03 | 2022

MAX PLANCK
Research

MOLECULAR BIOLOGY
A Copier for Genetic Material

ASTRONOMY
The Universe in a New Light

BIOGEOCHEMISTRY
The Overfertilized Earth

TO STAY OR TO GO?

2

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

The Wodaabe in Niger have traditionally lived nomadically. They move through the savannah in groups of several families with their herds of cattle, and use the barren land in a sustainable way. But since a devastating drought in the 1980s, parts of the ethnic group have begun to settle in cities to earn money. Nevertheless, pastoral life remains a point of identification for the Wodaabe, and the savannah a place of longing.

EDITORIAL

Dear Reader,

Mobility is a basic need for many people. This is evident, for example, in current discussions about the price of gasoline and diesel, public transit, or vacation flights. We tend to forget that even before the invention of engines, people had the urge to move around, to change location, and often to enter uncharted territory.

At the same time, mobility is not a purely human phenomenon; animals are, likewise, known to travel long distances. Wildebeests and reindeer, whales, fish, and sea turtles – not to mention countless birds – cover hundreds or even thousands of miles, year after year. In doing so, they follow a genetic program that researchers at the Max Planck Institute for Evolutionary Biology are studying in detail using the example of blackcaps. Their research has shown that genes not only dictate whether a bird will migrate in the fall, but also where to.

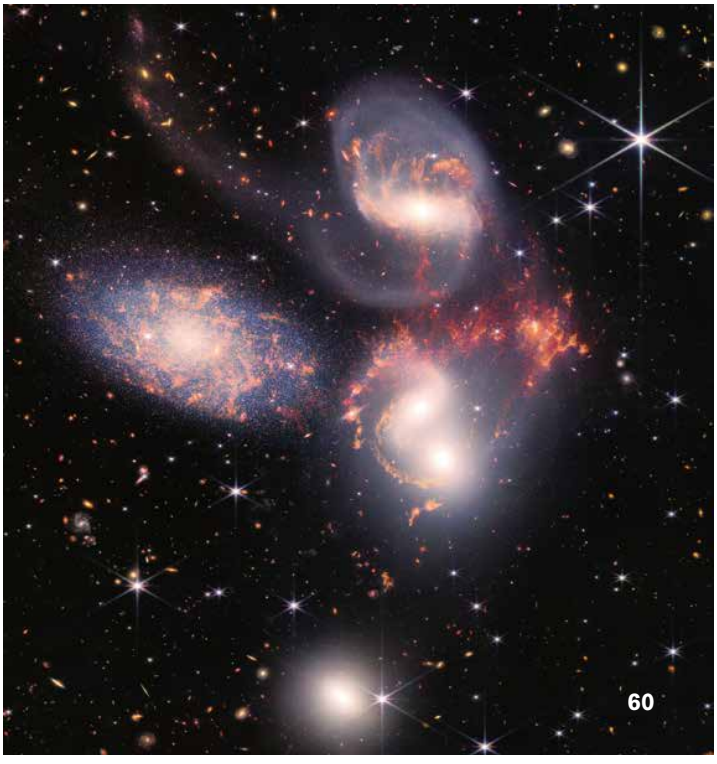
Humans are at least partially free to decide where they want to stay put, however, living conditions often provide very little leeway here. When traditionally nomadic ethnic groups like the Wodaabe in Niger lose a large part of their herds as the result of drought, they have to find other ways to make a living; hence, in recent decades, many Wodaabe have sought work in cities. Those working in the cities use the money they earn to support nomadic livestock farming in the countryside, as a researcher at the Max Planck Institute for Social Anthropology has observed. With this strategy, they spread financial risk and secure an income.

Within the European Union, citizens of member states are free to choose where they live and work, and for many, leaving their original home is a decision for life. How migrants fare in old age has been a subject of research for a team at the Max Planck Institute for Social Law and Social Policy, with varying results depending on whether one compares their well-being with those who stayed at home or with their fellow dwellers in their new home country.

The question of “Should I stay or should I go?” arises time and again in a wide variety of contexts. If you find yourself facing precisely this choice, then we suggest you take the time to do some reading – whether at home or on the move.

In any case, we hope you enjoy this issue!

Your editorial team



IMAGES: LUISA JUNG FOR MPG (TOP LEFT); KATRIN BINNER FOR MPG (TOP RIGHT); ISTOCK (BOTTOM LEFT); ESA / CSA / STSCI / NASA (BOTTOM RIGHT).

CONTENT

ELECTRONS IN WAVE FLIGHT

The question of "what holds the world together in its inmost folds" was already on the mind of Goethe's Faust all those years ago. Some considerable time has passed since then, nevertheless, the forces that hold the world together at the molecular level are still the subject of research today. Scientists at the Fritz Haber Institute (FHI) in Berlin, for example, are interested in the forces that act between atoms in molecules.

Each molecule has its own typical vibration spectrum – a fingerprint, as it were, that can be determined with the help of laser-like infrared radiation. The method of choice for generating such intense infrared radiation with adjustable wavelengths is a free-electron laser (FEL): in a vacuum, electrons are first accelerated to nearly the speed of light. These high-energy electrons then pass through very strong magnetic fields in what is known as an undulator. These undulators set the electrons in wave-like motion. This causes the electrons to emit photons – in a concentrated, intense beam. In principle, free-electron lasers can generate electromagnetic radiation of almost any wavelength, although this often involves radiation in the X-ray range, which has the shortest possible wavelength. For the experiments at FHI, meanwhile, long-wave radiation in the infrared range is required and generated.

Here, electronics engineer Marco De Pas checks the connections of the electromagnets used to deflect the electron beam on its way between the accelerator and the undulator. The scene is reminiscent of a stage on which a percussionist stands behind their instruments. There, as here, everything has to be coordinated very precisely to achieve the right outcome.

ON LOCATION

PHOTO: FHI / JUERGEN LOESEL

OUTSTANDING!

PHOTO: FRIEDRUN REINHOLD

ANTHONY HYMAN

The Körber Prize for European Science 2022 goes to Anthony Hyman, Director at the Max Planck Institute of Molecular Cell Biology and Genetics. The British cell biologist and his team discovered short-lived, droplet-like condensates of proteins in cells. The impaired degradation of these condensates can result in diseases such as ALS or Alzheimer's, and researching them thus opens up new therapeutic approaches. The Körber Prize, which is endowed with one million euros, is one of the world's most highly endowed research prizes and supports the winners in the continuation of their work.

NEW PHASE IN THE FUSION EXPERIMENT

The Wendelstein 7-X fusion facility in Greifswald, which belongs to the Max Planck Institute for Plasma Physics, has been further expanded after the first two experimentation phases. This upgrade makes it possible to generate plasma pulses in the facility for up to 30 minutes at higher heating power, thus demonstrating the ability to operate continuously. This marks the final completion of Wendelstein 7-X, adding a water-cooled inner lining and the new centerpiece, a water-cooled divertor. Divertors remove impurities from the plasma and will be used to remove heat for power generation in a fusion power plant that will be created in the future. A trial run with the new technology began in September, and the scientific experimentation phase is scheduled to begin in November. Federal Minister of Education and Research Bettina Stark-Watzinger and Bettina Martin, Minister of Science in Mecklenburg-Vorpommern, visited the facility in August to mark the completion of the expansion work. "Wendelstein 7-X is an important step on the path to creating a commercial fusion power plant," Stark-Watzinger said. "Should the transfer to application-readiness be successful, it would be a momentous innovation."

www.mpg.de/mpr-2022-033

PHOTO: MAGNUS SCHULT

Grand visit: State Minister for Science Bettina Martin, Max Planck Director Sibylle Günter, and Federal Minister of Education and Research Bettina Stark-Watzinger (from left) in front of the Wendelstein 7-X fusion facility in Greifswald.

START-UP PRIZE FOR AVATAR COMPANY

Presented by the Stifterverband für die Deutsche Wissenschaft [Donor's Association for the Promotion of German Science and Humanities], this year's Max Planck Start-up Prize goes to the start-up Meshcapade from Cyber Valley in the Stuttgart-Tübingen region. The company is expanding on techniques developed at the Max Planck Institute for Intelligent Systems relating to three-dimensional body modeling. The aim is to use images, sensor-based devices, body measurements, and similar data to create realistic human figures in an easily accessible 3D format. The resulting avatars have facial expressions, can perform realistic movements, and are compatible with all popular 3D visualization programs. The technology can be used in the fashion, gaming, and film industries. However, it also holds enormous potential for medicine and healthcare, because it enables the creation of lifelike, 3D recreations of real people. Michael Black, Director at the Max Planck Institute for Intelligent Systems, co-founded Meshcapade in 2018 with his collaborators Naureen Mahmood and Talha Zaman. Max Planck President Martin Stratmann views the start-up's award as a positive signal for Cyber Valley: "It is my hope that the award will help motivate other researchers who are willing to spin off, so that Cyber Valley can develop into a 'Start-up Valley'."

www.mpg.de/18471930

IN BRIEF

Hydroxyl radicals OH are formed on human skin and react with organic substances in the air. The reactivity (indicated per second) that takes place directly on human skin is particularly high.

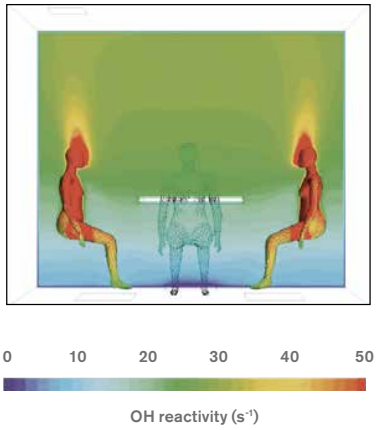


IMAGE: UC IRVINE

RADICALS IN THE AURA

Humans influence the chemistry in indoor spaces in previously unknown ways. As a team led by researchers at the Max Planck Institute for Chemistry has discovered, ozone that enters buildings along with the outside air reacts with fats, especially squalene, on human skin to form hydroxyl radicals. These molecules create an oxidative field around each person, as they alter or even degrade organic substances in the air. This means that, on the one hand, hydroxyl radicals rid the air of potentially harmful substances. On the other, however, they can also produce substances that are potentially harmful to health. Consequently, the full impact of the human radical aura on health must be clarified in further studies.

www.mpg.de/19157061

PHOTO: LADYFERN PHOTOS/UNSPLASH

Even a one-hour walk in nature can reduce brain activity associated with stress.

HEADING TO THE COUNTRY TO NURTURE THE BRAIN

Living in a city is a known risk factor when it comes to developing mental disorders. The amygdala, a central brain region involved in stress processing, has been shown to be less active in people living in rural areas than in city dwellers. Until now, it was unclear whether the rural environment causes this effect or whether people who choose to live in the countryside are simply wired differently to those in the city. To uncover the causal relationship, scientists at the Max Planck Institute for Human Development used functional magnetic resonance imaging to examine 63 healthy subjects before and after a one-hour walk. One group of the subjects walked in the Grunewald Forest, the other on a commercial street in Berlin. The results did indeed show that activity in the amygdala had decreased after walking in nature. This suggests that even spending as little as 60 minutes in nature has positive effects on the regions of the brain that are related to stress.

www.mpg.de/19168412

PHOTO: ADOBESTOCK

It is difficult for humans to survive in the tropical rainforest. Nevertheless, researchers are increasingly finding evidence of prehistoric settlements in such environments

EXPANSION THROUGH THE RAINFOREST

The Bantu expansion – a gigantic series of migrations by Bantu-speaking people – permanently changed numerous sub-Saharan African regions in terms of language and culture. The current ancestors of the Bantu-speaking people lived and farmed in an area near the border between Nigeria and Cameroon 5000 to 6000 years ago. Until now, the assumption had been that it was almost impossible for these people to spread their settlement area through the Central African rainforest. It was thought that migration was only made possible by a savannah corridor that formed around 2500 years ago. Based on linguistic data and with the help of novel computer-assisted methods, a team from the Max Planck Institute for Evolutionary Anthropology has now calculated that the southward spread must have taken place around 4000 years ago – long before the corridor through the rainforest had opened up. These results corroborate other recent findings that humans have been able to adapt surprisingly well to living conditions in tropical forests throughout their history.

www.mpg.de/19012651

SPYING WITH KINDER-GARTEN APPS

Apps designed to support kindergartens sometimes exhibit serious data protection and security flaws. This was the result of an analysis by a team featuring researchers from the Max Planck Institute for Security and Privacy in Bochum. Kindergarten apps are designed to make everyday life in kindergartens easier. Parents can use them, for example, to view reports on their child's development or communicate with kindergarten staff. The researchers examined 42 of these apps from Europe and the USA with regard to security and data protection. They found that several apps tapped users' personal data without their consent and shared it with third-party providers. In some apps, researchers were also able to access children's private photos. However, refraining from the use of these kindergarten apps is no better, the researchers say, because parents and kindergarten staff would then use messenger services that have other serious privacy issues. Instead, specialists should create guidelines and checklists for kindergarten apps, which government agencies, for example, could use to make recommendations for associations that support kindergartens. ***www.mpi-sp.org/43309***

A NOSE FOR FAKE PERFUME

In the future, a new technique will be used to unmask counterfeit perfumes or identify diseased plants. Researchers at the Max Planck Institute for Chemistry in Mainz and the Johannes Gutenberg University Mainz have developed a method for determining the chiral signature of volatile organic substances very precisely. "Chiral" is derived from the Greek word for hand and means that a substance – like hands – exists in two mirror-image versions. The chiral signature can be used to determine the ratio in which a plant's perfume or transpiration contains the two variants. Many biomolecules are chiral, although the two variants of many chiral substances have very different biological effects, for example on the sense of smell. In addition, some biomolecules only naturally occur in one variant, meaning counterfeit perfumes containing synthetic rather than natural components can be recognized by their signature. To achieve this, the Mainz researchers measure the direction in which their samples' components rotate the plane of polarization – the only physical property that differs between the two variants of chiral compounds.

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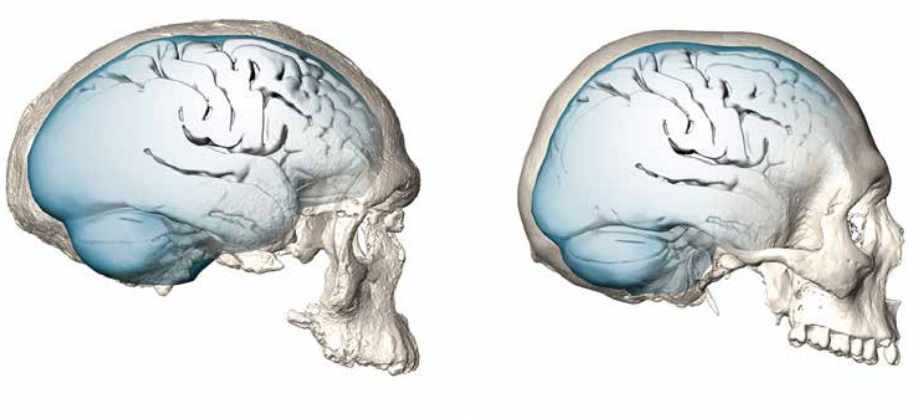

IMAGE: MPI FOR EVOLUTIONARY ANTHROPOLOGY / S. NEUBAUER, P. GUNZ (LICENSE: CC-BY-SA 4.0)

Skull and brain of a Neanderthal (left) and a modern human (right).

MORE BRAIN

The extinct Neanderthal had a brain similar in size to modern humans, but possibly with fewer neurons in a region important for higher cognitive abilities. According to an international team of researchers at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, there is a particularly abundant protein variant in the frontal lobe of our cerebral cortex that enables the production of more neuronal precursors. Referred to as TKTL1, the protein is produced primarily in basal radial glial cells in the human fetus; these produce the majority of neurons in this part of the brain. The protein allows more lipid molecules to form for the cell membrane of these progenitor cells. Only a single amino acid differs between the protein variants in modern humans and Neanderthals – but this tiny difference may have improved the mental faculties of modern humans. ***www.mpg.de/mpr-2022-031***

BATTLE OF THE TRASH CANS

In South Sydney, a dispute about trash has erupted: residents want to keep their neighborhood free of it, yellow-crested cockatoos want to eat it. The birds have learned to flip open the lids of trash cans to get to the contents. As soon as one cockatoo has opened a trash can, others come along and try to join in the feast. In the process, the birds generously distribute the trash all over the neighborhood. Researchers at the Max Planck Institute of Animal Behavior in Constance have observed that humans and animals adapt their behavior to each other. Residents try to keep the birds away from the contents of the trash cans in different ways: for example, they block the hinges of the lids or weigh down the covers with stones. So far, however, the birds are managing to consistently outwit the humans. For example, they simply grab the stones with their beaks and push them off the cans with all their might. There is no way to predict who will win the race to control the trash cans. However, the first locks to keep cockatoos out are already available for purchase in Sydney.

www.mpg.de/19174958

PHOTO: MPI FOR ANIMAL BEHAVIOR / BARBARA KLUMP

Clever bird: a yellow-crested cockatoo maneuvers a rock off a trash can.

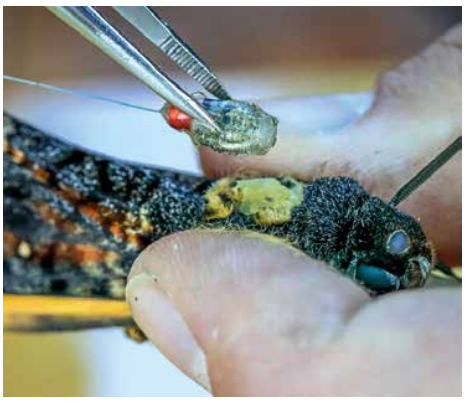

PHOTO: MPI FOR ANIMAL BEHAVIOR / CHRISTIAN ZIEGLER

A death's-head hawk moth is fitted with a tiny transmitter. The device weighs less than 15 percent of its body weight – less than what an adult moth eats in a night.

THE LONG JOURNEY OF THE HAWKMOTHS

Like migratory birds, many insects commute between breeding and wintering grounds during the year, covering enormous distances in the process. A study by the Max Planck Institute for Animal Behavior has found that death's-head hawkmoths – large, nocturnal moths – can maintain perfectly straight flight paths when migrating, even in unfavorable wind conditions. Researchers from the Institute used an airplane to track 14 death's-head hawkmoths equipped with radio transmitters. The moths traveled from Constance over distances of up to 80 kilometers in the direction of the Alps – the longest ever continuously observed distance of on an insect in the wild. The moths fly high in a tailwind and are carried by the current. In strong headwinds or crosswinds, however, they fly low and increase their speed to stay on course. Death's-head hawkmoths fly up to 4000 kilometers from Europe to Africa every year over several generations. Each individual travels only part of the way and reproduces at the end of its journey, allowing the next generation to continue the migration.

www.mpg.de/19067141

WARM PERIODS PROVIDE OXYGEN

When oxygen is scarce, life is hardly possible. This is true of mountainous regions above 7000 meters as well as waters with a low oxygen content, for example in tropical regions on the west coast of America. Oxygen-deficient ocean regions, where practically only specialized microbes or jellyfish survive, have expanded over the past 50 years. Until now, geoscientists have attributed this development to global warming, which, among other things, causes seawater to absorb less oxygen. However, in the medium or long term, it could be natural climate change that causes the low-oxygen zones in the oceans to shrink. This is exactly what happened in two previous warm phases of the Earth's modern era, about 16 and 50 million years ago, as an international team led by researchers from the Max Planck Institute for Chemistry discovered using sediment cores from tropical ocean regions. This could be due to various mechanisms in which altered mixing of deep and near-surface ocean layers plays a role. The mixing could occur locally, where it has a short-term effect, or in the Antarctic Ocean, which has long-term consequences. Therefore, the length of the period in which human-induced global warming may cause the oxygen-deficient ocean regions to shrink is still unclear. ***www.mpg.de/19158609***

Areas with low oxygen content (red), indicated in micromoles per kilogram, are found along the west coast of America, in the Bay of Bengal and in the Arabian Sea.

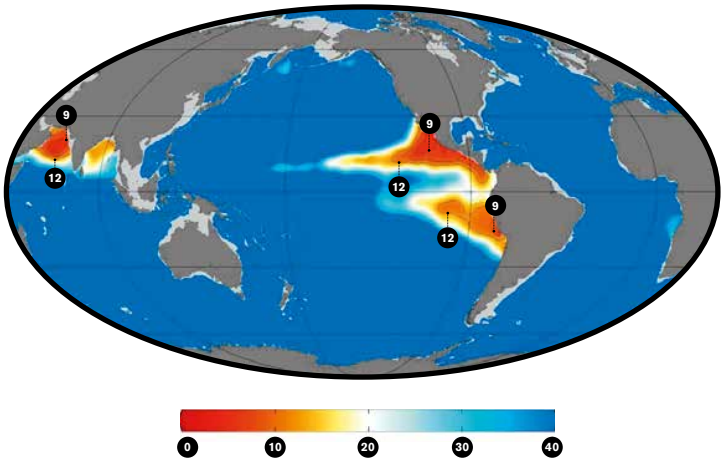

IMAGE: A. AUDERSET / MPI FOR CHEMISTRY

Oxygen concentration (µmol/kg) at 350 meters depth

The Baltic Sea isopod *(Idotea balthica)* on the red alga *Gracilaria gracilis*.

PHOTO: WILFRIED THOMAS, STATION BIOLOGIQUE DE ROSCOFF (SBR)

BEES OF THE SEA

On land, bees, hummingbirds, and even bats and lizards perform important services in plant fertilization. An international team, including researchers from the Max Planck Institute for Biology in Tübingen, has now discovered that animals also act as pollinators in the sea. The Baltic Sea isopod hides in the tufts of a red algae and feeds on microalgae growing there. The isopod shows its appreciation for this: when it feeds on a male alga, the sperm growing on the alga's leaf surface sticks to its body. Upon contact with a female alga, the sperm attach to and pollinate the female reproductive organs as the isopods pass by. The red algae need the help of this ant-sized crustacean, because their sperm cells cannot move independently. Without the isopods, therefore, it would only be favorable water currents and local proximity that determine whether the male and female algae could reproduce. The researchers now want to find out whether other algae species are pollinated in a similar way.

www.mpg.de/19006751

278

There have been 278 different molecules discovered in space to date.

