as quantum bits. In 2019, Google researchers used one such quantum processor called Sycamore, which contained 53 working qubits, to demonstrate for the first time that a quantum computer computes a task better than the most powerful conventional supercomputer. "However, this was a purely academic task with no meaningful application," says Cirac about this celebrated breakthrough. And Markus Hoffmann of Google Research in Munich compares it to the Wright brothers' first powered flight hop: "This flight has gotten us to the first island that couldn't be accessed before – but this island is still barren." He also stresses that Google Research is realistic about the technical development level of quantum computers, but he is also optimistic. Google expects the next milestones to be a hundred superconducting qubits, then a thousand, and finally – in about a decade – a million.

The limits of quantum computers

Even a hundred qubits would allow application in materials development. If you want to precisely calculate the properties of a microscopically small piece of superconductor, which are determined by a hundred strongly interacting electrons, you end up with a problem that has 2100 unknowns. This is far more than the universe has stars and would conceivably over-

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whelm all conventional large computers. A quantum computer, on the other hand, would need only a hundred entangled qubits to solve the task. But how will it do this?

Mari Carmen Bañuls, a senior researcher in Cirac's department, attempts to explain the procedure: "You write your instructions into the quantum bits that prepare them in a particular quantum state." The task to be computed, which uses a particular quantum algorithm, lies in the way the quantum bits are initially entangled. "Then you allow the system to develop for a certain amount of time," the physicist explains, "and then you take a measurement to get the result." This is, in a way, comparable to cooking in a pressure cooker: you put the ingredients in, close the pot, and start the cooking process. After the time stated in the recipe, you check to see if the stew was a success. During cooking, only the pressure indicator provides information about what is happening in the pot – but at least you have that.

In the quantum world, you are not even allowed a display like this while the entangled qubits are doing their thing. And this is where another peculiarity comes into play: quantum information is extremely sensitive. Even a minimal intervention is the equivalent of a measurement that causes the entanglement to collapse immediately. So, you must not take a look until the time specified in the quantum recipe is up, in other words: make a measurement, and then – maybe – get the desired result. This is because quantum mechanics has another peculiarity. It only describes probabilities with which certain quantum states occur. Hence a quantum computer would not return 1 + 1 = 2 but would output the result 2 only with a certain, but precisely calculable probability. This is another indication that the use of quantum computers will only be useful for special tasks for which such uncertainty is tolerable or there is no alternative.

Cirac's team is also exploring what those tasks might be. Because, despite the bold visions of the future, a great deal is still open here: "We're also investigating what quantum computers *can't* do," Cirac emphasizes. This, he says, is to prevent valuable resources from being wasted on unachievable goals.

SUMMARY

Governments and companies are currently investing heavily in the development of a quantum computer that could solve some tasks much faster than the best computers available today.

It may be decades before there is a universally programmable quantum computer, mainly because its calculations can be very error-prone and quantum information is very sensitive. Researchers at the Max Planck Institute for Quantum Optics, among others, are therefore working on error correction and validation of quantum calculations.

Today, quantum simulators can already be used for investigations in basic physics research. Soon, they could also facilitate the development of new materials and drugs.

After all, even a universally programmable quantum computer cannot solve arbitrary problems. And to fulfill the hopes placed in this computer at all, the one million qubits targeted by Google in around ten years will not even be enough. This is not least due to the difference between physical and logical qubits, as Google researcher Markus Hoffmann explains. One example of a physical quantum bit is an atom suspended in a light lattice or a microscopic superconducting circular current. But because these physical bits are so susceptible to interference from the environment, there is a plan to combine several physical qubits into one logical qubit to store quantum information in it in a much more stable way. In superconducting technology, as Google is exploring, a logical qubit would consist of a thousand synchronized physical qubits.

In a universal quantum computer, many ancilla quantum bits distributed between and around the logical qubits will be added. They will measure disturbances as additional sensors. All of this is intended to answer the challenge that the actual logical qubits may not be checked for errors while they are in the process of computing, which is what a conventional computer would do. A test would be a prohibited measurement, but based on the information from the ancilla qubits and the results of the logical qubits, the algorithm can make meaningful error correction

Such concepts for a universal, error-corrected quantum computer are estimated to come with a large price tag. "That amounts to maybe a hundred million physical qubits," Cirac says: "A quantum computer like this would fill our entire institute with its vacuum and cooling devices!" Hence with today's technology, as Cirac points out, these requirements are "crazy", and this is precisely why he's concerned about the current hype. In his view, even fundamental technical challenges have not yet been mastered.

