04 | 2023

MAX PLANCK
Research

75 YEARS OF THE MAX PLANCK SOCIETY
Patent Solutions

SYNTHETIC BIOLOGY
E-Drive for Life

LEGAL LESSONS
Nature in Dispute

BELOW ZERO

PHOTO: IAN JOUGHIN (DISTRIBUTED VIA IMAGGEO.EGU.EU)

Glacier runoff: The meltwater of the Greenland ice sheet drains through channels like this. Climate change, with its rising temperatures, is also changing this landscape, which was shaped by the cold.

EDITORIAL

Dear Reader,

Extreme cold is rarely an issue, at least in Europe, and that's exactly the problem. As a result of climate change, we are more likely to be concerned about unusually high temperatures. Heat costs thousands of lives and exacerbates drought in many regions. In addition, unusually mild temperatures cause the ice sheets of Greenland and Antarctica to melt. In the "Focus" section of our magazine, which deals with cold, we describe how the climate and the ice sheets influence one another.

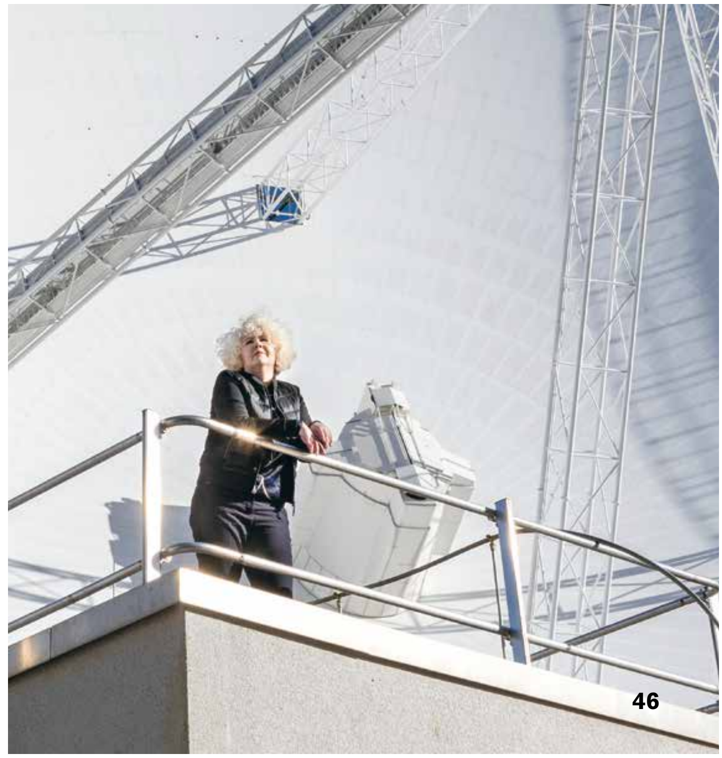
One thing we know for certain is that thawing ice caps result in rising sea levels. This threatens island states and coastal cities. The agreement at the World Climate Conference in Dubai on "transitioning away from fossil fuels" gives them renewed hope that they might avoid sinking underwater. The UN Climate Secretariat heralded the agreement as the beginning of the end of fossil fuels. However, the agreement is not binding under international law and leaves states a lot of room to shape the transition. Nevertheless, Max Planck researchers who followed the climate conference are cautiously optimistic about the results (www.mpg.de/21275331).