DISINFECTANT IN SPACE

For half a century, researchers have been using radio telescopes to search for molecules in the universe. Up until now, the fingerprints of 276 different substances have been found in the spectra. But the data base has grown again: using the Alma antenna array, a team led by the Max Planck Institute for Radio Astronomy discovered the alcohol propanol and its isomer isopropanol – a chemical compound with the same molecular formula but different structure – in a gas cloud called Sagittarius B2. This is a substance that many of us have literally held in our hands before: among other things, it is used to disinfect skin or surfaces. The observation was made as part of a long-term study in which the chemical composition of the molecular cloud is being surveyed using high angular resolution. Sagittarius B2 is located near the galactic center and resembles a cosmic delivery room where stars are born. Propanol is the largest alcohol molecule discovered in interstellar space to date. The size didn't make the search any easier, however, because it emits many spectral lines at different frequencies. And in a source like Sagittarius B2, there are so many molecules that their spectra overlap, making it difficult to identify the individual fingerprints.

www.mpg.de/18884791

DIAGNOSING DIGITAL DISEASE

Hate speech, propaganda, and disinformation are increasingly presenting problems on the internet and social media. Efforts to regulate undesirable online content through platform-specific rules or legislation have been unsuccessful. Johanna Rinceanu and Randall Stephenson believe that what is needed is a more precise diagnosis of the underlying causes. Such a legal approach should be inspired by lessons from social medicine.

What do medical diagnosis and modern-day internet regulation have in common?

The German physician Rudolf Virchow stated in 1848 that "medicine is a social science, and politics is nothing else but medicine on a large scale." As the founder of modern pathology and social medicine, Virchow challenged emerging 19th-century trends towards biological reductionism and genetic determinism. An impassioned advocate for social reform, he maintained that, if medicine was to fulfil its great task of nurturing health and reducing disease, then society as a whole must be changed through political action. Modern medicine's greatest idea was born.

Envisioning a medical profession that required physicians to explore complex relationships between socio-political stressors and bodily experience, Virchow regarded physicians as "the natural attorneys of the poor." This shift in the roles and identities of doctors and lawyers was born from his deep conviction that the lessons of medical science must be applied to the organization and structure of society's laws and regulations. Given this portrayal, if physicians were society's "natural attorneys" and politicians its "natural anthropologists," then lawyers might be best understood as its "natural diagnosticians."

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VIEW POINT

JOHANNA RINCEANU & RANDALL STEPHENSON

ILLUSTRATION: SOPHIE KETTERER FÜR MPG

Johanna Rinceanu is a Senior Researcher in the Department of Criminal Law at the Max Planck Institute for the Study of Crime, Security and Law in Freiburg im Breisgau. She studied law in Freiburg and Washington, D.C. In 2007, she received her doctorate from Humboldt University in Berlin. Her main areas of expertise are criminal procedural law, comparative law, and human rights.

Randall Stephenson is a comparative constitutional law and defamation scholar specializing in the intersections between press freedom, democratic theory, and networked accountability. He received his PhD from the University of Oxford in 2017 and joined the Max Planck Institute for the Study of Crime, Security and Law as a Senior Researcher in the Department of Public Law in 2019.

Following radical 20th-century breakthroughs in theoretical physics, this shift in scientific perspective precipitated the American psychiatrist George Engel's innovative biopsychosocial model of health and illness in 1960. In Engel's view, the medical profession was in crisis because of its adherence to an outdated biomedical model that was no longer fit for its scientific tasks and social responsibilities. In its place, Engel argued for a new paradigm that would employ a more dynamic, holistic approach. Like Virchow before him, Engel yearned for an epistemological shift in medical science focused on greater interaction between biological, psychological, and social factors. Socio-political influences were again attributed vital causal and diagnostic importance.

ELON MUSK LIKELY UNDERESTIMATED THE EXTENT OF THE PROBLEMS IN THE DIGITAL MEDIA LANDSCAPE

This short review of systems-inspired research paradigms is arguably more important than ever in our 21st-century media environment. An illustrative example is Elon Musk's proposed acquisition of the social networking platform Twitter for the sum of USD 44 billion. With his stated intention to redress increasing threats to freedom of expression and freedom of the press, Musk quickly learned of the underlying nature and dysfunctions of our modern digital media landscape. Twitter – like other social media platforms such as Facebook, YouTube, and Instagram – has been increasingly susceptible to alarming online content, including hate speech, image-based harassment, racism, right-wing extremism, propaganda, disinformation, and fake news.

Though the officially stated reason for Musk's attempt to walk away from the deal was misrepresentations concerning the number of fake Twitter accounts, it is important to emphasize that well-intentioned efforts to safeguard press freedom and human rights norms are increasingly frustrated by rising regulatory challenges – be it in the form of regulatory norms or self-imposed social media communication rules. The latter are unique to our networked public sphere and include community guidelines for prohibiting certain online content, such as threats of violence, hate speech, the targeting of private individuals, and support or praise of terrorism, organized crime, and hate groups. Breaches of self-imposed communication rules and guidelines normally result in the removal or blocking of the corresponding content by the social media platform itself. Yet, despite numerous state and platform-specific regulatory efforts, hate speech, online violence, and fake news are seemingly unstoppable.

One explanation for the failure of online media regulation could be that a mix of international, supranational, and domestic regulations have not

treated hate speech, right-wing extremism, or fake news as "symptoms" of an underlying disease, but rather as separate, specific ailments. As typified by the newly passed EU Digital Services Act – which aims to harmonize domestic laws in the European Union that regulate illegal online content – the primary outcome of this reductionist approach is a fragmented and ultimately ineffective strategy. As with Virchow and Engel in their own times, our modern public sphere is a uniquely self-referential and self-stabilizing system that requires concentrated and coordinated responses from its physician-attorneys, politician-anthropologists, and lawyer-diagnosticians.

Virchow's pioneering understanding of the complementarity between physicians and attorneys is further supported by remarkable synergies between functionalism – comparative law's dominant methodology – and the practice of medical diagnosis. The problems facing comparative law have increased in importance due to the global reach of digital communications technology and online media regulation. For example, the world's first online regulatory framework – Germany's NetzDG, which requires social media platforms to identify and remove illegal online content – has been hastily transplanted into jurisdictions with fundamentally different and potentially incompatible constitutional contexts. Countries like Belarus, Ethiopia, India, Kenya, Malaysia, Philippines, and Russia have adapted Germany's legislative approach by requiring social media platforms to delete or block "unlawful" political content within unreasonably short deadlines with little reflection on jurisdictional differences. Those failing to comply are subject to exorbitant fines. Such reactionary internet regulation poses an increasing threat to freedoms of conscience, religion, and expression and forces private social media platforms into the unwanted role of internet gatekeepers at the threshold of human rights – a role better performed by lawyers.

THE LAW FORCES SOCIAL MEDIA PLATFORMS IN THE UNWANTED ROLE OF GATEKEEPERS

Functionalist comparative law methods might one day mend this undesirable regulatory setting. Similar to issues of health and illness, the functionalist method aims to discover broader socio-political connections underlying outward differences in legal doctrine. Advancing from detailed descriptions of domestic legal regimes (e.g. differing hate speech regulations in Germany and America), to more theoretical "system-building" – which aims to expose hidden socio-political problems common to different countries – functionalist methods might be used to better diagnose the underlying nature of the online regulatory challenges impacting nations worldwide.

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These methodological similarities can be better understood by comparing functionalism and medical diagnosis in greater depth. First, both are best understood as a continuous process of information gathering, integration, and interpretation about underlying dysfunctions, and operate under conditions of uncertainty. As with comparative law, the purpose of diagnosis is not to attain "certainty," but to reduce the level of uncertainty to a degree that will allow timely and effective therapeutic intervention.

A second similarity involves shared approaches to exercising judgment. In medical diagnosis, this manifests as clinical reasoning which, as the clinician's "quintessential competency," is the cognitive process necessary for properly evaluating and managing patients' medical problems. Likewise, functionalism involves a self-reflexive process whose primary objective is to expose shared regulatory aims concealed by variations in legal doctrine. Similar to diagnostic methods, this process involves: first, obtaining data on domestic legal systems and their institutional contexts; second, evaluating differences and similarities between domestic legal regimes; and third, updating working hypotheses endeavoring to recast legal differences through the lens of shared regulatory objectives. Once this process has advanced enough to reduce uncertainty in our leading hypothesis, law reforms can be proposed to restore balance to the dysfunctional network with which the original "legal" problem most natively interacts.

IT'S ABOUT REDUCING THE LEVEL OF UNCERTAINTY TO TAKE THERAPEUTIC MEASURES

As in the field of diagnostics, the ultimate success of functionalism depends on optimizing our understanding of "medical" and "legal" phenomena by shifting our evaluative focus to systems and broader contextual thinking. Whether engaging in medical diagnosis or functionalist "system-building," this requires the physician-attorney and lawyer-diagnostician to replace overly reductionist methods by constructing "total pictures" and tracking complex causal interrelationships and their impacts on individuals and broader social systems.

What lessons can be learned from comparing medical diagnosis with internet regulation?

First, rather than seeking inflexible legal rules and principles, comparative law methods should be adapted to formulate a more flexible framework that exposes the underlying reality of today's digital media challenges. Given each nation's unique institutional and media context, efforts to "harmonize" and "universalize" regulations through legal translation or legal transplantation should be discouraged. Such regulatory approaches

might be manipulated by non-democratic states and, without appropriate constitutional and legal safeguards, could easily foster state propaganda and online censorship.

Second, online regulators ought to eschew rigidly categorized, overly-reductionist approaches. One such example is insisting upon an internationally recognized definition of hate speech that applies equally to all jurisdictions. Emergent metadisciplines such as media ecology can better inform our regulatory efforts by exposing the permanent connections and interdependence of complex phenomena such as hate speech and online violence. By revealing their underlying structure and dynamics, we are better positioned to distinguish between symptoms and root causes, thereby enhancing the accuracy and effectiveness of our diagnostic efforts and regulatory interventions.

WE NEED A "NETIQUETTE" OF TOLERANCE, EQUALITY AND RESPECT FOR DIVERSITY

Lastly, borrowing a page from Rudolf Virchow himself, today's generation of lawyer-diagnosticians must question the epistemic realities and structure of our contemporary media environment – a critical first step in diagnosing the true nature of the social ills that our global regulatory efforts ultimately aim to redress. Equally vital, a flexible, updated approach to media regulation should be accompanied by a "netiquette" of tolerance, pluralism, equality, and respect for diversity, in conjunction with inter-group dialog, counter-speech, and human-rights oriented education – none of which can be achieved without first heeding the systems-inspired lessons of our scientific forebears.

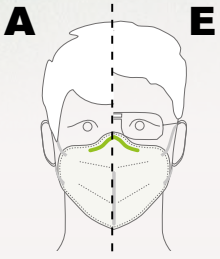
MASKS PROTECT!

How far virus-containing aerosol droplets from a person without a mask ❶ spread in an indoor area depends on the size of the particles. Small droplets can still be detected several meters away. A surgical mask ❷ filters a large proportion of the droplets from the exhaled air; however, numerous particles still flow into the environment, especially at the cheeks. With an FFP2 mask ❸, some particles escape, especially where the mask sits across the nose, but this can be minimized with adaptation of the nose clip to the wearer's face.

GRAPHIC: GCO

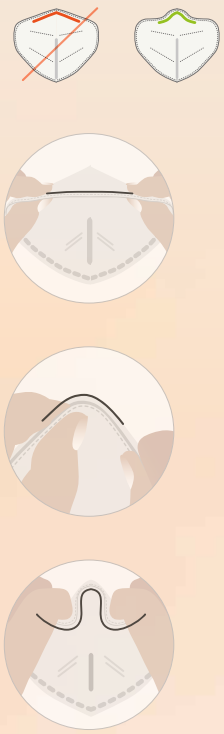
RISK OF INFECTION

Well protected on all accounts: masks significantly reduce the risk of infection. The extent to which this is the case depends on which mouth/nose covering is worn by the infectious person (A, left) and the susceptible person (E, right), and whether the masks fit well (green nose clip) or poorly (red nose clip). The percentages reflect the probability of infection after 20 minutes when the persons are standing directly next to each other. Most importantly, the infected person should wear an FFP2 mask, which should fit as well as possible.



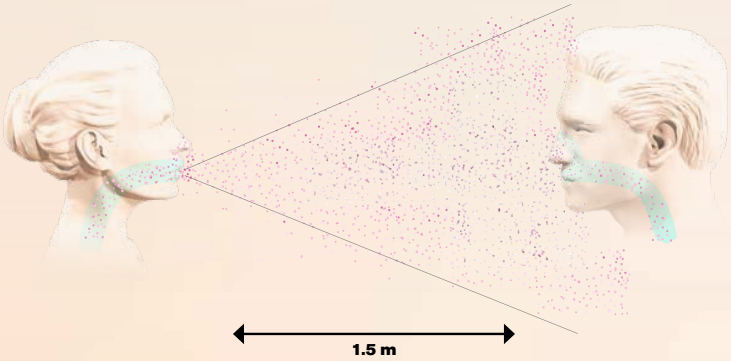
< 0.1 %

A PROPERLY FITTING MASK



To ensure that an FFP2 mask fits snugly on the nose, the nose clip should be bent in the middle, for example over a finger, and then made into a W-shape.

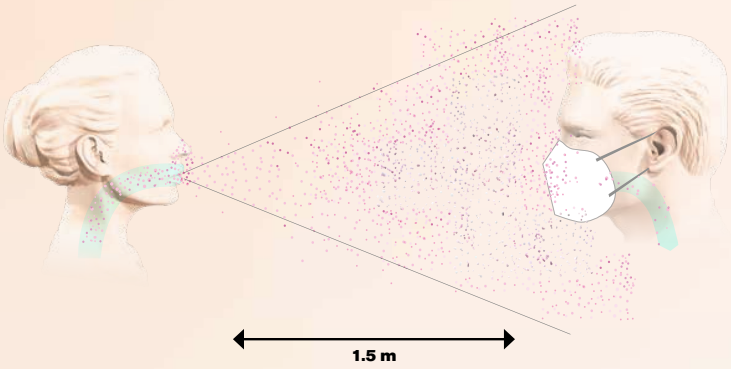
RISK WITHOUT A MASK



Very contagious: in the case of the omicron variants of the SARS-CoV-2 coronavirus, the maximum risk of infection is more than 99 percent after just three minutes if an uninfected person is standing 1.5 meters away in the breathing cone of a virus carrier.

> 99 %
3 min

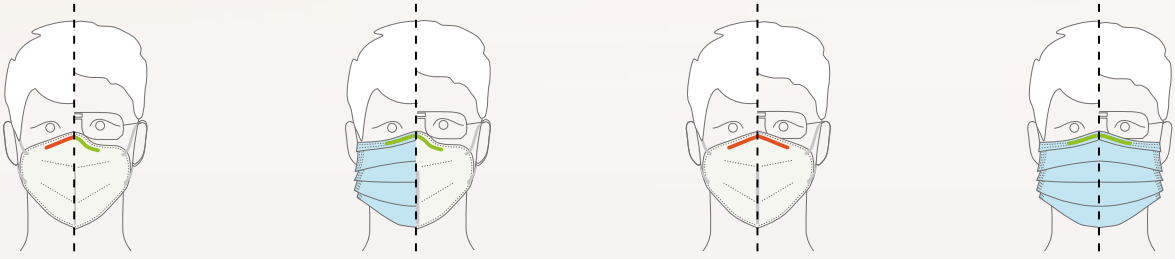
RISK WITH A MASK



Better than nothing: if the infected person is not wearing a mask, the risk of infection for an uninfected person wearing a well-fitting FFP2 mask at 1.5 meters is about 20 percent after 20 minutes and about 50 percent after 60 minutes.

~ 20 %
20 min

~ 50 %
60 min



0.5 % **0.8 %** **2.8 %** **7.6 %**

FOCUS

TO STAY OR TO GO?

On the move: two Wodaabe women load up parts of their mobile pastoral camp. Donkeys carry most of the loads, but motorcycles are also used, if available.

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

BETWEEN THE CITY AND THE SAVANNAH

TEXT: MECHTHILD ZIMMERMANN

The day-to-day life of the Wodaabe, a traditionally nomadic population group in Niger, has never involved staying in one place for long. But since the 1980s, an increasing number of them have begun to settle in cities to work. Florian Köhler, a researcher at the Max Planck Institute for Social Anthropology in Halle, has observed the effects this has had on the lives of the Wodaabe.

Nano, Taafa and Maalam Buuyo are brothers. And although all three have taken different paths in life, they still pursue a common goal. They belong to the Wodaabe, a traditional nomadic community. The brothers grew up on the savannah, moving from pasture to pasture with their herds of zebu cattle, animals not prone to excessive eating with long, curved horns. The group's other possessions fit on the backs of a few donkeys. Life was driven by the rhythm of the seasons, the search for water and pastures, the welfare of the animals. As boys, the three of them herded goats together and later, as teenagers, danced the Geerewol with their peers at clan festivals – a tradition for which the Wodaabe have become known beyond Africa.

Scattered groups, diversely networked

Since then, the lives of the three brothers have followed rather different paths. Maalam, the youngest, continues to live as a herder in the Damergou region, where he takes care of the family's herds. The other two have moved to the city for work. Nano lives about 150 kilometers from Maalam, in Zinder, the second-largest city in Niger, and often returns to the family's pastoral camp. Taafa, in contrast, lives far in Niger's south-east, in the city of Diffa, more than 600 kilometers away from his relatives. Despite this, he still maintains close contact with the family. "As different as the biographies of the three seem, they complement each other," says Florian Köhler, researcher at the Max Planck Institute for Social Anthropology. "Viewed in economic terms, this is a diversification strategy: the brothers who live in the city open up new income opportunities in order to spread the financial risks and improve the family's income, while the third brother takes care of the herds."

Taafa Buuyo was the first person from the Wodaabe ethnic group that Köhler met – purely by chance. The researcher went to Diffa in Niger in 2004 as an aid worker. While there he employed a watchman for the house that he was renting at the time. This watchman was Taafa Buuyo, who lived with his wife and children in a small house on the property. "The security situation in Diffa was quite relaxed back then," Köhler explains, "but it was just normal for foreigners from the West to employ security staff." And thus, he got the opportunity to get to know the Wodaabe family better. After three years in Diffa, Köhler worked on another development project, this time in the city of Zinder. And again, there was a Wodaabe watchman – Baji Buuyo, a half-brother of Taafa. Over time, Köhler's scientific interest in the nomads and their life between the city and the savannah grew. In 2010, the anthropologist decided to systematically research the changes in Wodaabe society. One central question that interested him was: what is changing in terms of belonging and social cohesion, mobility, and the relationship to other ethnic groups when a part of the group settles in cities for a longer period of time?

According to estimates from the 1990s, the Wodaabe comprise around 100,000 people, divided into fifteen clans. These clans live in small communities, which are scattered across the savannah, but are still interconnected in many ways. When a devastating drought hit the Sahel between 1983 and 1985, many nomads had to give up their former lives. Countless animals died and their owners settled on the outskirts of larger settlements; one reason for this being that the state and international organizations only distributed relief supplies in towns and villages at the time.

Some Wodaabe were able to rebuild their herds; others stayed in the cities. Much has changed in the pastoral areas of Niger. The country's population has grown from just under 7 million to more than 25 million since the mid-1980s. Population pressure means that an increasing amount of land is used for agriculture: areas that were once open pastureland are now fields. The pastoralists are running out of space, and these changes threaten the Wodaabe's existence. Florian Köhler says: "In light of this, income in the city ensures survival in the pastoral context as well." However, it was important for Köhler not to focus one-sidedly on the problems in his research, but rather on how people actively deal with them, their strategies and approaches to solving them.

To carry out his study, the researcher lived with a Wodaabe group for 15 months. This is in line with the ideal of participant observation, according to which anthropologists should, if possible, participate in the social and cultural life of the community under study for at least one annual cycle. The aim is to gain as deep an understanding as possible of community structures, ways of thinking and acting – but without judging these things. For Florian Köhler, that meant learning Fulfulde, the language of the Wodaabe, living by humble means with them in the city as well as in the savan-

"Many Wodaabe find the city dirty and confining."

FLORIAN KÖHLER

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

City life with privileges: this Wodaabe watchman (center) can live with his wife and children on his employer's property.

nah, and traveling together with them on open trucks, motorbikes, camels, in bush taxis, and on foot.

In Zinder, one of the main sites of Köhler's research, there lives a larger group of Wodaabe. Unlike the time before the great drought, when migration to the cities was a seasonal phenomenon, young men now settle in the city for longer periods. In Florian Köhler's research group, most of them work as watchmen, partly for expatriate businessmen or aid workers, partly at markets or in shops. Many have brought their wives and children with them to the city. The women also earn money: by braiding hair, or pounding millet, or as domestic helpers for wealthier families. The living conditions vary greatly: those working as watchmen for private individuals can often live with their families in a small house on the property. For others, it is more difficult to find a place to stay. They camp in unclaimed open spaces on the outskirts of the city or on construction sites, where the owner tolerates their presence, as it reduces the risk of construction materials being stolen. "If possible, the urban Wodaabe also keep a few goats in the places where they stay; they also grow millet or beans," Florian Köhler tells us. "That's quite common in Nigerien cities."

Regardless of the specific housing situation, the Wodaabe mainly have negative associations with the city. They find the urban environment dirty and unhealthy and feel confined there. The positive counterpart to the city is the open pastureland of the savannah. This is what most Wodaabe in the cities continue to identify with, even if they have not lived there for years or decades. The community of the pastoral camp from which they originate is still their "home" – even if this is not a fixed place, but a social group that is itself mobile. The deep connection arising from a community of origin remains, regardless of whether its members live in the city or in the country. Some urban Wodaabe also own cattle themselves: they ask relatives to buy the animals and take care of them. The investments are often not enough to build up larger herds. However, →

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

Improvised accommodation: some Wodaabe live in the city on building plots where work has been paused; this is a common occurrence in Niger.