New ideas from initial applications

Thomas Monz from the University of Innsbruck, on the other hand, is surprisingly laid back. He is part of a

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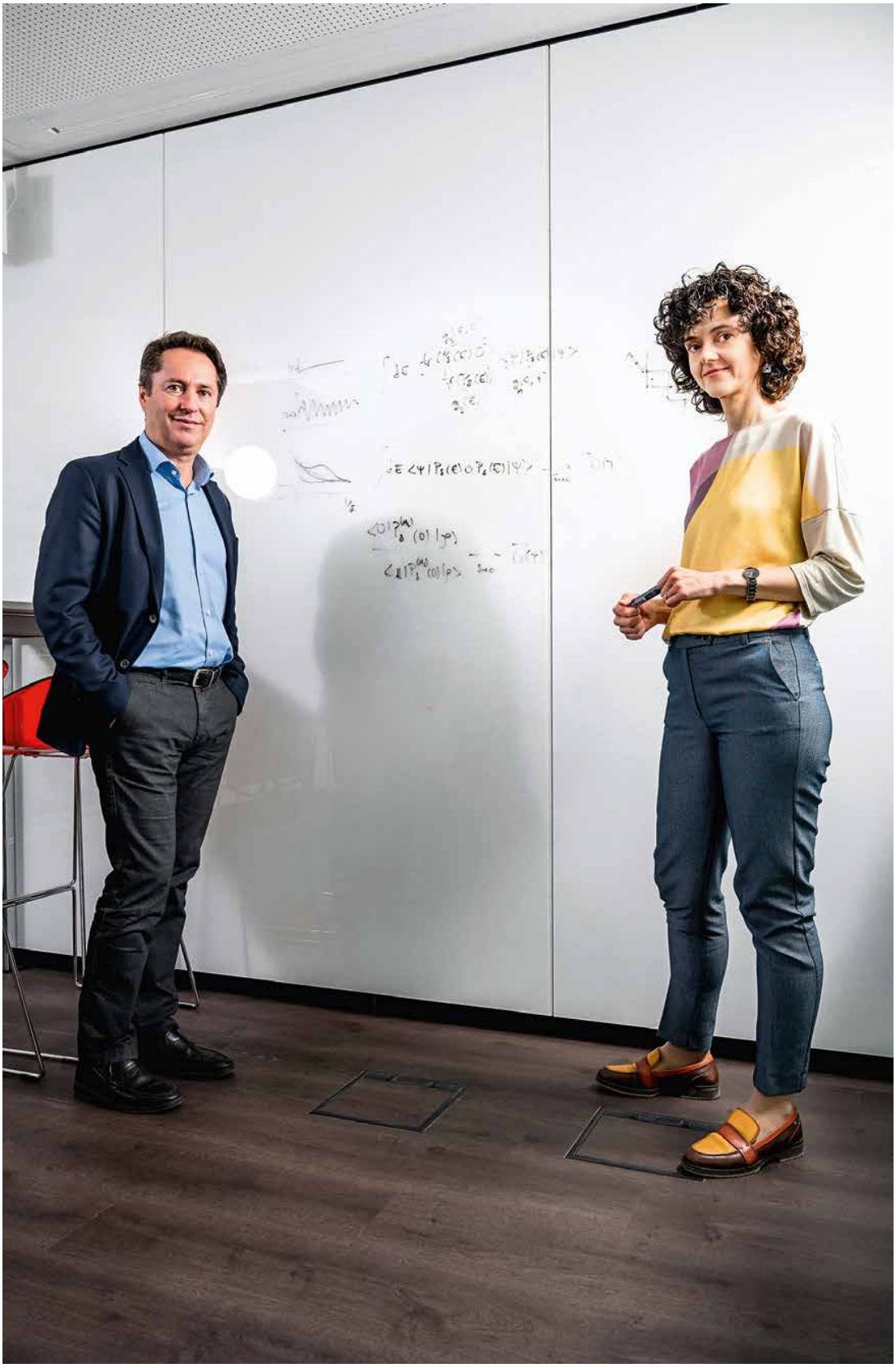

PHOTO: BETHEL FATH FOR MPG

Research with a short- and long-term perspective: Ignacio Cirac and Mari Carmen Bañuls explore how quantum computers can provide useful insights with relatively few qubits. In addition, they are developing algorithms for universally programmable systems with about one million qubits.

team led by Rainer Blatt that is pushing a different technology. The researchers use electrically charged calcium atoms that float – in a string like beads – in an electromagnetic trap called the Paul trap. They are controlled by laser beams. The advantage of these calcium ions is that they interact very strongly with each other due to their electrical repulsion. This can be used for very powerful entanglement. As many as 24 qubits could be entangled in this ion quantum computer.