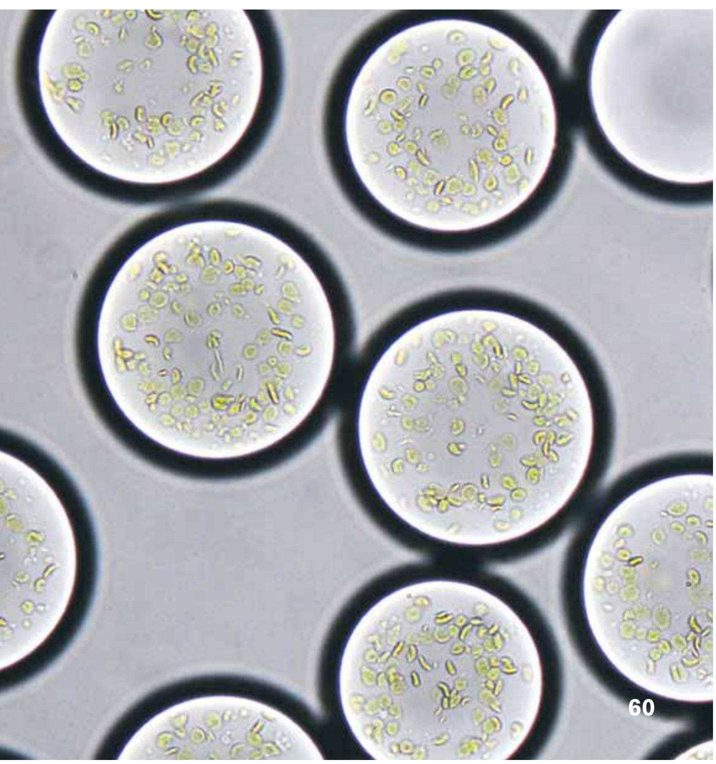
The worst excesses of global warming may still be averted and temperatures may also be kept reasonably stable in the Anthropocene. This is important for humanity, because it was only in the climate of the Holocene, free from extreme fluctuations, that the development of human civilization was possible. Despite the fact that today heat, drought, and floods are increasingly forcing populations in many regions of the world to flee, a look at the last glacial period shows how climatically inhospitable conditions affect people. At that time, ice and cold made large parts of Europe uninhabitable, as we also show in "Focus."

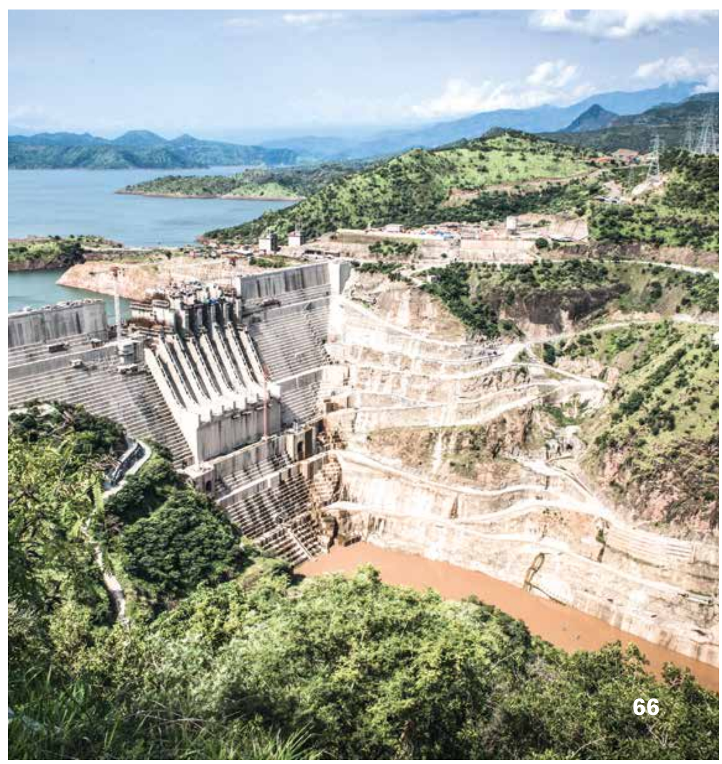
For our part, we have good news to report: the infographics we create together with the graphic agency GCO have won the Creative Communication Award 2023 (www.c2award.com/winners/c2a/2023/5483/).

We hope that the infographic in this issue on the seasonality of viral diseases will also provide helpful information – and we hope too that you will find a cozy place to read our magazine.

Your Editorial Team







IMAGES: NASA, ESA, CSA/SCIENCE LEADS AND IMAGE PROCESSING: M. MCCAUGHREAN, S. PEARSON, CC BY-SA 3.0 IGO (TOP LEFT), CHRISTOPH SEELBACH FOR THE MPG (TOP RIGHT), TOBIAS ERB / MPI FOR TERRESTRIAL MICROBIOLOGY (BOTTOM LEFT), FAUSTO PODAVINI (BOTTOM RIGHT)

CONTENT

PHOTO: ÓSCAR SOLIS TORRES

ON LOCATION

Humanity's origins lie in Africa. From there, *Homo sapiens* spread all over the world: from Europe and Asia to Australia and the islands of the Pacific. During this period of unprecedented hominin migration, the Americas were the last continental landmasses to be occupied in the Late Pleistocene. Around 20,000 to 30,000 years ago, humans migrated from Asia to the Americas through an ice-free land corridor in the Bering Strait region and expanded southwards from there.