Köhler sees this is an expression of attachment to pastoral life, one that simultaneously provides support for relatives who continue to live nomadically.

Cell phones now play an important role in the exchange between the scattered communities. The cell phone network in Niger has undergone increasing expansion over the last few years, stretching even to rather sparsely populated areas. At markets in rural regions, generator-powered chargers provide the necessary electricity. Cell phones allow nomadic groups to inform each other about the condition of pastures in different areas, about the condition of watering holes, or about market prices for animals or millet. Thanks to mobile telephony, those who live in the city can call their relatives in the pastoral camps at pretty much any time. One Wodaabe woman who settled in the city with her husband told Florian Köhler that cell phones had played an important role when it came to accepting a life far from her home community. However, cell phones do not replace the frequent mutual visits of relatives in cities and the countryside – on the contrary, they are also used to organize larger meetings.

Many Wodaabe are extraordinarily mobile – although few of them have a driver's license, or even their own car. They are already accustomed to changing location regularly thanks to the tradition of nomadic life. Even if they have lived in the city for a very long time, many Wodaabe there try to return to the pastoral camp as often as possible – preferably for longer periods of time. Women and children often spend the entire school holidays there during the summer rainy season. During this time, for example, the boys help their cousins herd goats, keeping them in touch with nomadic life. Conversely, relatives from the countryside often visit family members in the city, too.

"Most return to the pastoral camp as often as possible."

FLORIAN KÖHLER

Mobility in Niger, however, works somewhat differently than in Europe: there is no railroad, and the state operates hardly any public transport. According to figures from 2014, only about 4800 of the approximately 20,000 kilometers of road network are paved. Nonetheless, the Nigerien population as a whole is very mobile. Rural collective taxis operated by small entrepreneurs connect towns and villages; these could be minivans, Land Rovers, trucks, or old Unimogs with open loading areas, depending on the demand and the road conditions. This serves to provide a functioning transport system for people and goods – even if it is usually not very comfortable, as Florian Köhler experienced firsthand. In the countryside, camels, donkeys, and oxcarts are still vital means of transport.

Even though the urban Wodaabe's ties to their home community are strong, permanent close coexistence in the city entails new contacts with members of other ethnic groups. Europeans might find it surprising that different ethnic groups with different languages and cultures are living permanently on one and the same territory and have been doing so for some considerable time. In the 19th and 20th centuries, Europe developed into largely uniform states in terms of language and culture. On other continents, however, especially in Africa, the coexistence of different ethnic groups is a matter of course. And contrary to what we often perceive, this coexistence is often peaceful to a large degree. Despite the close proximity, the groups hardly mix. According to Florian Köhler, there are several reasons for this: "The cohesion within the community plays a role, but so does the individual's attachment to their own culture and rules – especially marriage rules that dictate that one should marry within one's own ethnic group." All this ensures that ethnic boundaries are maintained. At the same time, the different ethnic groups occupy different economic and social niches.

In Niger, for example, the Wodaabe traditionally keep mainly cattle, but there are also other nomadic ethnic groups that breed camels or sheep, as well as sedentary ethnic groups that mainly farm or trade. "Complementarity helps to avoid conflict and at the same time keeps the ethnic groups in contact via barter or trade," says Köhler. However, conflicts do also arise here, especially between farmers and keepers of livestock. For example, animals invading fields and eating or trampling cultivated plants is a common occurrence.

Mocking and joking encounters

One regional particularity in the relations between different ethnic groups in Niger is called known as joking relationships. These were even recognized as intangible cultural heritage by Unesco in 2014. A case in point is the playful taunting and banter that occurs between the Kanuri, an ethnic group that mainly practices agriculture, and the Wodaabe. All members of the respective ethnic groups, even if they are strangers to each other, exchange provocations and pleasantries when they meet. In doing so, they allude to clichés about each one another. For Köhler, joking together has a dual function: "On the one hand, you are setting yourself apart from the others by emphasizing certain

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GRAPHIC: GCO BASED ON A TEMPLATE BY THE MPI FOR SOCIAL ANTHROPOLOGY

Hardly any usable space: Niger is about twice the size of France, but two-thirds of the country is desert. Most of the population lives in the south, where agriculture is possible. Florian Köhler focused his research on the savannah areas of southeastern Niger.

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

Pastoral life in the city: many Wodaabe keep a few animals in the city to support themselves.

SUMMARY

Since the 1980s, members of the Wodaabe, a traditionally nomadic ethnic group, have increasingly been settling in cities – which also helps support nomadic life in the savannah.

In the city, there is increased convergence with other ethnic groups and a partial alignment with the majority culture.

At the same time, the urban migrants are in close contact with their pastoral relatives, which has the effect of strengthening cultural continuity.

characteristics of theirs in a witty and pointed way. On the other, this is exactly what establishes a relationship, because the mockery is reciprocal, and the shared humour connects."

In the cities, where the Wodaabe live in close proximity to other groups, relationships also change. The women in particular establish networks in the immediate vicinity. For example, the Max Planck researcher reports that sharing food with neighbors and acquaintances is common. The children naturally integrate the most; inter-ethnic friendships almost inevitably develop at school. This also means that the parents become better acquainted. However, proximity also has an effect on cultural distinctions. At school, Wodaabe children mostly speak the majority language Hausa, and many give up ethnic characteristics, such as traditional hairstyles. To avoid being ridiculed by their classmates, the girls forsake the characteristic topknot on their foreheads, and the boys cut off their traditional braids, sometimes without the consent of their parents. However, the hairstyle is an integral part of the Wodaabe ideal of beauty and thus important for participating in cultural events such as the Geerewol dance competitions. As Köhler has observed, though, the young men have come up with a pragmatic solution to the problem: they make hairpieces from their cut-off braids and join in the dances with these instead.

Not all contradictions between urban and rural life can be bridged so easily, however. The longer the Wodaabe live in the cities, the stronger the influence of the majority society becomes: the Wodaabe are not only increasingly adapting their outward appearance, but also changing their attitude towards certain moral issues. "The Islamic religion plays a special role here," says Florian Köhler. "Although almost all Wodaabe nominally belong to Islam, in rural areas the rules on marriage or sexual intercourse

PHOTO: FLORIAN KÖHLER / MPI FOR SOCIAL ANTHROPOLOGY

Three brothers, one goal: Maalam Buuyo (left) lives as a livestock herder, Nano and Taafa (center and right) work as watchmen in two different towns. Both of them support the extended family with their income.

before marriage, for example, are usually still determined more to a greater extent by their own tradition." Urban influence, for example, means that young women are encouraged to wear a veil and not to go out at night.

Translocal communities also exist in our society

"Today," says Florian Köhler, "the identity of the Wodaabe as an ethnic group is equally shaped by life in the savannah as by that in the city. Young people, in particular, who grew up in the city, get on there as naturally as they do in the rural pastoral camp, creating complex links between these two spheres through constant mobility, communication, and exchange," says the researcher with reference to the translocal dimension of urban migration. Translocality is a concept from social science that has been gaining importance for several years. It posits that social ties between people are not necessarily bound to one a single place, but exist evencan even exist over greater distances thanks to modern means of communication and transportation. In this respect, translocal relationships differ from the classic village community, whose members are tied to their hometown and concurrently to the people who live there. One particularity of the Wodaabe is that, as a nomadic ethnic group, they have always formed a translocal community. Consequently, maintaining social connection over a certain distance is not a new development for them – as Köhler has observed. The fact that the Wodaabe are culturally familiar with mobility and the temporary separation of the social group also helps them to maintain community ties between the city and the savannah.

"Today, Wodaabe identities are equally shaped by the city and the savannah."

FLORIAN KÖHLER

The example of the Wodaabe can also give us in Europe new perspectives on the coexistence of people from different countries or cultures. For example, many migrants here in Europe also maintain contact with their home community, language, and culture. Yet at the same time, they are an active part of our society – these parts of their identity are in no way mutually exclusive. Furthermore, this shows that even among people who have not migrated, circles of friends and relatives are now expanding over further distances. Translocality is becoming more and more commonplace for many of us. Perhaps this common ground can help us to develop more empathy for people with a migrant background and to define the concept of "homeland" a little more generously.

www.mpg.de/podcasts/gehen-oder-bleiben (in German)

Male and female blackcaps are easy to distinguish based on phenotype: where the males have a black cap reminiscent of the headdress of monks, the crown of the females is colored brown.

ILLUSTRATION: CORINNA LANGEBRAKE

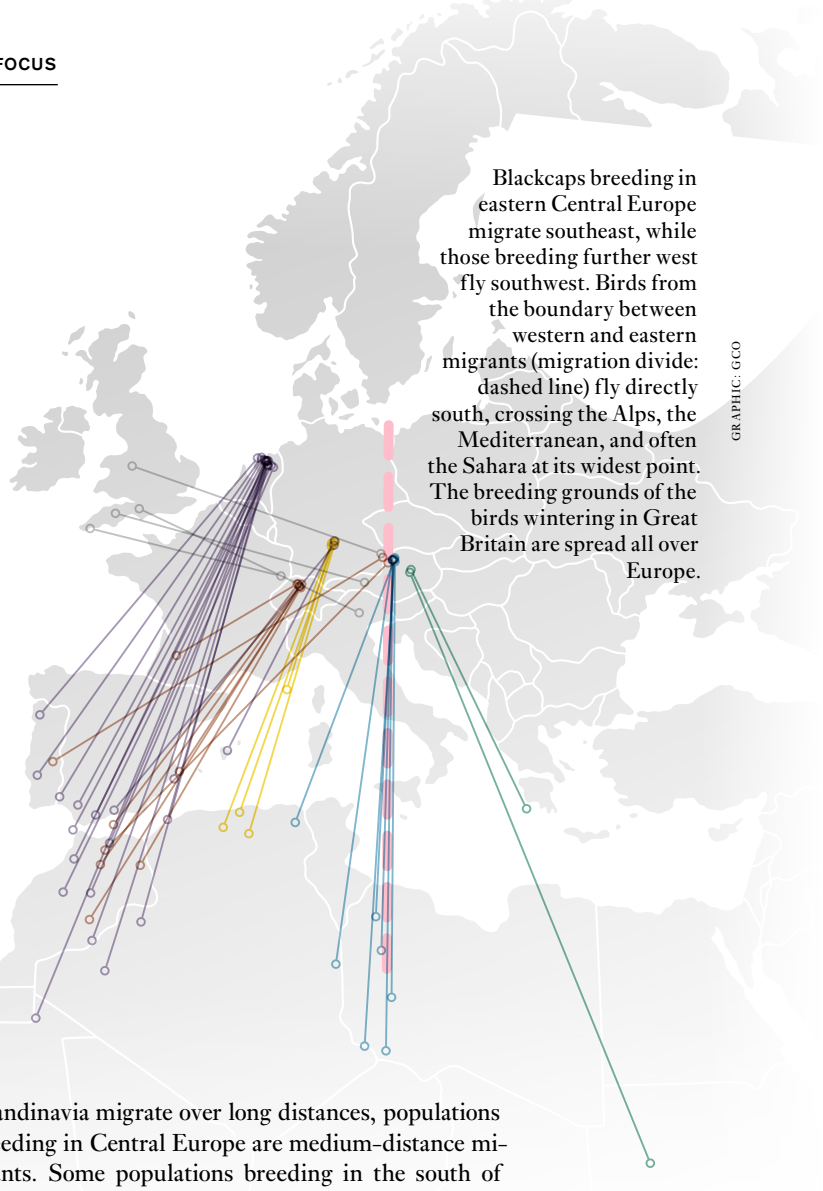
HOMESICKNESS IS IN THE GENES

TEXT: CATARINA PIETSCHMANN

This fall, millions of birds in the northern hemisphere once again heading south towards their non-breeding grounds. Miriam Liedvogel will be keeping her fingers crossed that some of them in particular will return safely next spring. The scientist at the Max Planck Institute for Evolutionary Biology in Plön has provided them with a bit of extra luggage to carry: specialized sensors known as light-level geolocators. Upon safe return next spring, these tiny light-sensors should reveal the birds whereabouts throughout the winter.

Through the open window comes a symphony of many voices. Loud and confident, as if the singers understood perfectly that they are the focus of the work that is done here. The trees and bushes of the grove that surrounds the Institute of Ornithology in Wilhelmshaven host songbirds of all kinds, with a few male blackcaps, easily recognizable by their black feather caps, also chirping along. The females, meanwhile, are still busy raising their young.

It is mid-July, and the young birds have no idea that they will soon be setting off on a great journey: southwards to North Africa, where it's pleasantly warm in winter and there are plenty of insects to eat. They will be traveling at night and alone; their parents often fly off two weeks earlier. Nevertheless, the young ones will know exactly where they are going and where their wintering grounds will be. Miriam Liedvogel is Director at the Institute of Avian Research, a non-university research facility with its renowned field office "Vogelwarte Helgoland." Here and at the Max Planck Institute for Evolutionary Biology in Plön, where part of her working group conducts research, the 44-year-old studies the genetic basis of the orientation and navigation abilities of migratory birds.



Blackcaps breeding in eastern Central Europe migrate southeast, while those breeding further west fly southwest. Birds from the boundary between western and eastern migrants (migration divide: dashed line) fly directly south, crossing the Alps, the Mediterranean, and often the Sahara at its widest point. The breeding grounds of the birds wintering in Great Britain are spread all over Europe.

GRAPHIC: GCO

Scholarships for bird migration research

Liedvogel's interest in bird migration manifested during her voluntary ecological year that she spent at the coast of East Frisia after graduating from high school. She then went on to study biology and earned her PhD at the University of Oldenburg. Initially, as a Marie Curie scholarship holder, she researched genes that control the timing of breeding in birds, and this was how she came to study the genetics of bird migration as a grantee of the Alexander von Humboldt Foundation in Lund, Sweden. This foundation eventually brought her back to Germany with a returnee fellowship, and since 2014, Liedvogel has been leading her own research group at the Max Planck Institute for Evolutionary Biology in Plön.

The desire to move – whether over land, through water, or through the air – is widespread in the animal kingdom. Birds possess this urge, but similarly, so do bats, butterflies, fish, sea turtles, whales and, of course, large mammals such as bison, buffalo, wildebeest, and reindeer. They all follow a genetic program that is passed from one generation to the next: "migratory genes" that have probably evolved, been lost, and re-emerged independently in these animals – necessitated, for example, by changing climatic conditions such as ice ages. Miriam Liedvogel wants to find out which genes control bird migration. The migratory behavior of blackcaps is the case study, since the birds exhibit the whole range of different behaviors; populations that breed in Scandinavia migrate over long distances, populations breeding in Central Europe are medium-distance migrants. Some populations breeding in the south of Spain only migrate a short distance, while other populations in southern Spain stay put. And even within a population, not all individuals exhibit the same behavior. Whether a bird from a partial migratory population decides individually from year to year if it will fly away or winter locally remains an unanswered question. Miriam Liedvogel therefore wants to find out whether one individual within a partial migrant population that migrates in one year does so regularly, and she's hoping to gain further insights from robins. These birds, too, are partial migrants in northern Germany: part of the population flies south in winter, while the other individuals winter locally. Conspecifics from Scandinavia, meanwhile, spend the winter with us.

Blackcaps present an especially good model for bird migration because their migration strategy varies not only in the propensity to migrate and migratory distance, but also in their direction of migration: populations breeding in eastern Europe migrate southeast in the fall and fly around the Mediterranean to the southeast, while blackcap populations breeding in western Europe circle past the Mediterranean to the southwest. This creates what is known as a "migration divide" – not a clearly recognizable border, but a narrow strip in which western and eastern migrants presumably mix.

The strip runs north-south across Central Europe between Berlin and Prague, and Liedvogel's team has found that breeding birds along the migration divide choose a "middle path." They fly directly south, crossing the Alps, the Mediterranean, and often the Sahara – the latter at a much wider point than if they were to fly around the Alps and the Mediterranean to the east or west. The last few decades have also seen the development of an entirely new flight route to Great Britain. But more on that later. The fact that songbirds inherit both the urge to migrate and the chosen route from their parents has been known for some time: Peter Berthold, Director at the Max Planck Institute in Radolfzell on Lake Constance until 2004, discovered this in the 1990s with elaborate breeding and crossbreeding experiments. His team mated parent birds from populations to the west and east of the migration divide and raised the young birds by hand. As soon as the parents left freely for their wintering grounds, the birds in the cage became restless. Without knowing the orientation preferences of their parents, the young birds tried to imitate them, fluttering excitedly in the same direction in which their parents took off. If birds from both populations were crossed with each other and the genes responsible for the flight direction were mixed, the offspring chose the middle path, i.e., the direct path to the south.

Liedvogel's research builds on Berthold's work. The main difference is that she no longer studies the animals under controlled conditions in a cage, opting instead to study them in the wild. But how does she know which migration direction a free-ranging blackcap has chosen in the fall and where it spent the winter? "The smallest GPS tracking transmitters still weigh three grams and are consequently too heavy for songbirds, which weigh about 20 grams, so we attach geolocators to the birds' backs," the researcher explains. These tiny archival "trip recorders" are 0.5-gram photocells with a memory card; they record the light intensity and thus

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PHOTO: MELINA MÖRSDORF FOR MPG

Miriam Liedvogel with a female blackcap. The researcher aims to find out which genes control the bird's migratory behavior. Birds at the institute are kept in large aviaries so that their behavior can be studied under controlled conditions.

the length of the day and night as well as the exact time. Using this data stored on the geolocator, the researchers can later determine, with an accuracy of roughly 50 kilometers, the particular location of the birds at any point on their migration, and thus reconstruct the route. "When the migration started, where the bird was flying, where and how long it rested, where its wintering grounds were, and when it flew back again – all this we won't know until we have recaptured the birds next spring and analyzed the data stored on the chip," Liedvogel explains. The researchers therefore have to hope that their birds will return to the same territory at their breeding grounds – which many of them do. Following this, they must retrieve the data, because it's still stored on the geolocator. It can take quite a bit of effort before a bird is netted. The researchers then remove the geolocator, download the data, and in addition to the migratory route, they also analyze the bird's genetic makeup using a blood sample.

This way, the researchers recover between 20 and 25 percent of the geolocators. So far, they have only tracked the routes of adults that had already successfully flown south once and returned. "We'd like to know how young birds fly to their wintering grounds the very first time, what they learn along the way, and how this newly acquired knowledge, combined with their inherited information, affects their subsequent routes," Liedvogel says. "Unfortunately, mortality in the first year is just too high for this technology to be working out." A migratory bird leaving its wintering grounds year after year has a lot of preparation to do each time: first, it molts in time to make sure all its feathers are fresh and unused for the long flight. At the same time, it builds up fat reserves. Blackcaps, for example, switch from insects to fruit as their food source in the fall and stock up on energy for the long journey. Many songbird species also change their chronotype from diurnal to nocturnal. In the cool of the night, they use less energy to cool their bodies, and therefore less fluid; in addition, they are better protected from birds of prey.

It is possible that just a few genes control all these processes, but these then act all the more strongly. "I suspect that a few master switches coordinate a complex network of further processes," says Miriam Liedvogel. One gene for a modulator of neuropeptide Y could be a candidate for such a switch, as a messenger substance that controls appetite and feed intake. "If this is produced in small quantities, the bird stays slim. If larger quantities are produced, appetite increases, and a lot of fat can be stored."

A build-up of fat reserves could be the domino that triggers the whole cascade. If the impulse fails, then the signal to leave also remains absent. Some populations breeding in Spain do not migrate at all and remain in the breeding area throughout the year. They do not accumulate fat reserves comparable to those of their migrating conspecifics, even during the migration period.

When a blackcap sets off for migration, it instinctively knows the direction, as Peter Berthold's experiments have shown. Since it flies at night, it can use the stars for navigation, and it also has a magnetic compass to keep its bearings. Other species that mostly migrate during the day follow conspicuous landscape features such as rivers, railroad tracks, or coastlines. They remember good resting places and include them as stopovers in their flight planning. But how does the small bird find its way when flying alone in the night sky? It orients itself according to the rotation pattern of the stars and the Earth's magnetic field – even when the sky is cloudy. According to the researchers' findings, there is a specific area in the bird's forebrain for night vision. "Since birds apparently perceive the Earth's magnetic field through their eyes, this area is probably also involved in magnetic field orientation," Miriam Liedvogel explains. This magnetic sense seems to be the most important aid to orientation, and it is possible that the birds inherit a kind of magnetic memory from their parents: "This is the right place, this is where I need to land." And on their return: "This is where I come from." Their sense of smell may also play a role. And what about when landmarks disappear, such as the River Po in northern Italy, which dried up this year? This is not a problem, because the migratory birds' "navigation system" has a back-up. "If

SUMMARY

Whether and where a bird migrates in fall is something it inherits from its parents, but the genes that control migration behavior are still to be identified.

To prepare for migration, birds change their behavior and metabolism. These adaptations are controlled by complex networks, which may, in turn, be regulated by a few controlling genes.

GRAPHIC: GCO AFTER MOURITSEN, H. LONG-DISTANCE NAVIGATION AND MAGNETORECEPTION IN MIGRATORY ANIMALS. NATURE 558, 50–59 (2018).

Birds can use various navigation aids on a long-distance flight: first, they orient themselves by the position of the sun and the starry sky as well as the earth's magnetic field (left). As soon as they reach their destination, smells, conspicuous landscape features, background noise, and the magnetic compass provide important clues (center). To orient themselves within their breeding area and find their nest, for example, birds rely on prominent landscape features such as trees or bodies of water as well as their sense of smell (right).

one navigation system fails, the bird can fall back on other strategies, such as the magnetic map and the star compass."