"It doesn't sound like much, but this entanglement is very stable," Monz says. He is also CEO of the startup Alpine Quantum Technologies (AQT), which already sells ion quantum computers on the commercial market. His group at the University of Innsbruck, supported by AQT, recently demonstrated successful quantum error correction for the first time in collaboration with Forschungszentrum Jülich. "To do this, we connected seven physical qubits each to form logical qubits," Monz says. The idea is simple: after a certain computation time, states of some physical qubits forming a logical qubit usually diverge due to errors; then the majority of qubits matching in state probably show the correct result. "Quantum error correction, after all, is simply about redundancy," Monz says.

To better deal with the error-prone nature of quantum computations, Cirac and his team have launched a project: "We're working on verifying computational results," he says: "I think this is an important question to ask." After all, it needs to be ensured that quantum computers produce reliable results. This kind of debugging must also be carried out repeatedly by established computer technology.

Despite all the limitations, despite the obstacles that quantum computers must still overcome before they can be used for broader applications, Cirac is convinced that once they exist, they will lead us to unexpected ideas. The inspiring effect of the progress in development also motivates him to move quickly to initial, smaller applications. He's certain that: "If you were to interview me again in fifteen years, the most important applications of quantum physics won't be the ones we're talking about today!"

GLOSSARY

QUANTUM COMPUTER
Computing with quantum bits, which – unlike digital bits – can also assume superpositions of the states 0 and 1. Moreover, the states of several such qubits can be entangled with each other. This allows them to process different solutions to a computational task in parallel and arrive at solutions to some problems significantly faster than conventional computers.

QUANTUM SIMULATOR
The name given to a specialized quantum computer that makes do with far fewer qubits than a freely programmable quantum computer and can solve special tasks, for example, in the field of materials science.

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Model of a quantum system: crossed laser beams form a lattice that resembles an egg carton. In its cavities, atoms can be trapped that can simulate quantum phenomena. Such systems are also candidates for universal quantum computers.

GRAPHIC: CHRISTOPH HOHMANN (MCQST CLUSTER)

Back to the Future ...

Did you read the headline, remember a 1980s film, and ask what frontier research has to do with it?

Like a VCR, your brain just generated a stream of memory-related sequential activity patterns.

The Foundation supports Yingxue Wang at the Max Planck Florida Institute for Neuroscience; she tackles the question how the hippocampus processes information, when our brain integrates past and future into the present.