Unfortunately, in many areas of the world these days, the night is no longer dark. Landmarks that birds previously used to orient themselves are now outshone by light pollution, which can easily cause migratory birds to veer off course. "We know of several cases especially in the US, where thousands of dead birds are regularly found at the foot of illuminated skyscrapers during migration periods," Miriam Liedvogel recounts.

The global decline in insects and the climate crisis are likewise causing populations of many migratory bird species around the globe to plummet. "The hardest hit are the long-distance migrants, because their migration program is the most firmly fixed at the genetic level. If they leave too late in the fall, it may already be too cold, and they will freeze to death on migration." Short- and medium-distance migrants like blackcaps cope better with such changes. Due to the mild winters, blackcaps are now returning to northern Germany from the south three weeks earlier. "This is good for them because the oaks are sprouting earlier these days. This in turn means that the moth caterpillars, which feed on the leaves, become available earlier in the year as a source of food for rearing the young," explains Liedvogel.

The speed at which birds can adapt to new conditions is shown by even more profound behavioral changes through which the animals react to the warming climate. Since the 1960s, ornithologists have observed that an increasing number of blackcaps are turning northwest to overwinter in the British Isles instead of flying south. The birds are lured to the parks and gardens of Great Britain thanks to the mild winters resulting from the Gulf Stream. Extra food is an additional incentive: the British are known to be bird lovers, stocking countless feeders year after year and even baking special bird cakes. Added to this is the much shorter flight distance. "A study, in which many enthusiastic volunteers participated, has shown that birds wintering in Great Britain are able to replenish their fat reserves much faster and leave for their breeding grounds ten days earlier than their conspecifics wintering in the south. This would also allow them to choose the best territories for breeding," Liedvogel surmises.

Wintering in gardens can even affect the birds' body type: garden-dwelling blackcaps have longer bills and rounder wing tips. Likely an adaptation to their change in winter ecology: eating different food, living in gardens where better maneuverability is beneficial, and flying shorter migratory distances overall. It would appear that the blackcap is rapidly adapting its behavior, physiology, and morphology to changing conditions, which is apparently benefiting it at present: unlike many other bird species, such as the pied flycatcher, blackcap populations in Germany are stable and even increasing slightly. Flexibility and adaptability could also guarantee its survival in uncertain times in the future.

www.mpg.de/podcasts/gehen-oder-bleiben (in German)

ILLUSTRATION: LUISA JUNG FOR MPG

A DECISION FOR LIFE

TEXT: SABINE FISCHER

For decades now, migration has been massively changing the structure of society in Europe. But how does it actually feel to grow older in a new country? And does the risk that comes with migration ultimately pay off for those who take it? Stefan Gruber and Gregor Sand at the Max Planck Institute for Social Law and Social Policy set out to find answers to these questions.

For Barbara and Andrzej Klimczyk, Germany is a story that began at a highway exit. It was 1986, and the couple had originally planned to return to their native Poland after spending two years in Algeria. However, on this return journey, they had a change of heart – a decision that altered the course of their entire lives.

"We had many good years in Poland," recalls Barbara Klimczyk, now in her seventies, leafing through a dark green photo album. She sits with her husband Andrzej in their living room in Gerlingen, Baden-Württemberg, in an upholstered armchair that she brought to Germany many years ago from her parents' home in Gliwice, Upper Silesia. The album on her lap contains many memories of her time in her homeland. Photos of her standing confidently at the wedding altar in a short dress. A close-up of laughing girlfriends at a large festive table. Pictures Andrzej once took of their little daughter playing. Back in Poland, he was an architect and cartoonist, while she worked at the university and studied Russian literature. Her circle of friends consisted of beautiful minds and people with a feeling for art – a life characterized by intellectual exchange.

But when martial law was declared in Poland in 1981, the couple's everyday life changed abruptly. The economy was in stasis; at one point it was no longer possible to buy coffee at the supermarket. Andrzej's critical drawings were edited before each publication in such a way that their original message was completely lost. "In addition, the air in Gliwice's industrial fog was full of heavy metals and fumes. We didn't want our daughter to grow up in that environment," says Andrzej Klimczyk, adding: "We lived on a war footing from one day to the next. Yet we're people who need freedom." In the wake of this, it was not a difficult decision for them to get off the highway in Germany after a period spent working in Algeria. They hoped to live in freedom within a democratic system.

Hope for better living conditions

Many people who decide to leave their home country have similar considerations to those of Barbara and Andrzej Klimczyk. "One of the main motivations behind migration is the hope of improving one's own well-being and living conditions," explains Stefan Gruber of the Max Planck Institute for Social Law and Social Policy. Together with his colleague Gregor Sand, he conducted two studies on how those who opt to leave their homeland are affected by this decision over the course of a lifetime. The two researchers specifically selected the question of whether migrants over the age of 50 feel comfortable in the land they now call home.

Domagoj Vlasic also yearned for a new future when he first came to Germany in the mid-1990s. In his case, it was the Balkans war that severely shook his life: the native Croat was forcibly conscripted as a soldier for four years. An experience that not only turned his life plans upside down, but also left its mark. After his military deployment, Vlasic began suffering from insomnia, having post-traumatic experiences, and longing for a better life. Before the war upset his plans, Domagoj Vlasic looked set for a career as a professional soccer player in his hometown in what is now Croatia. It was precisely this prospect that opened the way to a new life for him: "I was lucky enough to get the chance to join a soccer club abroad," he recalls.

"We lived on a war footing from one day to the next. Yet we are people who need freedom."

ANDRZEJ KLIMCZYK

Via many twists and turns, the then 23-year-old finally landed a contract with a soccer club in Radolfzell on Lake Constance, bringing him into contact for the first time with a culture that had previously been completely foreign to him. "I didn't speak a word of German, which made things really difficult at first," he says. Today, his pronunciation is characterized by a mixture of a sharp Eastern European accent and soft, rounded Swabian. Back then, he had no idea that he would be spending his life in Germany from that point on. For him, the move abroad initially meant the prospect of a better life. For decades now, migration has been changing social structures in Europe. According to an evaluation by Germany's Federal Agency for Civic Education, more than one in four people in Germany in 2020 has a migrant background – a figure that points to the extent of migration movements in and to Europe. Many migrants live in their new home country for many years, gain experience there, and often play a decisive role in shaping society. But how does it feel to grow older in a country in which you were not born? Do people really feel settled in their new home? How do they feel about their earlier decision to emigrate? And did it really pay off for them?

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PHOTO: VERENA MÜLLER FOR MPG

Settled: Barbara and Andrzej Klimczyk immigrated to Germany in 1986. Their interest in art and literature has helped them build a circle of friends here.

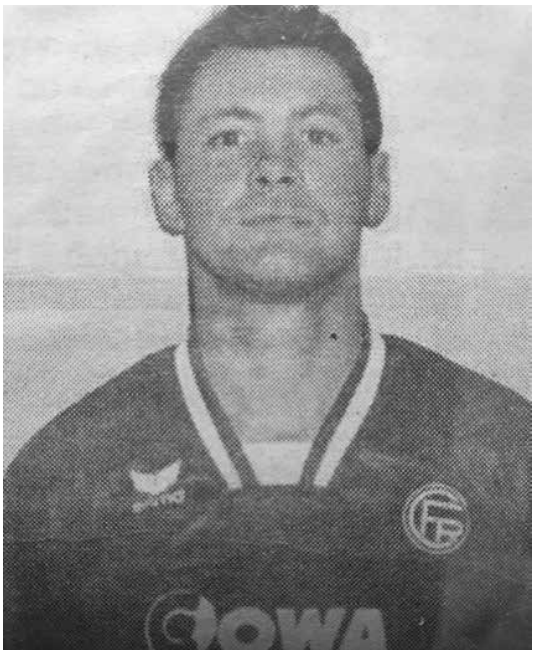

PHOTO: PRIVATE

New to the club: In the mid-1990s, Domagoj Vlasic came to FC Radolfzell on Lake Constance as a soccer player from Croatia. The newspaper picture is a souvenir from back then.

The answers that the researchers found to these questions in the course of their two studies are impressive: comparing the well-being of people who have migrated from one European country to another with the well-being of those who have remained in their countries of origin reveals positive effects of migration: "Migrated individuals – we restricted ourselves to intra-European migration – display significantly higher well-being than people who have not migrated. Here, the decision to migrate seems to have paid off in most cases," Gruber says.

"We now feel that we made the right decision in coming to Germany," says Andrzej Klimczyk, confirming this. And this was despite the fact that the young family, which was recognized as ethnic German repatriates by the German state in 1986, did not get off to an entirely easy start. Barbara Klimczyk, who belonged to the German minority in Upper Silesia, has spoken German as well as Polish since her childhood. Still, it took the couple a while to settle into their new home. After working in the border transit camp Friedland and in Aachen, Andrzej finally found a job as an architect in Stuttgart, while Barbara taught German to other immigrants. They also began to embrace their love of art and culture again here: "We love going to art exhibitions and readings, especially at the excellent Stuttgart Literaturhaus. It was through these things that we gradually began to network with people. That made it much easier for us to get settled," says Barbara Klimczyk.

Domagoj Vlasic, on the other hand, noticed a feeling of being at home in Germany almost in passing. For a time, he lived near the Swiss border and made frequent trips to the neighboring country. It was there that he experienced a realization: "I thought to myself every time, no, these are just not my people. It's nice here, but I also want to go back home – and by that I meant Germany," Vlasic says. According to the findings of Stefan Gruber and Gregor Sand, this feeling of being settled is contingent on many factors. The research duo uses results from the Survey of Health, Ageing and Retirement in Europe (SHARE). In their subsample, 105,000 people from 11 European countries were surveyed on various topics. About eight percent of them are considered migrants – that is, at the time of the SHARE interviews, they were living in a country in which they were not born. "The dataset is not limited exclusively to people who have migrated, but the subsample size is large enough to allow us to draw meaningful conclusions from it," Gruber explains. Especially exciting is the fact that those with a migrant background in the SHARE dataset emigrated a long time ago. On average, they have lived in their new home for 40 years – optimal for Gruber's and Sand's research objectives: "We can measure whether their circumstances have improved – across economic and non-economic factors," Sand says.

To do this, the researchers took a close look at the CASP index in the dataset – a scale that measures people's quality of life based on the factors of control, autonomy, self-realization, and pleasure. "Twelve items are surveyed to produce this index. For example, whether people are looking forward to the next day or whether they feel they have control over their lives and can do the things they feel like doing," explains Stefan Gruber.

For people to be happy throughout their old age in their new homeland, individual and social aspects are just as decisive as the financial situation, he says: "The level of income that people manage to attain in the destination country is important," says Gregor Sand. This is precisely where a crucial limitation lies with regard to the

"The more comfortable people feel in a country, the better integrated they are."

STEFAN GRUBER

SUMMARY

Those who emigrate within Europe benefit compared to those who remain in their home countries: on average, migrants are financially better off and more satisfied than their native counterparts.

However, compared to the native population of the country to which they have migrated, immigrants often have less money and feel less well-off.

Policies can help to boost migrants' satisfaction by improving their access to the employment market and citizenship and by facilitating family reunification. Society as a whole also benefits from this.

positive effects of migration: in spite of the fact that migrants are usually significantly more satisfied than people in their country of origin, the comparison with natives in their country of destination is often negative. On average, those who have emigrated here have measurably lower well-being than those who grew up in the country. "This is where the financial situation plays a significant role," Gruber says. "But other factors – such as whether individuals have citizenship in the country – also influence how happy they currently are."

If you take a closer look, the results also reveal some subtleties. The researchers identified significant differences, particularly regarding the origin and age of the respondents: "For example, if someone from northern or central Europe emigrates to Sweden, their well-being does not differ significantly from that of the locals," Sand says. The difference between natives and immigrants is particularly evident among people from southern or eastern European countries. And it depends significantly on the age of the respondents. In short, the older they get, the smaller the difference becomes. However, according to Gruber and Sand, this is not because migrants become happier in old age, but rather because other factors become more decisive than migration. "Well-being decreases with age for all respondents, proportionally more for natives than for migrants, meaning that the falling curves of both groups slowly converge," says Gregor Sand.

The level of satisfaction immigrants can reach in a society depends mostly, and decisively, on the integration policy of the new host country. How significant are the obstacles? How straightforward is access to the employment market and healthcare? To education, culture, citizenship? "To understand this influence, we also looked at the integration policies of different countries," Gruber says. The result of this observation is clear: countries that pursue an open integration policy actively contribute to closing the gap in satisfaction between immigrants and natives through this course of action.

"For us, there are three big lessons to be learned for better integration," concludes Stefan Gruber. To ensure greater well-being, he says, it is important for countries to create equal access opportunities for migrants and natives in the employment market. They should also make access to citizenship as easy as possible and provide opportunities for migrants' families to join them without having to jump through bureaucratic hoops. According to the two researchers, these recommendations to policymakers have meaningful societal implications. After all, the more comfortable people feel in a country, the better integrated they are – and the more invested they become, the more they contribute to society and help shape it. According to Gruber and Sand, the consequences of this include a reduction of the burden on social systems and living together in more diversity.

Confidently European, cosmopolitan, and invested

The ability to play an optimal role in society is also important to Barbara and Andrzej Klimczyk. Both see themselves as European, cosmopolitan, and invested. "We can get to know people and things that we wouldn't have been able to otherwise," says Andrzej Klimczyk. Today, they are involved in the German-Polish community and have also built up a circle of friends in Gerlingen with diverse interests. Apart from a few close relationships from their youth, this circle consists largely of people in their immediate vicinity.

Domagoj Vlasic has also built up a large circle of friends and his own family in Germany. When he compares his life with those of his acquaintances, he looks in both directions: how is he doing in comparison to his German neighbors? And where does he stand compared to his acquaintances in Croatia? In both cases, he is satisfied with what he has achieved. "I'm happy here. But I'm starting to wish for a little less hustle and bustle in my life – the opportunity to grow vegetables with my own hands, to relax," he says. He would now like to spend his retirement together with his wife in Croatia, near his parents' former farm. However, this does not mean he will be saying farewell to Germany for good. "The country has become my home. When it gets boring in Croatia in the winter, I'll probably go back to the Christmas market in Germany, although it's likely I'll return sooner than that."

www.mpg.de/podcasts/gehen-oder-bleiben (in German)

Crispy jellyfish, milk mayo, and crackling vegan sausage – just a few of the specialties from the laboratory of Thomas A. Vilgis. The research group leader at the Max Planck Institute for Polymer Research in Mainz approaches cooking with scientific precision and has thus found the perfect synthesis of his two passions.

TEXT: CATARINA PIETSCHMANN

Chanterelles with dumplings, interspersed with a few diced carrots, still slightly crunchy. "It's always important to have different textures in your mouth. That makes it more interesting for the tongue," says Thomas Vilgis as he continues to dissect the mushroom dish with his fork. "The carrots are still neatly cut by hand. Beautiful irregularities. Just the way I like it!" Anyone who dines with Vilgis can't help but ask what he notices about the meal, as well as pondering their own mouthfeel. This man is neither a celebrity chef, nor a nutritional physiologist or food chemist – he's actually a theoretical physicist. But he knows exactly what he's talking about. Thomas Vilgis is in charge of the "Soft Matter, Food Physics" group at the Max Planck Institute for Polymer Research in Mainz until 2024. He and his team investigate food structures and research novel foods. But exact science is only one side to Thomas Vilgis. In addition to countless specialist publications, the 67-year-old has now written more than 20 popular books covering the science of cooking, unusual taste experiences, and – of course – recipes. Spring this year saw the publication of *Der Genussforscher (The Taste Researcher)*, adapted from his Saturday afternoon podcast on SWR, *Kochen mit Genussforscher Prof. Thomas Vilgis (Cooking with Taste Researcher Prof. Thomas Vilgis)*, complete with a recipe for download. His latest work – *Noch mehr Kochen für Angeber. Die geheimen Tricks der Sterneküche (Even More Cooking for Show-offs. The Secret Tricks of Acclaimed Cuisine)* – has just hit bookstores, and his standard work, *Aroma. Die Kunst des Würzens (Aroma. The Art of Seasoning)* is already in its fifth edition. He is also co-editor of the *Journal Culinaire,* the magazine for the culture and science of food. Professor! How did this all come about?

Thomas Vilgis laughs. "Ah, that is a strange story. I had been working with soft matter for a long time. At first it was rubber and other polymers, later colloids, then proteins. I was a typical paper-and-pencil theorist – but then computer simulations developed incredibly quickly, and this soon made it possible to explore the boundaries of theoretical physics more easily than on paper via so many approximations." He didn't want to delve into simulation himself, not least because another window had already opened: through it, he could see pots and pans from which irresistible aromas wafted, unexplored textures of food … All of which was essentially just waiting for him to analyze and understand it. Partly to blame for this was food critic Wolfram Siebeck, whose column in *Die Zeit* was regular reading for Vilgis, himself a passionate amateur chef. Once, when Siebeck excoriated a special way of baking pizza, Vilgis wrote a letter to the editor: what Siebeck had tried out in this instance was nonsensical from a physics perspective anyway, he explained, because ... And a short time later, the editor-in-chief of *Essen & Trinken* asked whether Vilgis might write a regular column on "Food and Natural Sciences" – that was back in 1999. Mussel mousse, melon caviar – molecular cooking was also making its way into Germany's haute cuisine at the time. "People were

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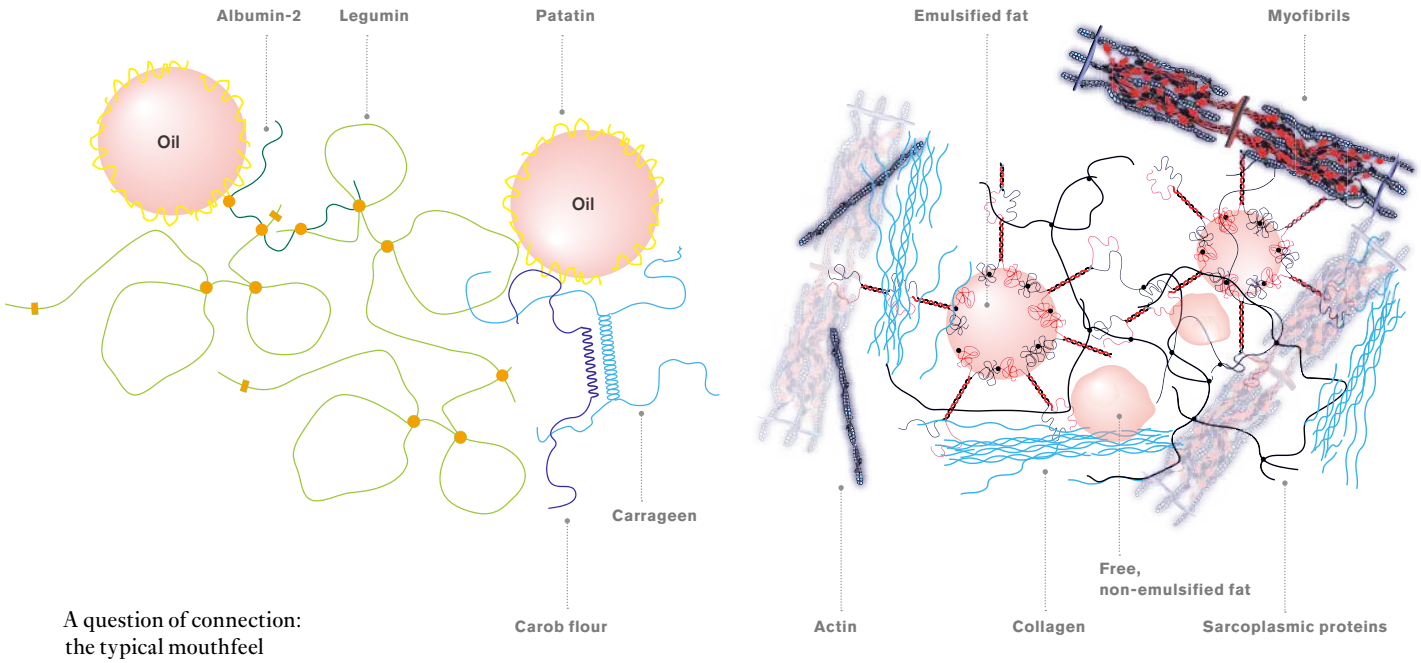
VISIT TO

THOMAS VILGIS

PHOTO: KATRIN BINNER FOR MPG

The tear test: Thomas Vilgis investigates the physical properties of food, including the difference in textures between Mortadella and vegan sausage.



A question of connection: the typical mouthfeel produced by meat sausage (right) results from the close-meshed linkage of myosin and sarcoplasmic proteins (black dots). The collagen also causes a partly elastic and partly viscous behavior. This effect, as well as the ability of collagen to bind water, is something researchers are trying to imitate in vegan sausage (left) using xanthan gum, carrageenan, or other binding agents. However, since the binders separate from the chemically cross-linked plant proteins due to their chemical properties, vegan sausage can generally stretch much more than meat sausage.

experimenting wildly with gelling and thickening agents – all pure polymer physics." Thomas Vilgis met the French physical chemist Hervé This, whose book *Kitchen Mysteries: Revealing the Science of Cooking* was causing a furor at the time. "We quickly became firm friends and have enjoyed many a discussion ever since."

Applying physics to analyze food and its preparation methods? Why not! "I was already at the Max Planck Institute at the time, and I mentioned it. It really sparked a fire right away. I got a budget, two lab rooms, and bought our first rheometer." The latter is a device that can be used to determine the elasticity, flow behavior, and shear forces of a material. It consists of one fixed and one movable plate, and the sample is placed between the two. "Things really took off when a manufacturer of food production machinery asked if we could investigate the flow properties of pasta dough for them," Vilgis recounts. The research project secured a postdoc position for two years. In addition to actors within the food industry, doctoral students frequently approach him with exciting ideas of their own. And he is largely driven simply by his own curiosity – for example, the question of what gives caviar its particular mouthfeel. "I got hold of some caviar and trout eggs for comparison and put both under a universal testing machine that had been temporarily converted into a texture analyzer." In it, a stamp slowly but steadily presses down on the sample from above. This is pretty much what happens between the palate and tongue as caviar is "processed" in the mouth. Initially, we see the high elasticity of the eggs' outer membrane, followed by their bursting as the force suddenly drops. "At that moment, all the flavors are released explosively in the mouth." Collagen and elastin in the tiny egg membrane form a very special network, Vilgis found. "In order to describe the tear propagation and bursting, I unpacked what I had learned some time before about the theory of rubber elasticity."

Sugar substitutes, vegetarian and vegan products, current food trends – the topics Vilgis covers are incredibly varied. Some of them are bizarre, such as the jellyfish chips he is researching together with Danish researcher Mie Pedersen. In Asia, where cnidarians are traditionally eaten, they are placed in a mixture of table salt, calcium chloride, and aluminum salts after being caught. "As the monovalent, divalent, and trivalent ions accumulate, the proteins contract, and the jellyfish is dehydrated. The result is a kind of gelatin gum, but it's quite crunchy," Vilgis explains. Aluminum salts are suspected of promoting Alzheimer's, so Mie Pedersen tried some-

GRAPHIC: MEAT, VEGETARIAN, AND VEGAN SAUSAGES: COMPARISON OF MECHANICS, FRICTION, AND STRUCTURE; PHYSICS OF FLUIDS 34, 047112 (2022); M.GHEBREMEDHIN, M. BAECHLE, T. A. VILGIS

thing new: instead of salt, she put the animals in 96-percent alcohol. Jellyfish proteins bind a large amount of water but are poorly soluble in alcohol and clump together – polymer physics par excellence. This also removes water from the animal and shrinks it into a flat disc, which is then dried out. "You get a crisp, salty chip that makes a great aperitif or provides a textural element in certain dishes."

Sometimes the Institute resembles an experimental kitchen. Mayonnaise is usually made with eggs, but milk can also be used as an emulsifier, as studied by master's student Katja Braun. "We took some milk and then slowly drizzled in the oil while stirring vigorously." Vilgis had already tried this a few times at home. But how stable does this emulsion remain? How big are the droplets of oil in the milk mayo? "For this project, we purchased transparent rheometer plates. This allowed us to see exactly at what shear rates the oil droplets become deformed and begin to fuse. In the process, the viscosity changed." It's the moment when mayonnaise suddenly becomes more liquid in the mouth. A milk mayo (without additives) remains stable in a fridge for seven days. The same principle also works in a vegan version – really well, actually – with soy milk. Oat milk, on the other hand, was a flop, for reasons of pure physics.

with minced meat sauce. "To me, it was a fascinating new taste, and that's what ended up on the table at home."

It was while the food projects at the Institute were getting underway that Stiftung Warentest asked if Vilgis could co-author a book on how best to use flavors in the kitchen – all based in science, of course! "As a physicist, I had zero idea about flavorings and fragrances, so I started by reading a lot of original literature." Somehow, Vilgis had to come to grips with thousands of different aromas. But how? Are there specific types of aroma? Apparently, yes. "Chemically, the smell you get from flowers in the spring is all down to acyclic terpenes. Although flowers smell different depending on the plant species, the basic odor is the same, and that also goes for the sulfur compounds in garlic, onion, and cabbage." Herbaceous aromas are based on cyclic terpenes. And so it goes on through eight aroma types that Vilgis color-coded. But wait, there's a ninth: for odorless substances that do not stimulate the taste buds for sweet, sour, salty, bitter, or umami – but rather the trigeminal nerve. Like the pungent capsaicin in chili or oxalic acid, which accounts for the dull, astringent mouthfeel of sorrel, spinach, and rhubarb. "One thing became clear to me: aroma chemists may laugh their heads off at my systematics, but you can put it to

"One thing became clear to me: aroma chemists may laugh their heads off at my systematics, but you can put it to good use in the kitchen."

Even as a young boy, Thomas Vilgis liked to look inside the pots and pans while his mother cooked. So what was his favorite food when he was little? "Liver sausage pate at noon and liver sausage pate in the evening," he recalls with a smile. "This phase was then replaced by chocolate loaf at lunch and dinner, but also lentil stew, Pichelsteiner stew, and sour tripe." In the late 1960s, he took part in a cooking club at school, which was led by the landlady of the Ochsenwirt, a rustic local restaurant in his birthplace of Oberkochen. "The first guest workers from Italy had already made it to small-town Baden-Wurttemberg, and so we once cooked 'baschta schutta'" – *pasta asciutta,* or spaghetti

good use in the kitchen." In 2014, however, an important publication appeared by those previously dismissive experts at the Technical University of Munich. They had been searching for primary aromas in foods and their origins and now indirectly confirmed that Vilgis had been quite right with his intuition. "Phew!"

Nature is playful and complex, and so almost every spice, herb, vegetable, or fruit combines several aroma groups. Vilgis' color code makes it easy to see which ones. It's also easy to see which spices, such as garlic and onion, are similar to each other and enhance the flavor – specialists call this food

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PHOTO: KATRIN BINNER FOR MPG

There may be many cooks, but the broth stays good: Mathias Bächle, Marta Ghebremedhin, Hannah Hartge, Thomas Vilgis, and Juan Carlos Zambrano (from left) jointly develop ideas for new research projects—recently, sustainable nutrition has been a major topic.

pairing – or create exciting contrasts, referred to as food completing because they bring flavors that garlic, for example, lacks – such as lemongrass, ginger, or thyme. Flavors change with processing – and with temperature. So it can make a big difference whether something is eaten raw, boiled, fried, or fermented. Regular sugar, for example, is just sweet. When it is heated to over 150°C in a pan and melted, it becomes caramel – aromatic and crunchy. That's right, textures change, too! "Textures essentially determine the mouthfeel of a food," Vilgis emphasizes. Analyzing and changing them is part of his profession. Recently, for example, his team discovered what makes foie gras melt so delicately and how to recreate it without cruelty to animals – from livers of geese that have not been stuffed. But just how they managed it remains a secret for now.

On the subject of more sustainable foods in general, Vilgis has recently devoted his attention to sausage substitutes. Conveniently, the sausage from a well-known manufacturer is available in the refrigerated section of the supermarket in its original meat version, as a vegetarian version (with egg white), and as a vegan version (with potato and pea protein). "I wanted to know what made the difference, so I talked two PhD students into a Friday afternoon experiment." That gradually evolved into a comprehensive study published in the journal Physics of Fluids. In the rheometer, the samples behaved almost identically, but tensile experiments revealed glaring differences: while the meat sausage was initially very elastic and then quickly tore apart, the vegan one could be stretched almost endlessly. "Most manufacturers mix something together and only pay attention to whether it tastes good, but the emulsification properties of muscle proteins from animals are different to those of plants." Based on the experiments, the team developed models of the microstructure of sausage and sausage substitutes that explain how different proteins affect mechanical behavior and thus mouthfeel. Crucial to the typical feeling of biting into a sausage is the network that the proteins form. Proteins from sunflowers have a better structure for

emulating this than those from peas, and the company has since adapted the recipe for its meatless sausages accordingly. Nevertheless, Vilgis finds it almost reprehensible that pure protein is often used as a meat substitute. "Fiber, polyphenols, vitamins, bulk – everything is disposed of! That's crazy and also makes you less full."

He has no regrets about his shift to food physics. "Quite the contrary! It was the best decision of my life," says Thomas Vilgis. "Methods from physics are very suitable here; they can be applied directly— and I also directly benefit from my work." That's because at the Vilgis family home, they cook every night. "One look in the refrigerator, full power to the flavor library in your head, texture and cooking physics programs running in parallel: and so it begins." His wife takes care of the appetizer; he prepares the main course. After that, there's a tiny bit of cheese, a dessert (often fruit), and a bit of chocolate to finish. You wouldn't know it by looking at him – no wonder, then, that he confesses to doing "a bit of exercise": 100 push-ups and 100 situps almost every day after getting up, and extensive weight training on Sundays. At the Institute, meanwhile, he always moves with "excessive speed," running up and down the stairs. Even when sitting or standing, he fidgets around, sometimes tensing one muscle, sometimes another. This is good for the autochthonous dorsal musculature, says his personal physiotherapist – and longtime spouse.

was no fresh fish, so Vilgis was treated to fish fingers or "fish sticks" instead. "I loved them! Whenever we have them in the cafeteria, I stand at the front of the line and feel like I'm five again."

Thomas Vilgis generally cooks without a recipe and is always on the lookout for new, unusual taste experiences. The scientist wastes no time; food completing starts with Sunday breakfast – to the large muesli, comprising various fresh and dried fruits, are added herbs from the family's own garden. Sometimes marjoram – "the more intense, the better" – sometimes thyme, sometimes basil. Whatever's growing at the time. His favorite spice is tonka bean (hay-like, notes of vanilla, slightly bitter). "In desserts, it is often used together with vanilla. Add a pinch of nutmeg, and it's like a perfume." But he also adds the tropical spice as a "final rub" to savory things: roast potatoes, chicken, fish, and even red cabbage. "Caramelize sugar and butter with a little vanilla in the pan, briefly roast the finely chopped cabbage in it, pour some cream over it, a little tonka bean, and salt. Mmm! Perfect with game." This is likewise covered in the cookbook Der Genussforscher – as are cold fruit minestrone with Campari, heel muscle of beef flavored and trussed, and creamy celery nut vegetables, among other things. To finish, perhaps a "Cossack croissant" from the famous Loriot comedy sketch? Instead of whipped cream, Vilgis crowns the legendary dessert – a mocha truffle parfait with lemon cream balls – with a tiny meringue. That

"Convenience foods and frozen goods only make it onto my plate for scientific purposes."

The couple met in Ulm, where he was studying physics. Since then, they have been going to the weekly market together every Saturday. Vilgis' dietary principles: only fresh and seasonal food. Snacks between meals? Never! Never eat until you're completely full. Variety is what satisfies you – not quantity. "Convenience foods and frozen goods only make it onto my plate for scientific purposes." Although … there is one thing he finds hard to resist. In the past, at home in the Swabian Alb, there

makes it particularly difficult to divide exactly down the middle – a problem that ruined the friendship of two married couples in the Loriot sketch. But Thomas Vilgis, of course, is not interested in sowing discord with this variation; rather – as you might guess – in the exciting combination of textures and flavors for the sake of an exhilarating mouthfeel: cold, creamy, and crisp – bitter, sour, and sweet.

www.mpg.de/fleischfreie-wurst (in German)

PHOTO: AKG-IMAGES

DOUBLE TAKE

MAX PLANCK INSTITUTE FOR HUMAN DEVELOPMENT

April 1822. Ottoman soldiers kill thousands of Greek civilians on the island of Chios during the Greek War of Independence. Reports and pictures of the event, like this one by Eugène Delacroix (left), spread across Europe, triggering a wave of compassion and support. Historian Caroline Moine sees this as one of the origins of international solidarity. Today, it is the war in Ukraine that arouses feelings of solidarity in Europe – in a similar way to back then. Images of atrocities, a clearly identified enemy, and common values that are at stake drive people onto the streets – just like here in Berlin.

PHOTO: CARO / KRUPPA / FOTOFINDER.COM

A COPYING MACHINE FOR GENES

TEXT: ANDREAS LORENZ-MEYER

Nothing works with incomprehensible code – not even a cell. Patrick Cramer is carrying out research on the enzyme that transcribes the DNA code to enable a protein to be synthesized from a gene. To do so, he relies on high-resolution microscopes and artificial intelligence.

Showtime! The movie zooms right into a cell nucleus. Like a screw, the DNA double helix propels into the active center of the RNA polymerase. "There, it is unwound, and one of the two DNA strands then serves as a template for synthesizing the messenger RNA molecule," explains Patrick Cramer, Director at the Max Planck Institute for Multidisciplinary Sciences in Göttingen. On Cramer's screen, the RNA product emerges as a single strand from the body of the polymerase enzyme. The RNA later serves as a construction plan for a new protein.

In technical language, this process of copying DNA into RNA is called gene transcription. "It is the process that brings our genes to life," says Cramer. It's no wonder that the sole function of a large fraction of our proteins is to enable and regulate transcription – about 1800 in total. And one of these players dwarfs all the others: the enzyme RNA polymerase II, which is responsible for producing messenger RNA. "Our central copying machine," is what Cramer calls this enzyme made up of several subunits. When he tells us that the enzyme develops a force of 20 trillionths of a newton and incorporates 3000 building blocks per minute into RNA, the 53-year-old molecular biologist's admiration for the enzyme's capabilities is palpable. Even after years of research, he has lost none of his enthusiasm for the fascinating processes that underlie cellular life.

Cramer's scientific career took him to Stanford University in California, where he was a postdoc from 1999 to 2001. It was during that time that Cramer became the first to decipher the complicated spatial structure of RNA polymerase II. His mentor at Stanford was Roger Kornberg, who later won the Nobel Prize for Chemistry for elucidating the molecular basis of transcription. The work at Stanford provided researchers with a first glimpse of the inner workings of the polymerase machine. In Cramer's office at Göttingen, there is a model of the enzyme that resembles a colorful coral. Among other things, it shows the cleft in the molecule where DNA is transcribed into RNA.

The research work back then at Stanford was the starting point for decoding the entire transcription process: this enabled many questions to be answered – for example, how RNA polymerase is directed to the start site of a gene. Or why the enzyme constantly takes breaks when it slides along DNA: "These pauses are necessary because there is sometimes grit in the transcription gear, in which case, helper molecules, known as elongation factors, rush in. They remove the obstacles – and transcription can continue," Cramer explains. To decipher the process further, the researchers have had to develop several different experimental and computer-based methods over the years.

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PHOTO: SRINIVASAN RENGACHARI, SHINTARO AIBARA, PATRICK CRAMER; MPI-NAT

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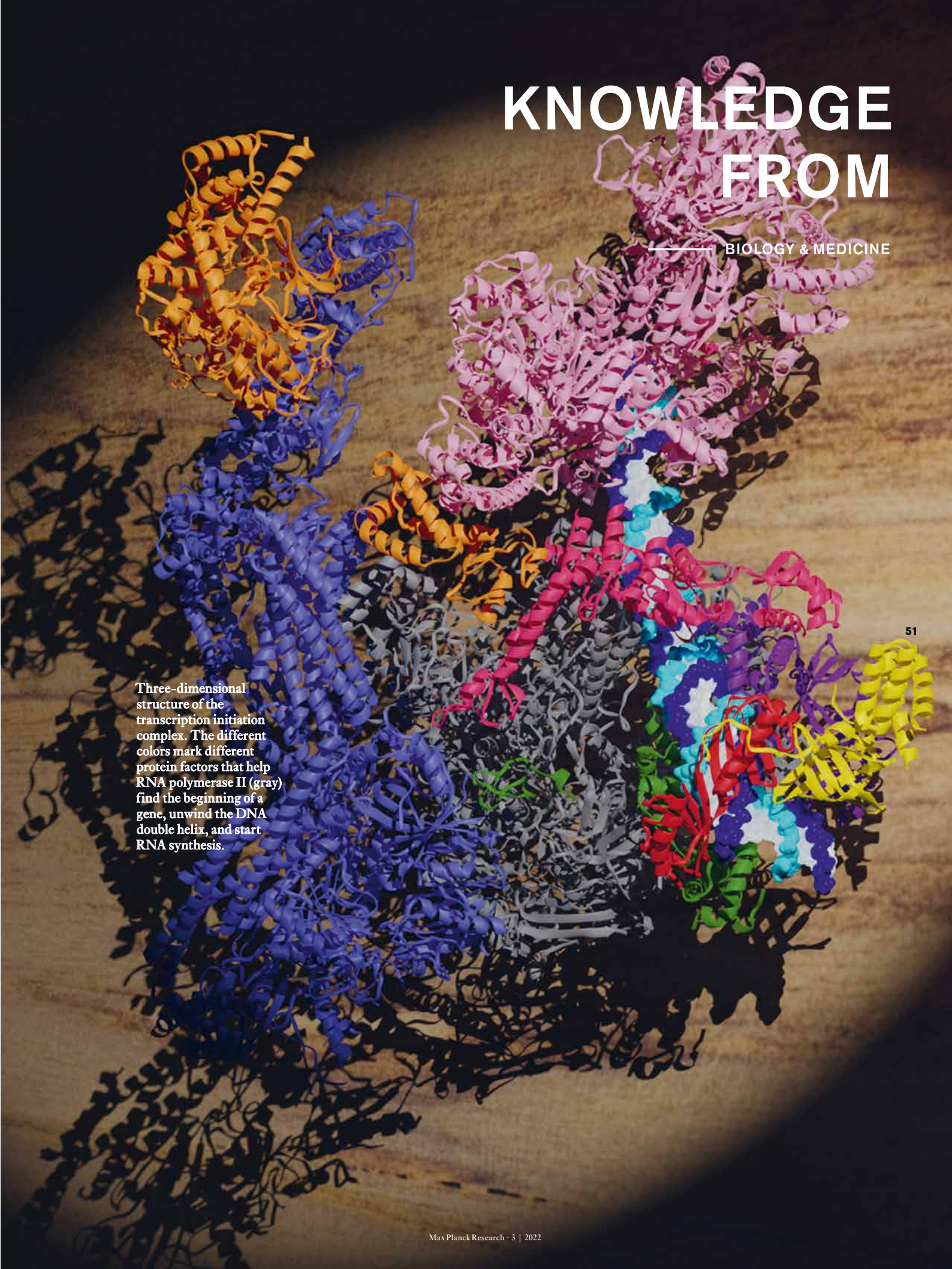

Three-dimensional structure of the transcription initiation complex. The different colors mark different protein factors that help RNA polymerase II (gray) find the beginning of a gene, unwind the DNA double helix, and start RNA synthesis.

PHOTO: IRENE BOETTCHER-GAJEWSKI / MPI FOR MULTIDISCIPLINARY SCIENCES

Decoding gene transcription is a team effort: Patrick Cramer (center) with members of his laboratory.

Twenty years on, transcription research is now entering its next phase. "So far, we have reconstituted and studied the transcription process on single genes outside the cell in the test tube. Now we want to analyze the process in its natural environment," Cramer says. "We want to watch the RNA polymerase at work." It is still unclear whether this will be successful because new methods will have to be developed once again. To demonstrate what such future work will involve, Patrick Cramer shows an electron micrograph of portions of a cell nucleus. The DNA and its accompanying proteins appear as a granular mass – but there is no sign of the polymerase! At least for now, because Cramer's department is currently testing a new approach that also involves cryo-electron tomography. In such tomography, researchers image the granular mass from different angles. "It will become difficult to see RNA polymerase directly," Cramer explains. "Which is why we want to fit known structures, as if they were pieces of a jigsaw puzzle, into the lower-resolution tomographic reconstructions. With the help of artificial intelligence, not only are the images now getting sharper, but we can also predict the structure of the puzzle pieces. In light of this, we hope soon to see what a gene looks like during transcription."

Making progress in the research is one thing, but Cramer is also trying to bring new knowledge to a wider audience. He writes essays for the general reader, gives public lectures, and sends out tweets. "It's important to me that we explain what we do and why we need basic research."

The urgent need for this kind of research was starkly demonstrated in the past two and a half years of the coronavirus pandemic. Since the outbreak of Covid-19, scientists have been at the center of public attention like never before. But how to act in such troubled times, when fake news and conspiracy theories threaten public debate and democracy? Patrick Cramer sees science as an advocate for reason and the starting point for fact-based politics. "Especially on issues that are directly relevant to people, we need to take a stand. We need to state clearly what we know, but also what we do not know."

SUMMARY

The enzyme RNA polymerase II is the central enzyme of transcription, in which a gene located on the DNA is transcribed into an RNA molecule. Deciphering the spatial structure of polymerase and the mechanism of gene transcription is a milestone in molecular biology.

In the future, transcription is also set to be studied in living cells instead of merely in test tubes. This should be made possible by methodological developments, including the combination of microscopy techniques.

Blocked polymerase as a way to stop the virus

His everyday life as a researcher has likewise been changed by the virus, since SARS-CoV-2 also contains an RNA polymerase. This polymerase is a great target for developing antiviral drugs because blocking it will stop the virus from replicating. Cramer remembers all too well the beginning of the pandemic in the spring of 2020: "We knew we weren't able to help develop a vaccine, but we knew about polymerases and thus knew we might be able to help develop antiviral drugs – so we got to work." Half a dozen employees immediately returned to the lab from their home offices – under the applicable safety regulations, of course. And thus began a race against time – and against research groups in China. The latter had gotten a jump start, but Cramer's team was able to catch up. Moments of euphoria alternated with setbacks, but already in early April 2020 – just six weeks after the coronavirus reached Europe – the big moment had come: almost simultaneously, the teams from Germany and China published the structure of the viral polymerase. Unlike the data from Asia, the Göttingen results also showed the novel molecular hooks of the corona polymerase, which allow the polymerase to cling to the RNA template until it has copied it. This is particularly important for the coronavirus because its genome consists of around 30,000 building blocks and is thus particularly long for a virus, making copying a truly mammoth task.

In the months that followed, Cramer's team also studied the effect of antiviral drugs. The researchers were able to show why the antiviral agent remdesivir, which was the first Covid-19 drug to be approved, has a fairly weak effect on patients. "Remdesivir does interfere with the polymerase in its work, but it does so only after some delay. And the drug does not stop the enzyme completely either," explains Patrick Cramer.

In contrast, molnupiravir – a compound originally developed as an influenza drug – acts quite differently against SARS-CoV-2. As the Göttingen researchers showed in detail, molnupiravir, in contrast to remdesivir, does not directly impair the function of the copying machine. Instead, the active ingredient ensures that mutations occur during replication of the viral genetic material, which means that the virus can no longer duplicate. Since the beginning of 2022, the drug has been in use in various countries to treat Covid-19.