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

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VIEW OF A COSMIC DONUT

TEXT: HELMUT HORNUNG

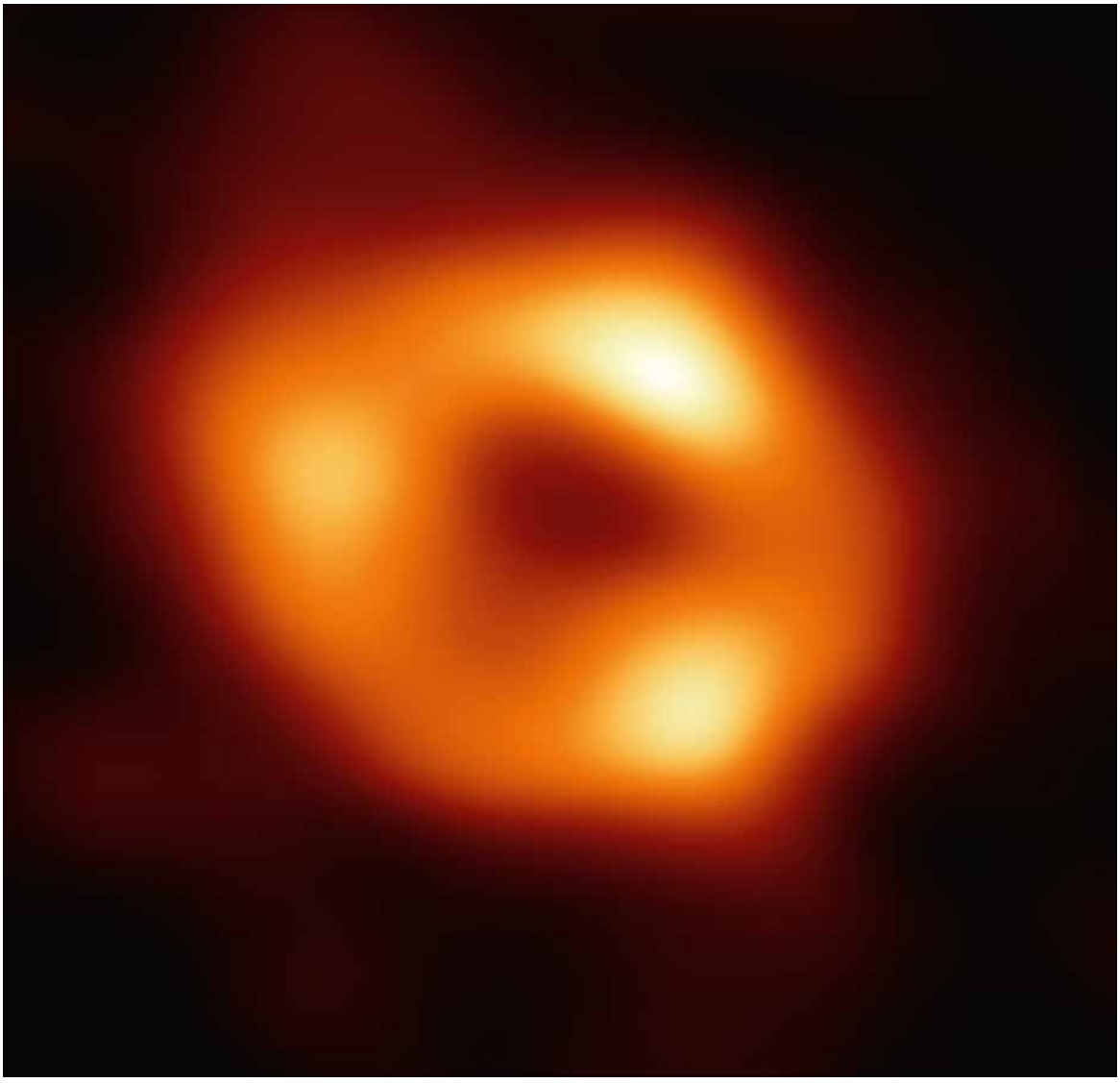

IMAGE: EHT COLLABORATION

Ring of fire in space: this is the first image of Sagittarius A*, the black hole at the center of our Milky Way. It was taken by the Event Horizon Telescope (EHT), which includes the 12-meter Apex telescope of the Max Planck Institute for Radio Astronomy and the 30-meter antenna of the Institut de Radioastronomie Millimétrique (Iram). The image is a false-color rendering and depicts the shadow of the black hole surrounded by a bright, ring-shaped formation of swirling gas.

Sitting deep in the heart of the Milky Way, it is 27,000 light years from Earth and resembles a donut: this is how the black hole at the center of our galaxy looks in the image obtained by researchers using the Event Horizon Telescope (EHT).

Astronomers have been peering into the center of the Milky Way for more than three decades, watching stars orbiting around an invisible, compact, and very massive something. In 2020, Andrea Ghez from the University of California and Reinhard Genzel from the Max Planck Institute for Extraterrestrial Physics were awarded the Nobel Prize for this work.

The researchers' findings, obtained with their precise measurements, have now been confirmed: "Our discovery indicates that the object at the center of the galaxy must indeed be a black hole," explains Anton Zensus, director at the Max Planck Institute for Radio Astronomy and founding chairman of the EHT Supervisory Board. The image is the first direct visual proof of this. The black hole itself is not visible in the image because, by its nature, it does not emit any radiation. But the glowing gas swirling around this cosmic gravity well exhibits a telltale signature – a dark central region ("shadow") surrounded by a bright ring. The immense gravity bends the light, so to speak.

This shadow is about two and a half times the diameter of what is known as the event horizon – the boundary of the black hole past which light is unable to escape. In the sky, its radius looks only the size of a ten-millionth of an arcsecond – the size of a one euro coin on the moon. This indicates that the galactic black hole has a natural diameter of about 24 million kilometers.

To obtain an image of the mass monster, eight radio observatories scattered halfway around the globe were connected to serve as a single virtual telescope the size of the Earth. With this method, which is called interferometry, the researchers were able to observe the dark heart of the Milky Way, which is known as Sagittarius A*, over several nights in April 2017. The individual antennas collected data for many hours at a wavelength of 1.3 millimeters. Two supercomputers – one at the Max Planck Institute for Radio Astronomy, the other at the Haystack Observatory in the United States – analyzed the data.

The latest observation comes on the heels of the first image of a black hole (M 87*) at the center of the galaxy Messier 87 published earlier in 2019. That the images of the two objects resemble each other may be surprising: indeed, M 87* is about 2000 times farther away from us than Sagittarius A*. The black hole in the distant galaxy, however, has a significantly greater mass and thus a diameter 1500 times larger than that in our Milky Way. As a result, the two images in the earthly firmament appear at a similar angle.

Data interpretation for Sagittarius A* was more difficult than for M 87*. Although the gas swirls around each of the two black holes at virtually the same speed – almost as fast as light – it takes weeks to orbit M 87* but only a few minutes to orbit Sagittarius A*. This meant that the brightness and structure of the ring of fire changed very quickly during the observations causing the photo to be "blurred". The solution: the image is not a snapshot of a single moment, but the average of hundreds of images obtained over two days in April 2017 at the Event Horizon Telescope. The data analysis was made even more difficult by the fact that Earth is in the galactic plane and hot gas with charged particles and magnetic fields are "dancing around" in the line of sight.

Observations confirm the model

The image of Sagittarius A* can be used to test models of how gravity and matter behave in the vicinity of such mass monsters. "Thanks to previous measurements like those made by Reinhard Genzel, we now know both the distance and the mass of the black hole very precisely," says Michael Kramer, director at the Max Planck Institute for Radio Astronomy and one of the leaders of the European Black Hole Cam project that is part of the Event Horizon Telescope. Because of this, it had been possible to calculate the shadow's expected size.

"The value calculated by the EHT team is consistent with the model of a black hole with the mass of four million suns, just as my group determined," says Max Planck Director Genzel, who sees the work of his colleagues as a "wonderful confirmation of our observations." Going forward, he said, the goal is to find out how fast the black hole is rotating. And the pitch of the plane of rotation is also still uncertain, he said.

www.mpg.de/black-holes

PHOTO: ISTOCK/GBRUNDIN

When summer draws to a close, the Swedes celebrate their crayfish festival, *kräftskiva*. The crustaceans, traditionally prepared with lots of dill, are the culinary focus.

Max Planck researchers collaborate with partners from more than 120 countries. Here they describe their personal experiences and impressions. Henrik-Alexander Schubert, a doctoral student at the Max Planck Institute for Demographic Research in Rostock, traveled to the Swedish capital, which is one of the top destinations for demographers. The researcher from the Max Planck Institute talks about lively parties, productive breaks, and where to get the best cinnamon buns in town.

Many people have a clear idea of how many children they would like to have one day. In Germany, the average is 1.96. However, the actual number of children born to each woman is only 1.53. Why is there a difference here, and what influences how many children a person has? These are the kinds of questions we grapple with at the Max Planck Institute for Demographic Research in Rostock. My thesis compares male fertility in eighteen different developed countries, looking for factors that influence the number of children. To do this, I used computers to analyze demographic registry data from a variety of time frames. This showed that the overall number of births declined after events such as the financial crisis or the coronavirus pandemic, but only in the short term. Conversely, regional imbalances in the dating scene have long-term effects: for example, it is often difficult for men in rural areas to find partners as many women migrate to the cities. What I find so exciting about this field of research is the multidisciplinary approach. To be able to correctly interpret the data, demography always needs to be linked to other sciences such as politics or biology. Each discipline approaches the same question from a different angle.

There are only a small number of universities and institutes around the world that focus on demographic research. These include the Max Planck Institute in Rostock and the University of Stockholm. That is why this university is also a partner of the International Max Planck Research School for Population, Health, and Data Science, where I am doing my PhD. I was already familiar with Stockholm from a trip I took after graduating high school, and it immediately caught my interest. Its nickname, the "Venice of the North", is completely accurate – there are countless bridges and jetties, and you're never far from the water. Stockholm inspired me to start learning Swedish while I was studying. For German native speakers, it's not so difficult: many of the words are similar, and Swedish grammar is simpler than German grammar. My language skills have certainly proven to be very useful. Because of how relaxed the

POST FROM

STOCKHOLM, SWEDEN

PHOTO: PRIVATE

Henrik-Alexander Schubert

26, studied political science and sociology at the University of Rostock before specializing in demography. He is currently studying towards his doctorate at the Max Planck Institute for Demographic Research in Rostock. He compares data from eighteen countries in the fertility and wellbeing research area, which is led by Mikko Myrskylä, to find out which factors influence fertility in men.