In the third year after the outbreak of the pandemic, the excitement is picking up again in Göttingen: Cramer's team is hoping to find an active agent that aggressively blocks the polymerase of the virus and thus inhibits the multiplication of the pathogen more effectively. For this, the researchers are collaborating with colleagues at the Max Planck Institute of Molecular Physiology in Dortmund. Together they have screened more than 300,000 substances for potential active ingredients that inhibit viral polymerase

Yet the researchers are just starting out here: the Lead Discovery Center, also located in Dortmund, will now help bridge the gap between inhibitory substances and drug candidates, which is notorious among pharmaceutical researchers, and thus start the movement toward the development of new drugs. "The core of the Max Planck Society brand is basic research. At the same time though, we should ensure that new knowledge

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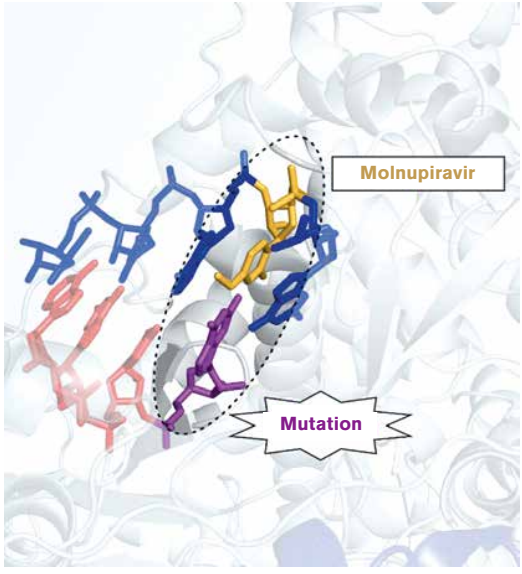

Molnupiravir (yellow) is incorporated into the RNA of the coronavirus (blue, red), where it leads to mutations (purple). This enables the drug to interfere with the replication of the virus.

GRAPHIC: FLORIAN KABINGER, CHRISTIAN DIENEMANN, PATRICK CRAMER / MPI FOR MULTIDISCIPLINARY SCIENCES

PHOTO: IRENE BOETTCHER-GAJEWSKI / MPI FOR MULTIDISCIPLINARY SCIENCES

Christian Dienemann analyzes results of his investigations with the cryo-electron microscope.

from which people can potentially benefit is also exploited," Cramer emphasizes.

The promotion of innovative research will occupy Cramer even more intensively in the coming years – albeit less in his capacity as Institute Director, but rather as President of the Max Planck Society. In June, the Senate of the research organization elected him to be Martin Stratmann's successor, and he is set to take up this office in June 2023.

What principles will he follow during his tenure? "For one thing, excellence means more than outstanding research results. Our standards must be higher, because not everything that can be measured counts. And not everything that counts can be measured. Excellence requires breaking new ground in research, daring to be bold. We have the privilege of determining where we go." Equally important to the President-elect is nurturing the work culture: "As the Max Planck Society, we are only as good as the way we treat our employees. Promoting young talent and diversity is of crucial importance."

Commitment to values

Dealing with non-democratic states will be another challenge for the future President. It is a balancing act, as Cramer knows from his own experience. "We should find ways to jointly advance research that is important for people's future, but we also need to clearly identify what is not consistent with our values. When doctoral researchers and postdocs come to us from abroad, they also learn something about our culture. That shapes young people and contributes to understanding." And what about Russia? Cramer thinks it was good that the Alliance of Science Organizations suspended all collaborations with Russian institutes after the attack on Ukraine. Yet there's not only the political level to consider here, but also the personal one: Cramer's institute employs 27 Russian and ten Ukrainian staff. When the war began, Cramer wrote to the Russian employees to say they were still welcome, while to the Ukrainians he offered help. Many relatives of coworkers from Ukraine were subsequently given accommodation at Göttingen.

Research on transcription is now also being carried out by many of Cramer's former employees in their own laboratories in various countries. This allows Patrick Cramer to prepare for the new post, as part of which he is currently traveling to all the Max Planck Institutes. "I want to know from people what their concerns are and what ideas and dreams they have." The coronavirus, Russia's war of aggression, rising costs for energy and construction—all of this also affects the Max Planck Society. "But that's precisely why we have to develop positive future scenarios and new opportunities for action. If not us, then who?"

←

GLOSSARY

CRYO-ELECTRON MICROSCOPY
In an electron microscope, a beam of electrons penetrates the molecules under investigation and provides images of the molecule in different orientations. Thousands of images are then used to calculate the spatial structure of the molecule. The resolution of electron microscope images is higher than that of a classic light microscope. The sample can be protected from damage by the electron beam by prior shock freezing at a low temperature (hence "cryo").

CRYO-ELECTRON TOMOGRAPHY
With this technique, the object to be examined is rotated slightly after each image is taken so that the electron beam of the microscope hits the sample at different angles. The 2D individual images are then processed by software to form a 3D reconstruction. In this way, even large and very complicated three-dimensional objects can be examined.

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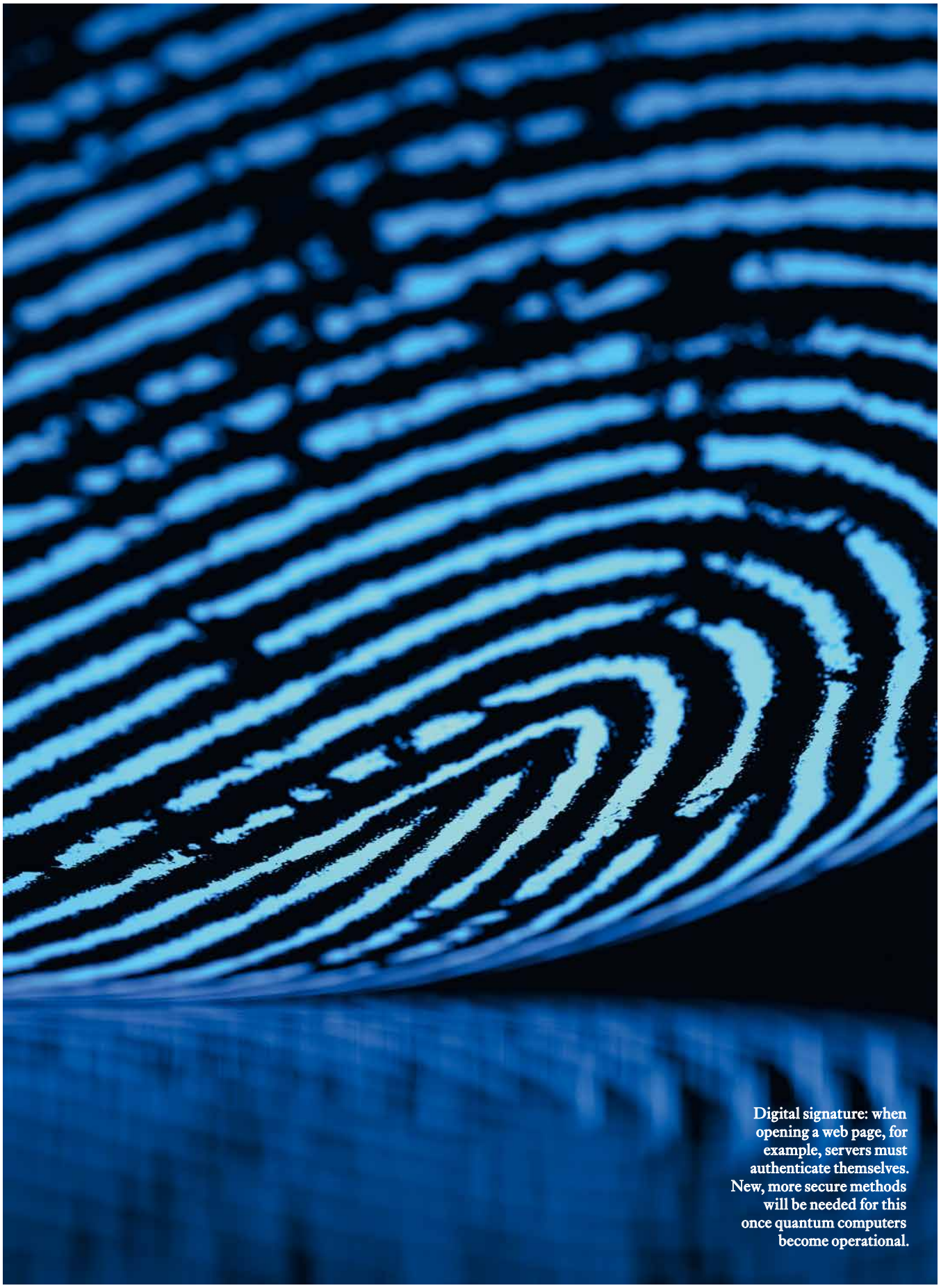

Digital signature: when opening a web page, for example, servers must authenticate themselves. New, more secure methods will be needed for this once quantum computers become operational.

PHOTO: ISTOCK

QUANTUM-PROOF

TEXT: PETER HERGERSBERG

It's a threatening scenario for online communications: the arrival of powerful quantum computers will make current encryption techniques vulnerable overnight. Peter Schwabe, Research Group Leader at the Max Planck Institute for Security and Privacy, is therefore developing methods of post-quantum cryptography with international partners. Four such processes are now being standardized by the National Institute for Standards and Technology in the USA – Peter Schwabe was involved in the design of three of them.

For many, the quantum computer is hugely promising – not least for modern intelligence services. Online services that rely on secure data exchange, on the other hand, also see it as a threat. No one can predict when the first powerful computers of this type will start performing their work. What is clear, however, is that "the cryptographic protocols that protect the vast majority of data traffic today will be worthless as soon as the first quantum computers are available," says Peter Schwabe, Research Group Leader at the Max Planck Institute for Security and Privacy and professor at Radboud University in Nijmegen. "This is because they can efficiently solve the two mathematical problems on which current cryptographic methods are based." For example, they can parse a large number into two prime factors in the blink of an eye. Since conventional computers would need tens of thousands of years to do this and would also consume as much energy as the sun sends to the earth in this period, prime number factorization forms the core of one encryption method that is currently in widespread use.

In order to protect data traffic against attacks using quantum computers in the future, 69 teams submitted proposals for new cryptographic methods to the National Institute for Standards and Technology (NIST); they refer to this as post-quantum cryptography. After several rounds, NIST decided to standardize four of these procedures. "They constitute better protection for digital communication – precisely because quantum computers would render previous encryption methods and signature systems obsolete," says Eike Kiltz, who researches and teaches as a professor at Ruhr University in Bochum and works with Peter Schwabe and numerous partners on such new encryption techniques.

Three of the selected methods are used for authentication, including the Sphincs+ and Crystals-Dilithium methods, which Peter Schwabe helped to develop: "During authentication, a digital signature ensures that a server, for example, is actually what it claims to be." Schwabe also coordinated the international team that designed Crystals-Kyber and made it application-ready. This method is used to securely transmit keys for further communication.

The example of key exchange is a good way to explain some aspects of cryptography. In many applications, be it a messenger service or an online shop, communication is protected using a combination of asymmetric and symmetric cryptography. This means that the key used to encrypt a message is

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public. Only the code required to decrypt the message is secret. Unlike symmetric cryptography techniques, which use a single secret key, the public keys used in asymmetric techniques can be exchanged over non-secure channels. After all, what channel is really secure? It is not for nothing that we receive a PIN number from the bank as an elaborately packaged scratch code. Sending a secret letter of this kind to every e-mail contact is likely to spoil the joy of online communication rather quickly. Asymmetric methods of cryptography include the widely used RSA method, which is ultimately based on prime number factorization, but can be leveraged by quantum computing.

Simple, efficient, and secure procedures

Considering all this, post-quantum cryptography techniques, such as Crystals-Kyber, work with mathematical problems that are, based on knowledge available today, almost as challenging for quantum computers as they are for conventional computers. The actual calculations in Crystals-Kyber are very simple – just multiplication and addition. A value, more precisely a polynomial, is multiplied by another value, which is the secret key. Another value is added to the product, which complicates the whole thing. The secret key and the added value – which are also polynomials – are small. Nevertheless, this setup makes it arbitrarily difficult to determine the secret key, even if you know the result of this operation and the output polynomial, which together serve as the public key.

"Some of the proposals for post-quantum cryptography are based on this principle," Peter Schwabe explains. However, it is not just the mathematical problem behind a method that matters, but also how the calculation rule is formulated in software code. And that is precisely what Peter Schwabe is particularly good at. "In the implementation, we have to balance numerous factors, because a win for one always comes at the expense of another. My contribution was to make a lot of decisions in a way that ultimately made the process simple, efficient and, above all, secure." Those were precisely the criteria NIST used to make its selection. Now it will write standards for the selected procedures. This means it will provide explanations of the cryptographic techniques and formulate instructions so that online services, for example, can incorporate them into their applications comparatively easily – and, above all, without tearing holes in their existing security precautions.

Nevertheless, there are also reservations about NIST's work. Some critics fear the agency could standardize encryption methods at the behest of the NSA, leaving backdoors open to U.S. intelligence. "We can be pretty sure that this happened in one case in the past," Peter Schwabe tells us. However, he says that the government agency had presumably done this unknowingly and has since admitted that it was a significant mistake. "In contrast to the methods now up for selection, the backdoor method didn't come from academia. These days, the cryptography community is also more involved in the selection process." This means that it is no longer just NIST who looks for ways to exploit possible security vulnerabilities, but also the vast majority of the world's cryptography community. "NIST has already shaped the selection of new cryptography standards twice, as it is doing with post-quantum cryptography," says Peter Schwabe. "The processes that came out of that have proven to be very secure – and they are used all over the world today."

It is therefore quite possible that NIST will set standards with its decision, at least for the USA and Europe. However, the German Federal Office for Information Security (BSI) published a Technical Guideline in 2020, in which it recommends two other methods for key exchange in the age of quantum computing. "We consider these methods to be especially secure," says Stephan Ehlen, a mathematician at the BSI who studies quantumproof encryption. These are based on a mathematical problem related to the principle of Crystals-Kyber. However, the procedures are not as efficient as those that NIST is now standardizing, Ehlen says. For NIST, however, efficiency is an important criterion for ensuring that the methods are also well suited for widespread application in everyday internet use. "It is entirely possible that when we update the Guidelines, we will bring in other procedures, including those that have now been selected by NIST," Ehlen said. If nothing else, this would facilitate secure communications between federal agencies that follow the BSI recommendations and, for example, companies that use the NIST standard. The BSI has yet to select procedures for digital signatures. "This hasn't been

SUMMARY

The arrival of powerful quantum computers will make current encryption techniques vulnerable overnight.

The National Institute for Standards and Technology will now standardize four of 69 proposed post-quantum cryptography methods.

Peter Schwabe played a key role in the development of three of the selected methods, two of which are used for authentication and another for the secure exchange of cryptographic keys.

so urgent because the problem of encrypted communications potentially being intercepted and stored now and decrypted later doesn't exist here."

The computer scientist predicts that standardization could be completed by the end of 2023. But major companies such as Google, Amazon, and the IT security provider Cloudflare, are already experimenting with post-quantum cryptography methods – alongside today's standard methods, which are vulnerable to attacks using quantum computers. In addition, car manufacturers are already looking at post-quantum cryptography to ensure that they can still securely update the software of the vehicles they build today, even in 15 or 20 years' time. "We assume that an increasing number of services will use the new processes after standardization," explains Peter Schwabe. Hopefully, the encryption methods that the Bochum researchers helped to develop will secure visits to websites, e-mail traffic, or banking transactions even before the first powerful quantum computer is available.

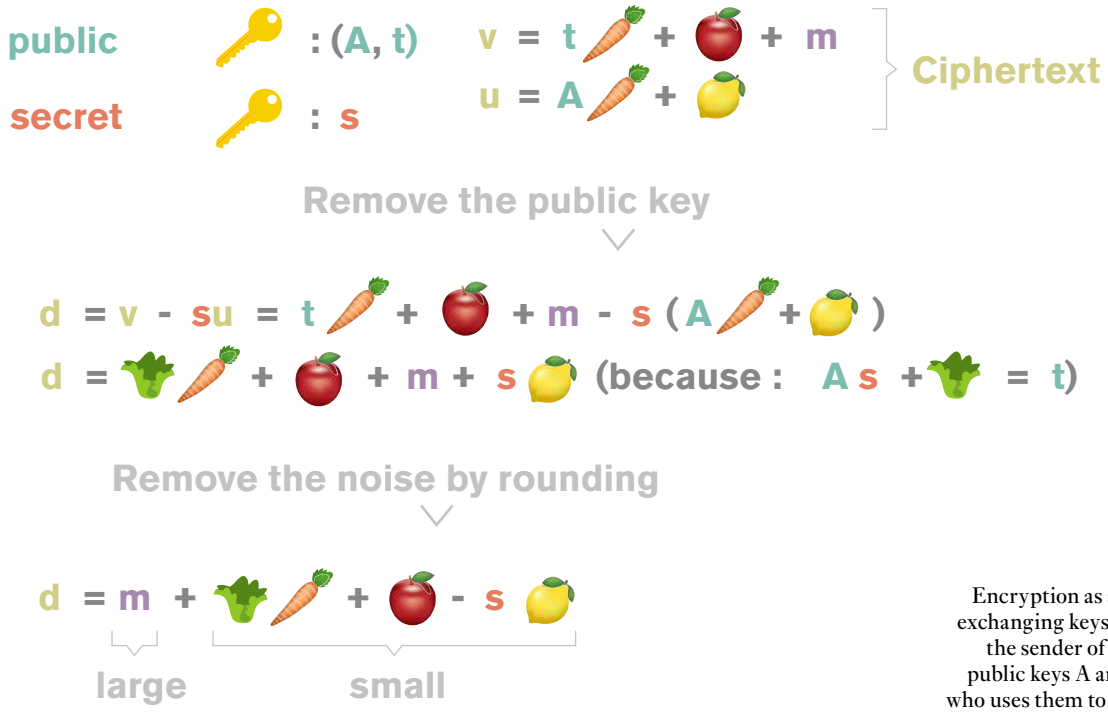
GLOSSARY

AUTHENTICATION ensures in online communication that a computer or server is what it claims to be, such as the server of an e-mail service.

POST-QUANTUM CRYPTOGRAPHY refers to encryption and authentication methods that even quantum computers cannot crack.

KEY EXCHANGE is a cryptographic technique that allows two parties to exchange a shared secret key over an insecure channel.

NIST STANDARDIZATION includes explanations of the encryption methods and guidance on how to integrate the methods securely and as easily as possible into programs for digital services.



GRAPHIC: GCO BASED ON A TEMPLATE BY KYBER AND POST-QUANTUM CRYPTO – HOW DOES IT WORK? RUBEN GONZALEZ, KRIJN REIJNDERS

Encryption as a salad of letters: when exchanging keys using Crystals-Kyber, the sender of a message receives the public keys A and t from the recipient, who uses them to encrypt their message m. The recipient can only decrypt the message with the secret key s. The icons represent small values that easily distort the crucial components and make decryption complicated for attackers. In the last step, they are removed by rounding to the zero or one of a bit.

THE UNIVERSE IN A NEW LIGHT

TEXT: HELMUT HORNUNG

Six months after its launch, the James Webb telescope has delivered its first images, revealing fascinating insights into distant galaxies as well as turbulent scenarios encompassing the birth and death of stars. The space observatory has also captured the spectra of exoplanets. The Max Planck Institute for Astronomy in Heidelberg was involved in building the instruments.

"It all looks fantastic and has exceeded our already high expectations," says Oliver Krause. The scientist and his team at the Max Planck Institute in Heidelberg had been eagerly awaiting the publication of images and data on July 12. The astronomers had a long wait for this moment – originally, the telescope was supposed to lift off into space in 2007, and in the years that followed, there were repeated delays.

When the roughly ten-billion-dollar observatory finally began its journey on December 25, 2021, aboard a European Ariane 5 launch vehicle, a great deal could have gone wrong in the six months leading up to the first successful observations in the summer: experts had identified no fewer than 344 crucial sources of error before the mission began. "Single point failures" is what Oliver Krause calls them. Each of these errors would have jeopardized the project, in which the American, European, and Canadian space agencies are all involved, or even caused it to fail completely.

Indeed, the journey from launch to the operational telescope was extremely complex. "James Webb" had been sent into space practically as a construction kit, so the two most important structures had to literally unfold first: these were the five-layer solar shield the size of a tennis court and the main mirror consisting of 18 honeycombs, which has a diameter of 6.5 meters.

During the unpacking, the engineers and technicians had to make sure that all the mechanical processes ran perfectly and without error. For the sunshield, for example, 107 bolts and springs were used, while the hexagonal beryllium segments of the main mirror were pushed into the correct positions by more than 100 small motors to within a fraction of a millimeter. If one part had snagged, there would have been no one to intervene directly.

Over a period of about three months in spring 2022, the 6.5-meter telescope gradually cooled down to the operating temperature of minus 230°C. Its four scientific instruments prefer an even colder temperature – up to 267°C below zero. In addition, the observatory was carefully maneuvered to its observation post, Lagrange Point 2. "This location makes it possible to position the Sun, Earth, and

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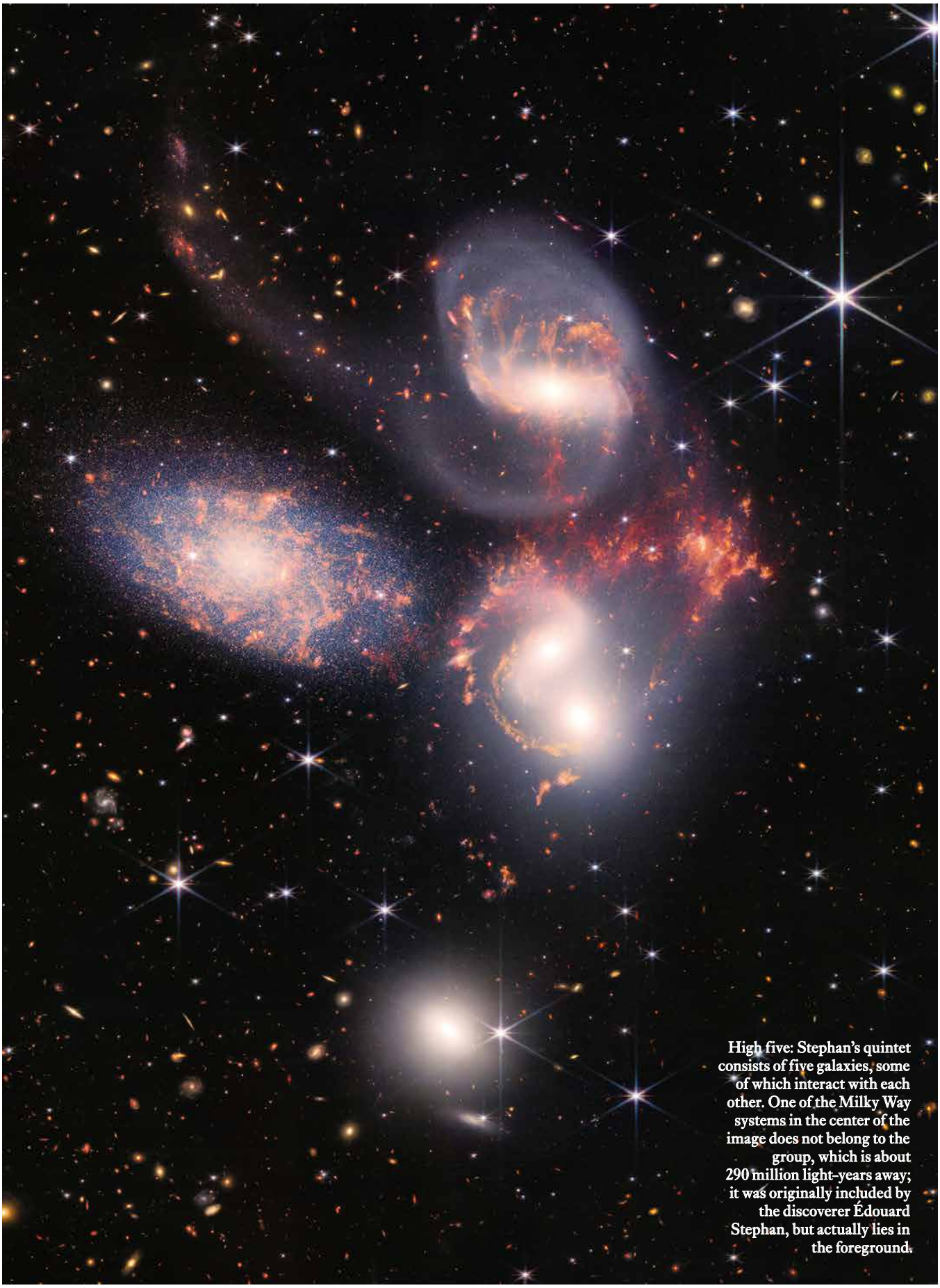

IMAGE: ESA / CSA / STSCI / NASA

High five: Stephan's quintet consists of five galaxies, some of which interact with each other. One of the Milky Way systems in the center of the image does not belong to the group, which is about 290 million light-years away; it was originally included by the discoverer Édouard Stephan, but actually lies in the foreground.

PHOTO: NASA / DESIREE STOVER

Honeycombs for the heavens: the primary mirror of the James Webb telescope consists of 18 hexagonal beryllium segments and has a diameter of six and a half meters. With it, the observatory surveys the universe in infrared light.

telescope as if strung on a string of pearls, allowing James Webb to consistently gaze into space in the shadow of the protective shield," explains Oliver Krause.

However, the space observatory is not stationary at Lagrange Point 2, located 1.5 million kilometers away from the Earth (there are a total of five such points where the gravitational forces of celestial bodies balance each other out). Rather, it orbits it on a path whose diameter is larger than the distance between the Earth and the Moon. It takes half a year to complete one circuit, whereby the telescope's control nozzles must constantly ensure precise choreography.

Before the first images and data could be obtained, the four scientific onboard instruments first had to go into operation. Krause and his group had intensively followed and supported the preparatory work during this phase. One of the instruments, for example, known as MIRI (Mid-Infrared instrument), contains a filter wheel that was developed and built at the Max Planck Institute for Astronomy. With MIRI, the telescope surveys the cosmos in mid-infrared light, while with NIRCam (Near Infrared Camera) it makes observations in the near infrared. The quartet of instruments is completed by the two spectrographs NIRSpec (Near Infrared Spectrograph) and FGS/NIRISS (Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph), both of which break down the light of cosmic objects into small rainbows, i.e., generate spectra. The telescope thus covers a wavelength range from 0.6 to 28 micrometers (thousandths of a millimeter).

Micrometeorites hit the mirror

The tests, data, and test images from early summer were already looking great. Even after several micrometeorites hit and slightly damaged the mirror, the telescope's vision was not diminished, according to the US space agency NASA. James Webb finally peered into the depths of the universe as planned – and delighted specialists and laymen alike.

One of the images shows the spectrum of WASP-96b. This gas planet, 1150

light-years away, is half the size of Jupiter and orbits its parent star once every three and a half Earth days. "You can really appreciate the telescope's superior accuracy of measurement when you compare it to its predecessors, for example, Spitzer or Hubble," says Maria Steinrück. The researcher at the Max Planck Institute for Astronomy works on the atmospheres of exoplanets – a research field to which the space telescope is expected to bring a whole new impetus. Department Director Laura Kreidberg has successfully submitted two observation proposals. And Maria Steinrück is convinced that "in the future, the James Webb telescope will make it possible to determine the composition of the atmospheres of exoplanets that were previously too small or too cool to measure." In August, a second observation of an exoplanet was published: the observatory had measured infrared light filtering through the atmosphere of the hot gas giant WASP-39b, some 700 light-years away. This enabled Webb not only to record the first detailed spectrum of an alien planet in near-infrared light, but also to detect carbon dioxide in its atmosphere.

WASP-39b has only about a quarter of the mass of Jupiter, but a diameter 1.3 times larger, while in the exoplanet's atmosphere the temperature is around 900°C. Unlike the cooler, more compact gas giants of Jupiter and Saturn in our solar system, WASP-39b – like WASP-96b – orbits its star in close proximity; its distance is only about 7 million kilometers, which is one-eighth the distance between the Sun and Mercury. The short distance means that this planet, which was discovered in 2011, is traveling at breakneck speed – one orbit takes just over four Earth days.

From our vantage point, we observe the orbit laterally. That means that WASP-39b periodically passes in front of the star and obscures it, which leads to minimal dimming. During such a transit, a small part of the star's light passes through the planet's atmosphere, which is thus illuminated. When this happened, the NIRspec instrument registered a small increase in brightness in the fanned-out light between 4.1 and 4.6 micrometers. This way, carbon dioxide was clearly detected on a planet outside our solar system for the first time.

"This finding is an important milestone for characterizing the atmospheres of exoplanets," explains Max Planck astronomer Laura Kreidberg. "Carbon dioxide is an important indicator of the formation history of planets. It helps us measure the complete carbon and oxygen inventory of the atmosphere, which is very sensitive to conditions in the disk where the planet formed." With the help of the CO_2 measurement, specialists can better narrow down, for example, the plan-

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SUMMARY

The first data and images provided by the James Webb telescope suggest many exciting discoveries.

The space observatory does its observing 1.5 million kilometers from Earth.

The four onboard scientific instruments sample the cosmos in the range of infrared light between 0.6 and 28 micrometers (thousandths of a millimeter).

IMAGE: ESA / CSA / STSCI / NASA

Cradle of the stars: what looks like a rugged mountain range is actually a region in the Carina Nebula, about 7600 light-years away, where new suns are born.

IMAGE: ESA / CSA / STSCI / NASA

IMAGE: THE HUBBLE HERITAGE TEAM (STSCI/AURA/NASA)

A fiery finale: having reached the end of its life, a star blows its gaseous atmosphere into space, creating this Southern Ring Nebula. The added value of the James Webb telescope is evident from the object designated NGC 3132: its photo (above) is juxtaposed with an image taken by the Hubble Space Telescope (below).

et's point of origin or the properties of the solids and gases that were introduced.

Group of galaxies in Pegasus

Photos of astronomical objects are particularly attractive to the general public. Galaxies, for example, are the main motif in the image of Stephan's Quintet, an ensemble of five Milky Way systems discovered by the French astronomer Édouard Stephan in 1877 in the constellation Pegasus. The group of five, at a distance of 290 million light-years, is quite close together, with some of the members interacting with each other due to their gravitational pull. Gas swirls around, and new stars are born in droves. "The clarity and sharpness of the image is not the only thing that is special here," says Max Planck researcher Krause. In the photo, he says, the surroundings of Stephan's Quintet appear in a dramatic view. "There are many astrophysical processes reflected there that can now be studied with unprecedented precision."

Previously unknown detail and unique dynamics are also revealed in the images of the Southern Ring Nebula and the Carina Nebula. This is where the James Webb telescope shows its strength, because – unlike the famous Hubble Space Telescope – it observes not in the optical range of the electromagnetic spectrum, but in the infrared window, which is inaccessible to us humans. Webb thus sees the world with different eyes, so to speak. While the Southern Ring Nebula announces the death of a star, the Carina Nebula

resembles a cosmic delivery room in which hundreds of suns are born. Both celestial objects belong to our Milky Way and are 2000 and 7600 light-years away from Earth, respectively.

Gravitational lens reveals distant objects

In deep space, too, the observatory is opening up new dimensions. It has set its sights on the galaxy cluster SMACS J0723.3-7327, which acts like a gravitational lens. Here, the cluster of galaxies in the foreground focuses and distorts the light of the much more distant objects behind it, so that these appear – partly as multiple images and as arcs – as if seen through a magnifying glass. Before James Webb's observation, a total of 19 multiple images of six background sources were known to exist behind the cosmic gravitational lens, which is about 4.5 billion light-years from Earth. The telescope's data revealed 27 additional multiple images of ten other objects.

"The images are really amazing and so beautiful. They have enabled us to significantly refine our gravitational lensing mass model," says Gabriel Bartosch Caminha, a postdoctoral fellow at the Garching-based Max Planck Institute for Astrophysics. The researchers used their model to estimate the distance of these lensing galaxies, and the light from some objects appears to have started its journey about 13 billion years ago. Because electromagnetic radiation rushes through the cosmos at finite speed (about 300,000 kilometers per second), telescopes act like time machines: for this reason, observing celestial bodies at great distances always means looking into the past. James Webb is therefore shining a light on the early days of the universe.

Astronomers expect new findings in cosmology as well as in the study of exoplanets, the evolution of galaxies, and the development of stars. If the James Webb telescope remains in good shape and no technical defects occur, it could operate for up to two decades – enough time for a whole host of surprising discoveries.

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GLOSSARY

EXOPLANETS
are celestial bodies orbiting a distant star. To date, around 5000 such objects have been discovered. The search for exoplanets that resemble the Earth is particularly interesting.

GRAVITATIONAL LENSES
are derived from Einstein's theory of relativity. According to this theory, light from a distant source – a galaxy, for example – is influenced by the mass of an object lying in front of it from the observer's perspective, such as a galaxy cluster, as if by an optical lens. The image can be amplified, distorted, or even multiplied.

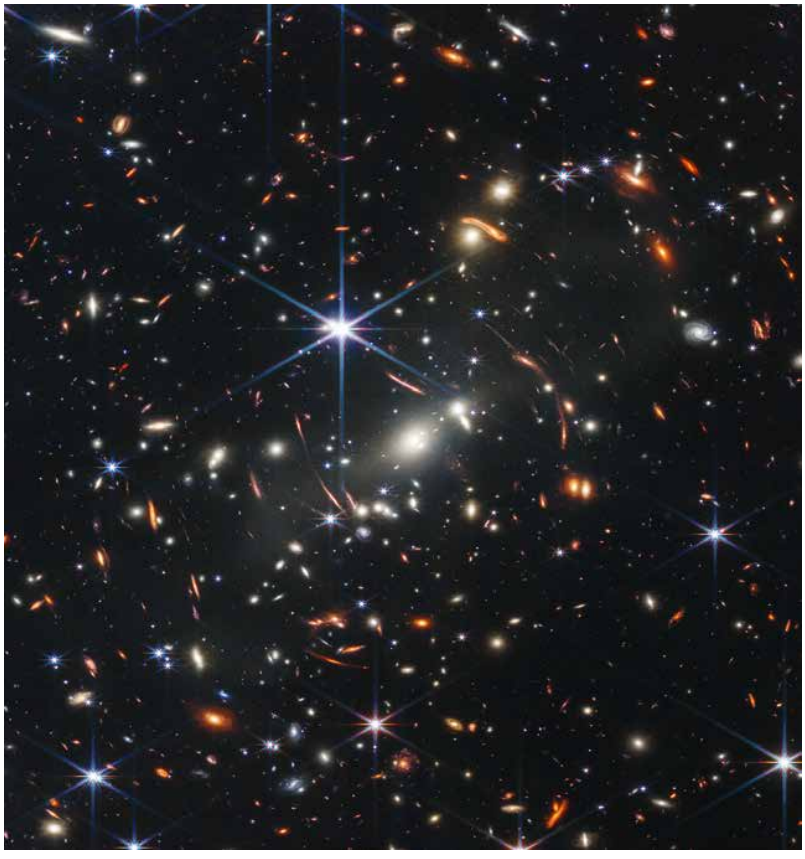
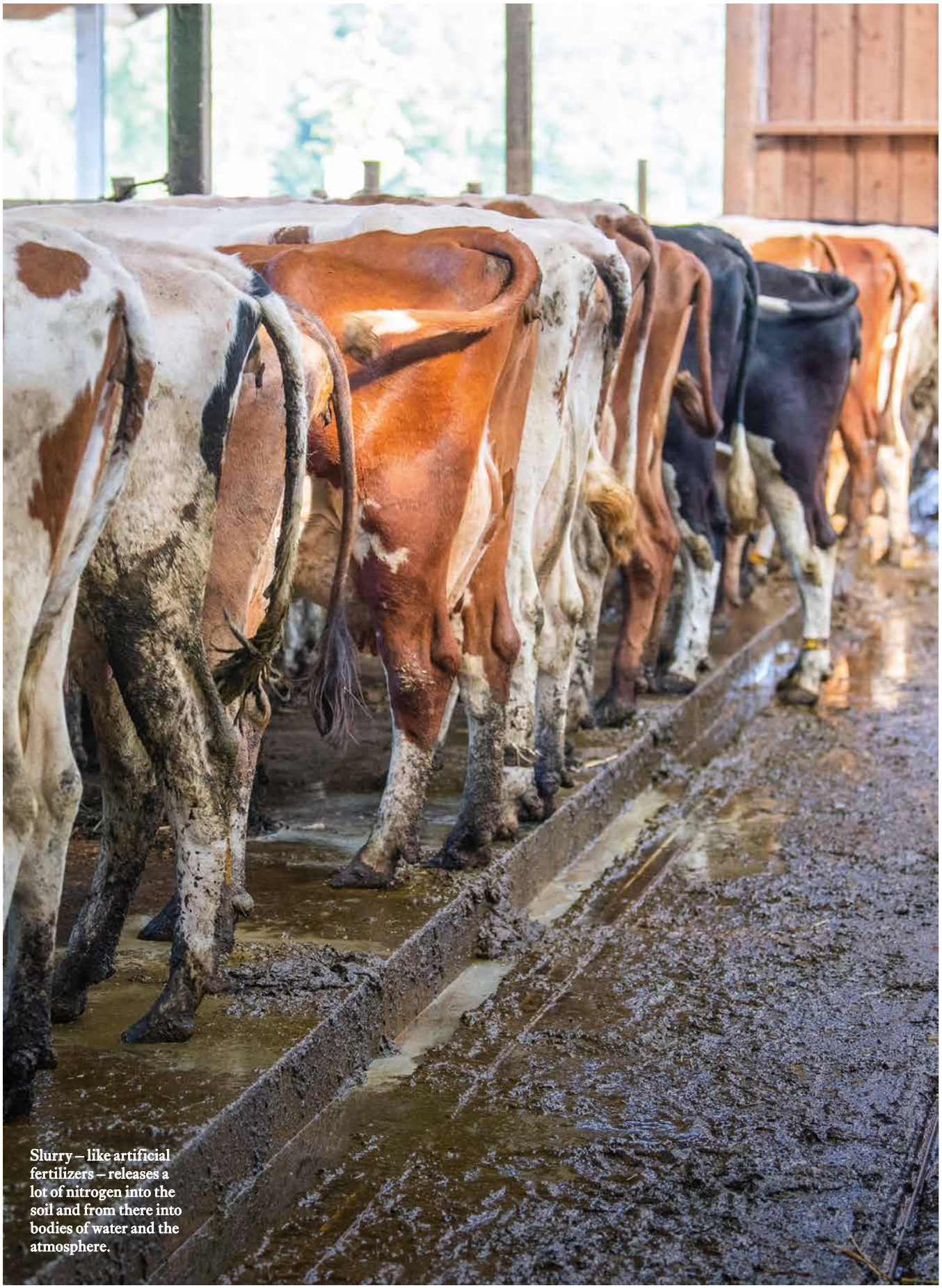


IMAGE: ESA / CSA / STSCI / NASA

A window into the past: the light emitted by some of the galaxies shown here has been traveling for more than 13 billion years. The lines and arcs are produced by the galaxy cluster SMACS J0723.3-7327, which acts as a gravitational lens.



Slurry – like artificial fertilizers – releases a lot of nitrogen into the soil and from there into bodies of water and the atmosphere.

PHOTO: PICTURE ALLIANCE/DPA | LINO MIRGELER

THE OVERFERTILIZED EARTH

TEXT: KLAUS JACOB

No animal, plant, or single-celled organism can do without nitrogen, but humans are putting more and more of it into circulation – with various consequences for health and the environment. Sönke Zaehle, Director at the Max Planck Institute for Biogeochemistry in Jena, is studying the nitrogen cycle and its relationship to the climate. The findings are important for environmental policy.

If awards were presented for the importance of chemical elements to life, carbon would be the big winner. It plays the lead role in organic chemistry, after all. Meanwhile, nitrogen is often overlooked, but such disregard is anything but justified, since life would be unthinkable without it. There is no protein that does not contain nitrogen. Every plant and every animal needs it to thrive. No biochemical reaction is conceivable without nitrogen. And when people eat meat or vegetables, they consume nitrogen in the process. In pre-industrial times, there was a nearly constant, marginally increasing amount that circulated through the air, soil, waters, and living creatures in its biologically usable form. In this virtually closed cycle, changes occurred, at most, on a local level – however, this has been disrupted by massive human intervention, for example, the fertilization of fields. The way in which the cycle is disrupted by this intervention and how this affects the climate is being studied by Sönke Zaehle, Director at the Max Planck Institute for Biogeochemistry.

But first things first: although nitrogen is the main component of air at 78 percent, it is by nature rare as a building material for biomolecules. This is because, in its very stable elemental form, in which it occurs for the most part within the atmosphere, it cannot be utilized by most plants and animals. Nevertheless, lightning has the power to transform it into a biologically available form – something geoscientists refer to as reactive nitrogen. Consequently, every time there is a thunderstorm, this also has a fertilizing effect. Yet, in the course of evolution, some organisms have also found a way to obtain this rare, basic substance themselves: nodule bacteria, which live in symbiosis with legumes such as clover, vetch, or soybean, and dock onto their roots, supply these plants with nitrogen compounds. Hence, before there was artificial fertilizer, people often practiced three-field crop rotation and grew legumes for a season to enrich the soil with nitrogen. The cards were entirely reshuffled, however, with the invention of artificial fertilizers. Just over a century ago, German chemists Fritz Haber and Carl Bosch developed a process to produce saltpeter from atomic nitrogen and hydrogen, a precursor of artificial fertilizers such as ammonium nitrate – but also of explosives. And that's not the only reason why the Haber-Bosch process is both a blessing and a curse. In other respects, too, it has had both a positive and negative impact. On the one hand, it has led to an agricultural revolution that has made it possible to feed the world's rapidly growing population. On the other, it has substantially altered the nitrogen cycle – with far-reaching consequences for ecosystems and health.

As with fossil fuels, the problem is the sheer volume. Production of artificial fertilizers has virtually exploded since the Second World War. To get an idea of the dimensions: the Haber-

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Bosch process gobbles up about 1.4 percent of the world's energy because it requires elemental hydrogen, heat, and high pressure. And according to Sönke Zaehle's calculations, use of synthetic fertilizers adds around 90 to 100 million metric tons of reactive nitrogen to the global cycle every year. But that's not all: the combustion of fossil fuels in coal- and gas-fired power plants, and not least in diesel engines, also produces nitric oxides, from which harmful particulate matter is formed. Added to this are forest fires, which also release some of the nitrogen from biomass in the form of nitric oxides.

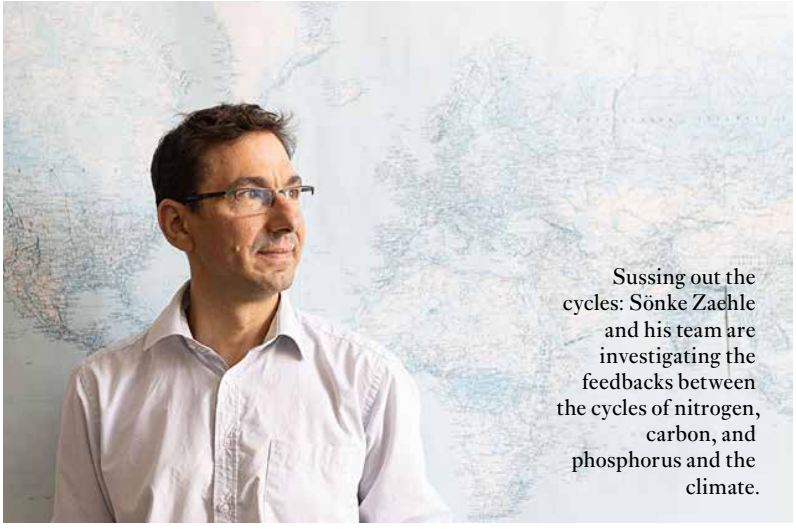

PHOTO: STEFFEN WALTHER FOR MPG

Sussing out the cycles: Sönke Zaehle and his team are investigating the feedbacks between the cycles of nitrogen, carbon, and phosphorus and the climate.