Swedes are, I immediately felt at home at the university in Stockholm. One very important part of the day is the coffee break – fika in Swedish. Rather than constantly e-mailing back and forth between neighboring offices, people meet for coffee, talk to each other, and enjoy an apple or a cinnamon bun. This makes you much more productive again immediately afterward. And if you're looking for the best cinnamon buns, head over to Ingrid's Bakery in the Östermalm district. Speaking of food: the fermented canned fish that the Swedes love so much is, in all honesty, not at all to my taste. But there are wonderful fresh fish dishes to try out too, especially on the coast!

The Swedes have a strong connection with nature. And they like to party! I have experienced a few festivals there. The most famous one is probably Midsummer, which I spent in an idyllic red wooden cottage in the countryside together with some friends. There was dancing and group games, almost like at a child's birthday party. The Swedes celebrate the crayfish festival of kräftskiva in August. During this festival, the whole family comes together around a long outdoor table. Everyone is given a paper hat to wear. You sing a song together, drink a shot, then eat a crab, over and over again. Needless to say, the atmosphere quickly becomes quite boisterous!

Apart from that, the Swedish temperament is rather quiet and reserved. Criticism is always expressed in a very polite way. Instead of telling someone they made a mistake, they would say, "You could have done that differently." To meet new people, I started playing floorball in Stockholm. Despite this, making friends was not easy: for the most part, you run into tight-knit groups and have a hard time getting in. But once you've formed a friendship, you know it's one that will last.

FIVE QUESTIONS

ON PARROTS

TO AUGUSTE VON BAYERN

Parrots are among the most intelligent creatures on Earth, but they are also one of the most endangered groups of animals. Will these fascinating creatures survive the great species extinction of our time? Auguste von Bayern studies the mental capabilities of various parrot species and knows all about the threats to these animals and their needs.

Ms. von Bayern, what kind of research are you doing with parrots?

AUGUSTE VON BAYERN My working group aims to better understand the development of intelligence and complex communication in vertebrates and to find out how language is linked to intelligence. To add to this, parrots are able to learn and imitate sounds extremely easily, and these abilities could be a key to unraveling the evolution of language in human beings.

What is the greatest danger to parrots?

The most serious threat is the destruction of their habitat. It's not surprising, because most species live in tropical and subtropical rainforests, and these, too, are particularly endangered, unfortunately. Another problem is the pet trade, not to mention that some parrots, including even endangered species, are hunted for their feathers or simply for sport.

Which species are particularly endangered?

Of the 387 parrot species known today, 109 are on the red list, so almost one-third. Of these, 17 are "threatened with extinction" and 38 are "threatened". There are also 16 species we know of that have died out over the last few centuries. Particularly endangered, for example, is the Brazilian Spix's macaw made famous by the animated film Rio, which has meanwhile become extinct in the wild – also the Puerto Rican Amazon or the possibly already extinct New Caledonian lorikeet.

So, which organizations are working to protect parrots?

Birdlife International, World Parrot Trust, and Parrots International, to name but a few. The Loro Parque Foundation, with which I collaborated for my research, also works to protect parrots. For 30 years, the Foundation has been supporting protection projects for 30 to 40 parrot species and some mammals with the aim of saving endangered species from becoming extinct. Its efforts have helped to save nine parrot species from extinction, five of which have even been downgraded in their threatened status. In addition, as the most species-rich parrot collection in the world, the Foundation's parrot breeding program supports international reintroduction programs.

Parrots are popular pets. What constitutes appropriate parrot husbandry?

Parrots should actually only be kept by experts. Without the international breeding programs by zoos and professional breeders like the Loro Parque Foundation, some species would die out in the near future. As pets, however, many parrot species are decidedly unsuitable. They need a lot of space and should not live alone, on top of which, they are often relentlessly noisy. They easily develop quirks such as feather-pulling or incessant screaming if they cannot live out their natural behavioral repertoire and their urge to move and nibble, or if they get too little attention. You, therefore, need to consider carefully in advance whether you are able to meet these requirements over many years. Anyone who has a parrot is practically taking on a toddler that will never grow up and shrieks a lot more.

Interview: Harald Rösch

Auguste von Bayern leads the research group "Comparative Cognition" at the Max Planck Institute for Biological Intelligence (currently being set up).

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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