Determining how much nitrogen is in circulation, where it accumulates, and in what quantities it flows back and forth between the biosphere, the geosphere, and the atmosphere is quite an undertaking. Describing the entire cycle in a model and simulating it on the computer is so complicated that Sönke Zaehle's team has divided up the problem: first, into the path that leads from ecosystems to the atmosphere, and second, the reverse. To determine the amounts of the various nitrogen compounds that enter the air from diverse sources, the researchers divide the earth into grid cells with edge length of about 50 kilometers. For each of these fields, their model calculates how much nitrogen is released by the ecosystems there, i.e., forest, grassland, or agricultural land. During this process, the researchers take into account the role played by the rising concentration of CO_2 in the atmosphere, which also stimulates plant growth, and phosphorus fertilization. They likewise investigate how material cycles change with climate change. The researchers feed the model additional data from other research groups on manmade nitrogen emissions from vehicle traffic and industry, for example, and this gives them a precise overview of where and how much reactive nitrogen escapes into the atmosphere. With all this, they are arriving at the same outcome as studies by other groups that use the global distribution of ammonia, nitric oxides, and nitrous oxide to infer emissions of the substances: "Humans have more than doubled the input into the nitrogen cycle since the beginning of the industrial revolution." That's a massive intervention, especially since there appears to have been little globally significant change over many millennia.

The researchers from Jena also calculate the input of nitrogen from the air into waters, soils, and ecosystems with models that likewise take the local climate into account. For this, they use data on how nitrogen compounds are distributed in the atmosphere worldwide, and the results reveal where the nitrogen accumulates and in what quantities. But they're not stopping at these two, one-way observations. "As part of a major EU project, we are working with international colleagues to model the entire nitrogen cycle," says Sönke Zaehle. A particularly complex aspect is the interactions between the different parts of the Earth system, i.e., the oceans and other bodies of water or the terrestrial ecosystems and the atmosphere, but also the very different lifetimes of the globally relevant nitrogen compounds – which can range from fractions of a second to centuries.

Consequences for ecology and health

Just as diverse as the atmospheric chemistry of nitrogen are the harmful effects that each of its compounds can unleash in turn. They alter ecosystems, cause eutrophication and sometimes even collapse water bodies, harm drinking water and the respiratory tract, influence the climate, and destroy the ozone layer. Humans bringing nitrogen into play are like Goethe's sorcerer's apprentice, who thought he had a clever idea bewitching a broom to do his chores for him, but was then unable to stop it as it went completely berserk.

First of all, there is the impact on health: a study by the organization Environmental Health Analytics (LLC) in Washington has shown that every year around 100,000 people die prematurely due to nitric oxides, although such analyses are subject to some uncertainties due to the large number of influencing factors. As they are hazardous to health, there are limits set on air pollution with nitric oxides and particulate matter. Where these have been exceeded, some German cities have already temporarily banned the use of diesel vehicles.

But why does reactive nitrogen harm the environment if it is also an effective fertilizer? The answer is a recurring topic in the media and politics. Plants typically cannot take up all of the large amounts of fertilizer, partly be-

PHOTO: STEFFEN WALTHER FOR MPG

SUMMARY

It is mainly thunderstorms and nodule bacteria that naturally convert elemental nitrogen into a form in which plants can absorb this vital element.

Primarily through fertilization and the burning of fossil fuels, humans have doubled the amount of nitrogen that is cycled between the atmosphere, bodies of water, soil, and terrestrial ecosystems.

Nitrogen compounds stimulate plant growth, but their excess reduces biodiversity, is harmful to health as well as the ozone layer, and affects the climate.

cause rain washes it out before growth starts to speed up. This means nitrogen ends up in rivers and groundwater, and eventually in the sea, mainly in the form of nitrate. In the body, however, nitrate can be converted into the related nitrite, which is harmful to health, so limit values also apply to drinking water. Some drinking water wells in Germany have already had to be shut down because of excessive contamination, with the problem particularly acute in northern Germany where there are large fattening farms with heavy manure production.

Overfertilization also harms natural ecosystems; not all plants like a lot of fertilizer. Vegetation that thrives on poor soils suffers as a result of this unwanted gift, and this is an area where species diversity is particularly high, perhaps because these plant specialists were able to find ways to live with a lack of nitrogen. Even carnivorous plants, such as the Venus flytrap, have evolved to meet their nitrogen requirements by catching insects. Such diversity is in danger of disappearing as a result of the fertilizer glut, and overfertilized regions are dominated by just a few nitrogen-loving species such as stinging nettles or dandelions. When plant species disappear, so do numerous animals that depend on these masters of eking out a living for their own survival. The oversupply of nutrients is equally harmful for rivers and lakes, since eutrophication leads to an overproduction of biomass, which, in the worst cases, can cause ecosystems to collapse.

The oversupply of nitrogen also has an impact on the climate. The nitrogen cycle inevitably produces nitrous oxide, a potent greenhouse gas, because soil organisms convert nitrate into elemental nitrogen and nitrous oxide in the absence of oxygen. This is why a particularly large amount of nitrous oxide is released into the atmosphere

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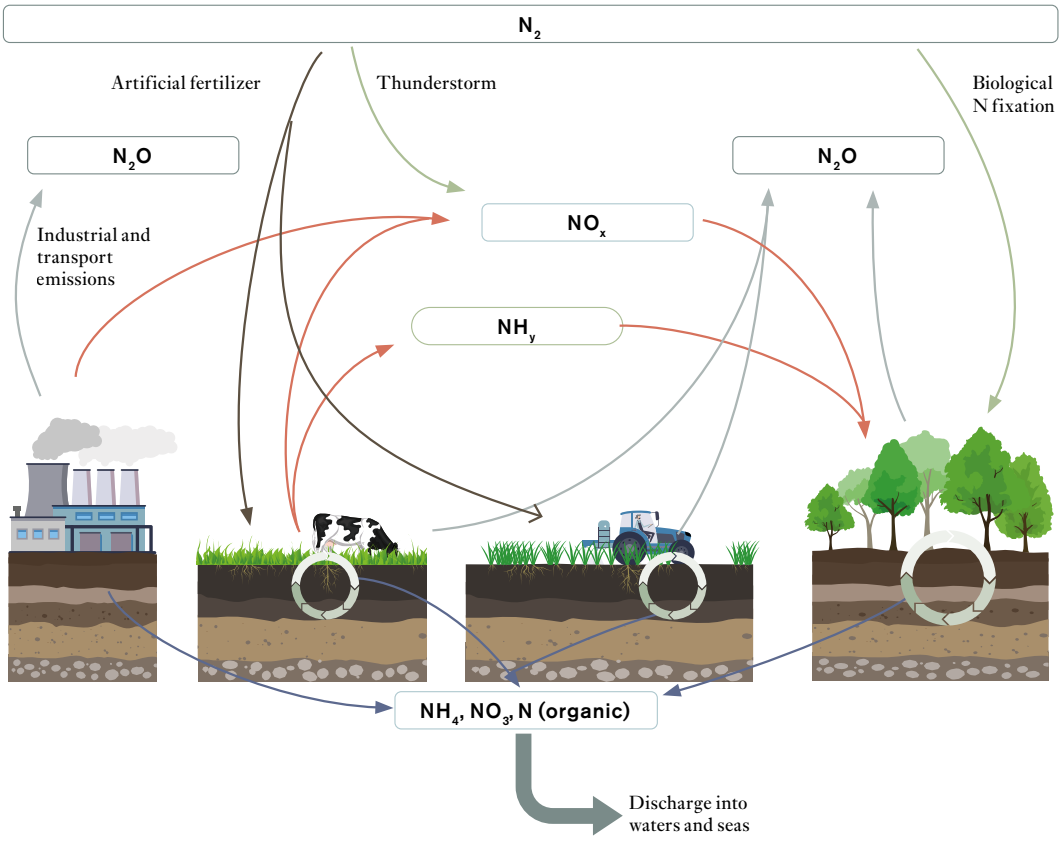
Hot on the trail of greenhouse gases: Heiko Moossen (left) and Sönke Zaehle are researching the increase and decrease of nitrous oxide, as well as carbon dioxide and methane, in the atmosphere, and analyzing their isotope ratios with mass spectrometers for this purpose. The pure substances from gas cylinders serve as a reference here.



Through thunderstorms, biological fixation by bacteria, or conversion into artificial fertilizer, elemental nitrogen N_2 is converted into a reactive form such as NO_x nitric oxides that plants can utilize. Nitric oxides NO_x and N_2O from industry and traffic as well as emissions of NO_x, N_2O, and NH_y from agriculture are also involved in the nitrogen cycle.

GRAPHIC: GCO AFTER SÖNKE ZAEHLE

after each rainfall, when water cuts off the oxygen supply to the soil. The greenhouse effect of nitrous oxide is almost 300 times that of carbon dioxide, and it remains in the atmosphere for an average of around 110 years, about ten times longer than methane. Nitrous oxide concentrations in the atmosphere have increased by 33 percent since 1750, Zaehle's team has calculated. Analyses by various research groups, including the group working under Sönke Zaehle, agree that most of it comes from agriculture – close to 80 percent in Germany.

Yet nitrogen doesn't just affect the climate in the form of nitrous oxide. Other nitrogen compounds also affect the climate because they boost plant growth. This removes carbon dioxide from the atmosphere, which has a cooling effect. In addition, nitric oxides form aerosols near the ground, creating fine dust. These act as a shield against sunlight and thus also have a cooling effect. All of these sometimes opposing effects are currently being captured by Zaehle's team in models in order to estimate the net effect of nitrogen on the climate. The calculations are complicated by the fact that nitric oxides are distributed very inhomogeneously: they reach high levels over conurbations, but low levels over large, forested areas. "Initial analyses suggest that the effects of reactive nitrogen that amplify or counteract climate change more or less offset each other," says Zaehle.

Conversely, there is another harmful impact that nitrous oxide has on the atmosphere, in addition to its greenhouse effect, that is not counteracted by an opposing effect from other nitrogen compounds: the gas also gnaws away at the ozone layer in the stratosphere, which protects us from harmful UV radiation. It reaches these high altitudes because it is extremely inert in the lower atmosphere. In the stratosphere, shortwave radiation from the sun splits the nitrous oxide molecules, and the degradation products attack the ozone.

Livestock sector as the largest source of nitrous oxide

Considering the many harmful effects of reactive nitrogen, it stands to reason that nations must take countermeasures. However, too little has been done to date – especially when it comes to overfertilization. After all, fertilizer is cheap, as is the disposal of slurry in fields. Moreover, farmers are under pressure to produce cheaply, and policymakers rarely make bold interventions because they do not want to deprive farmers of their livelihoods by imposing strict requirements. It is true that the amount of

reactive nitrogen released in Europe has declined over the last forty years, mainly thanks to EU regulations, but it is growing in Asia, Africa, South America, and even in the US, not least because meat consumption is rising in countries like China. This means that an increasing quantity of artificial fertilizers are being used for feed production, and increasing quantities of manure are being disposed of. "The livestock sector is the biggest source of nitrous oxide," Zaehle says. Aquaculture, which now produces about half of the fish consumed worldwide, also impacts the nitrogen cycle. Not only is it the fastest-growing sector within food production, but it is also the fastest-growing emitter of nitrous oxide. Aquaponics, a process that uses the excrement from fish farming as a nutrient for plants, is one way of counteracting this.

EU action against the German government

Even declining figures in Europe are no reason to sit back and relax. Take Germany, for example: according to the German Federal Statistical Office, the use of nitrogen fertilizers fell from 1.85 million metric tons to 1.27 million metric tons between 2000/2001 and 2020/2021. But that is not enough. According to the German Advisory Council on the Environment (SRU), nearly half of Germany's natural and seminatural terrestrial ecosystems were overfertilized in 2009. And nitrate concentrations in groundwater still exceed the limit of 50 milligrams per liter set by the EU's Nitrates Directive at around 17 percent of monitoring sites. The European Commission therefore filed a lawsuit in 2016, and the European Court of Justice ruled in its favor two years later. The German government subsequently tightened the fertilizer ordinance in 2021, as a result of which farmers in nitrate-polluted areas must reduce their use of fertilizer by at least 20 percent and will have to comply with longer embargos in the fall and winter. Yet the upper limit for the amount of nitrogen fertilizer is still 80 kilograms per hectare per year.

"That is clearly too much for many locations," says Sönke Zaehle. To give an idea of the amount, he cites another figure: a natural ecosystem, such as a forest, converts an average of about 120 kilograms of nitrogen per hectare per year. By comparison, an additional 80 kilograms is a lot. Nevertheless, the president of the German Farmers' Association, Joachim Rukwied, decried the "technically flawed regulation that prohibits fertilization according to need in nitrate-sensitive areas." The constant piling on of legal requirements, he said, ignores the capability of farms. Sönke Zaehle likewise sees problems with implementation, but for him and his colleagues the current efforts do not go far enough. He therefore welcomes a resolution by the UN Environment Programme to reduce the nitrogen surplus by half by 2030.

An increase in organic farming could help here, since this involves no artificial fertilizers and the application of slurry is only permitted in a strictly regulated manner. While this does mean that the nitrogen is used more efficiently in the closed cycle, it can lead to lower yields than those achieved by conventional farming. Many conventional farmers are now also trying to avoid overfertilization by measuring the nitrogen content of the soil and adjusting the amount of fertilizer accordingly. Meanwhile, we can all help to ensure that less nitrogen is put into circulation. After all, overfertilization in agriculture is also a consequence of our diet. We can help to reduce it by throwing away less food, using organic products, or eating less meat. This would mean less use of artificial fertilizer and less slurry.

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GLOSSARY

REACTIVE NITROGEN is the name given to inorganic and organic nitrogen compounds that plants and microorganisms can use, unlike the elemental form.

NITROGEN CYCLE denotes the cycle of the element through the different parts of the Earth system: the atmosphere, hydrosphere, geosphere, and biosphere.

Nitrogen recycling: in aquaponics, plants are fertilized with the excrement of fish, so the large amounts of nitrogen produced in a fish farm do not contribute to the overfertilization of bodies of water.

PHOTO: SHUTTERSTOCK/TANAKORNSAR

PHOTO: ADOBESTOCK

An exclusive location: the Big Bear Solar Observatory is surrounded by water. This reduces disturbing turbulence due to rising warm air and creates the best conditions for solar observation.

Max Planck researchers collaborate with partners in more than 120 countries. Here, they write about their personal experiences and impressions. Hans-Peter Doerr from the Max Planck Institute for Solar System Research spent three weeks working at the Big Bear Solar Observatory in California. He explains why the solar telescope stands on the water and tells us about anglers, gun enthusiasts, and alternative ways of transporting data.

Like many astronomers, I was fascinated by the universe even as a child. I grew up in the countryside, where you can still look up at a dark night sky, so the view of the stars captivated me from an early age. Our Sun is the only star close enough that we can see details on its surface from Earth. The Goode Solar Telescope at the Big Bear Solar Observatory, which is operated by the New Jersey Institute of Technology, was for a long time the largest ground-based solar telescope in the world, before it was recently superseded by the Daniel K. Inouye Solar Telescope in Hawaii.

With a mirror diameter of 1.6 meters, the California-based telescope is powerful enough to resolve structures on the sun that are 50 to 60 kilometers in size. The observatory is located in the San Bernardino Mountains at an altitude of 2000 meters, in a spot at the end of a causeway that juts some 200 meters out into Big Bear Lake. The location seems unusual, but it is ideal for solar observation because the water heats up less than the land surface, meaning poor "seeing" – disturbing turbulence due to rising warm air – is significantly reduced. Close to the observatory there is a guesthouse with self-catering facilities, which serves as accommodation for the scientists who are working there. For shopping, we travel to Big Bear City, which is less than 15 minutes away by car. We also go out to eat there from time to time. Incidentally, the name "Big Bear" comes from the many grizzly bears that used to live in the area.

The lake is a popular recreational destination for people living in the greater LA area, and this scenic part of the world was a real magnet for visitors during the Covid-19 pandemic when international travel wasn't possible. At one point, a fence even had to be erected because a few trigger-happy Americans had the idea of using the observatory door for target practice for their air rifles! The clean water and abundant fish attract mainly an-

POST FROM

BIG BEAR LAKE, USA

glers to the lake, but you can also hike through pine forests, swim, go boating, or enjoy the romance of a campfire at the campground. In winter, the area is popular with skiers.

During our multi-week campaigns, however, these kinds of leisure activities are not much use to us. Under the direction of Michiel van Noort, we are developing instrumentation for ground-based solar observation, and we are kept busy with setting up and commissioning new instruments because there is always something that needs to be tested and improved.

For the Goode Solar Telescope, we have developed a polarimeter and a camera system. The special thing about our instruments is that they are optimized for the application of computer-aided image reconstruction methods, which allow the theoretical resolving power of the telescope to be almost fully exploited. For optimal results, we need hundreds to thousands of individual exposures in quick succession.

This results in huge amounts of data and an enormous demand for computing power for the purposes of reconstruction. Our camera system delivers about ten terabytes of raw data per hour at a rate of 360 exposures per second. With several hours of data recording per day, this is far too much to transfer over the existing Internet connection, so we resorted to a method aptly referred to as "Sneakernet" by my American colleagues: we carried stacks of hard drives with the observation data across the site on foot and brought them back to Germany in our hand luggage. Lucky for us, the clearly overweight bags were not weighed at the airport, and no one at the security checkpoint was interested in looking at our luggage.

PHOTO: PRIVATE

Hans-Peter Doerr

43, has always been a technology enthusiast and loves to tinker with new instruments for solar observation. After completing a physics degree at Albert Ludwig University in Freiburg, he went on to obtain his doctorate there. Since 2015, he has been working as a postdoc at the Max Planck Institute for Solar System Research in Göttingen in Sami Solanki's department, focusing on observing the atmosphere of our parent star.

FIVE QUESTIONS

ON THE ENERGY CRISIS

TO ROBERT SCHLÖGL

Gas shortages and the climate crisis are reasons enough to move away from fossil fuels as quickly as possible. Robert Schlögl assesses energy policy and explains what science can contribute.

Prof. Schlögl, what's your view of the current energy policy?

ROBERT SCHLÖGL: The government has done quite a lot, and in the short term I don't think they could do much more. In principle, however, there is a problem with the overall system in Germany. There is no sense in using the Climate Protection Act to divide the energy transition into sectors that are tailored to ministries. Now five ministries are each taking independent action. Instead, the overall system needs to be optimized, rather than one sector at the cost of all the others. Everyone now wants access to green electricity that just isn't available: some want to drive electric vehicles, others want electric heating, and still more want to electrify their industry. A big problem is that we will need much more electricity for this than we currently require; we need to store about 50 percent of the energy in order to compensate for fluctuations in the wind and sun This costs four times the energy, however, than just using it directly. I am concerned that we don't have an overall plan.

Do systemic concepts already exist in science?

Two years ago, the German Federal Ministry of Education and Research launched the TransHyDE project, which I coordinate. The focus of this project is investigating the transportation of hydrogen for Germany. In a sub-project, around 40 companies and 250 people are developing concepts for the overall system.

Why are you promoting a global renewable energy market?

The energy transition that is politically advocated now is not based on a global energy market, but on independence. That is a grave error. How can we, as the world's export champion, be self-sufficient? We do, however, need to diversify energy imports. That's easier to do with renewable energy than with fossil energy, because it can be produced efficiently in transportable form within a band of plus/minus 20 degrees around the equator. Half the land area of Saudi Arabia would be enough to meet the energy needs of the entire world.

How can our energy supply be secured in the long term?

We need to get our infrastructure up to speed as quickly as possible. There are no power lines for the thousands of wind turbines that are now to be built, nor are there any pipelines for the green hydrogen we want to buy. In order to utilize the natural gas pipelines, as their operators propose, the hydrogen would have to be available first, and that will take another 20 years. By then, it won't be possible to use the old pipelines. To replace Russian gas with hydrogen, all the factories in the world that produce electrolyzers would have to produce electrolyzers for 40 years – and that's just for Germany. To meet hydrogen demand in 20 years, we must start now. With projects of this magnitude, you lose the most time at the beginning. Once the diggers get going, it takes as long as it takes. What we can do is speed up all the talk about whether the diggers should get going in the first place.

How can basic research in nuclear fusion, for example, contribute to the energy transition?

Nuclear fusion is a topic for the 22nd century, but it is something to pursue, of course. There are a million difficulties in the engine room of the energy transition, though. Catalysts, for example, are needed everywhere. Most of them don't work properly, and we are losing a lot of energy this way. We're doing a lot of work on this at the Max Planck Society. The only thing is that the energy transition does not work according to Max Planck's motto: insight must precede application. We have to get started now and then seek out the optimum approach. Opponents of the energy transition often say: we will implement the energy transition when you have all the necessary knowledge. But that's totally wrong.

Interview: Peter Hergersberg

Robert Schlögl is the director of the "Inorganic Chemistry" department at the Fritz Haber Institute of the Max Planck Society.

ILLUSTRATION: SOPHIE KETTERER FÜR MPG

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

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- Nijmegen

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- Rome
- Florence

USA
- Jupiter, Florida

Brazil
- Manaus

Luxembourg
- Luxembourg

PUBLISHER'S INFORMATION

MaxPlanckResearch is published by the Science and Corporate Communication Office of the Max Planck Society for the Advancement of Science. Legal headquarters of the association: Berlin.
ISSN 1616-4172

Publisher's mailing address
Hofgartenstraße 8
D - 80539 Munich
Tel: +49 89 2108-1719 / -1276 (before midday)
e-mail: mpf@gv.mpg.de
www.mpg.de/mpresearch
App for free download: www.mpg.de/mpr-mobile

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To improve readability, we have used only the masculine form in some of the texts. However, the chosen formulations address all genders equally.

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