At that time, the Americas were home to many large mammals, including elephants, rhinoceroses, and horses, but also giant ground sloths – more than six meters long and several tons in weight. Together they are known as the North American megafauna. However, at the end of the Late Pleistocene, around 10,000 to 12,000 years ago, most of these animals became extinct at the same time as humans spread throughout the continents. Is this a mere coincidence or could these events be linked? Are humans partly responsible for the extinction of the megafauna? Or, in the case of the sloths, maybe even the primary cause? Perhaps they hunted these large, very slow-moving animals to extinction?

Óscar Solis Torres from the Max Planck Institute of Geoanthropology is investigating these questions. He is exploring tropical caves on Mexico's Yucatan Peninsula, where some of the earliest known traces of human presence on the American continents have been found. Solis Torres is looking for evidence of human presence and the remains of megafauna – in this case in the Sac Actun cave system on the northeastern coast of Yucatan. The challenge: the stalactite caves of the Sistema Sac Actun have been under water for around 9000 years. With 347 kilometers discovered to date, Sac Actun is one of the largest underwater cave systems in the world. It is also one of the most important sites of underwater archaeology.

PHOTO: PICTURE ALLIANCE / ABACA | LEVEL DAVID/ABACAPRESS.COM, GRAPHIC: GCO BASED ON INFORMATION FROM MPG

NOBEL PRIZE IN PHYSICS

FERENC KRAUSZ

Ferenc Krausz received the Nobel medal from King Carl Gustaf in Stockholm on December 10, 2023.

A Nobel Prize is not a walk in the park. You could clearly see how intensely Ferenc Krausz was concentrating at the award ceremony on December 10. The Director at the Max Planck Institute of Quantum Optics and Professor at the Ludwig Maximilian University of Munich (LMU) was awarded the Nobel Prize in Physics together with Pierre Agostini from Ohio State University (USA) and Anne L'Huillier from the University of Lund (Sweden), for the establishment of attosecond physics. During the introduction to the subject, before Swedish King Carl Gustaf presented the medals, there was a deep wrinkle on Krausz's forehead. The tension may not only have been due to the magnitude of the moment. Ferenc Krausz and the other prize winners had already had to complete a rigorous program during Nobel Week: press appointments, rehearsals, receptions, public presentations – all within a tight schedule followed by a banquet in the evening.

What's more, before the Nobel Committee even becomes aware of them, laureates have already come a long way and mastered many challenges. Nevertheless, for Ferenc Krausz, all the effort was worth it. "It is a very nice feeling to see that it pays off not to be discouraged by setbacks, but to continue on the path undeterred," said Ferenc Krausz, shortly after the Nobel Committee had notified him. "And that's what I want to pass on to future generations."

The physicist, who comes from Hungary, began his path into attosecond physics in the 1990s. At the beginning of the 2000s, his team succeeded for the first time in generating light pulses in the attosecond range – an attosecond is one billionth of a billionth of a second. For comparison, as many attoseconds fit into one second as seconds fit into the amount of time that has passed since the Big Bang. Ferenc Krausz and his compatriot Robert Szipöcs laid the foundation for this achievement by developing mirrors that can be used to generate extremely intense laser pulses, in which a light wave oscillates just a few times. In 2002, Krausz and Theodor Hänsch, who is also Director at the Max Planck Institute of Quantum Optics and a Professor at LMU, succeeded in controlling the exact shape of a light wave with Hänsch's likewise Nobel Prize-winning frequency comb technique. Krausz's team fired these flashes of light, which lasted a few femtoseconds, at noble gas atoms. The strong electromagnetic fields of the pulses pulled electrons out of the atoms. When they captured the electrons again, they emitted flashes lasting a few hundred attoseconds. The shortest light pulses last significantly less than 100 attoseconds.

With the extremely short laser flashes, Ferenc Krausz's team of researchers can film electrons, for example in the quantum mechanical process of tunneling. Here, the charge carriers penetrate an energy barrier that they should not be able to break through according to the laws of classical physics. The team also photographed the pulsating positively charged hole that an electron leaves in a noble gas atom after being knocked out by a flash of light. The researchers are now also tracking electrons in solids. For example, they have observed how quickly electrons pass through individual atomic layers of a metal. Attosecond physics makes it possible to control the electrons. This could also help in the development of faster electronic components.

GERMAN-UKRAINIAN CORE OF EXCELLENCE LAUNCHED IN HALLE

To strengthen Ukrainian science, the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) will support four centers of excellence with 2.5 million euros each over the next four years. These centers will also make an important contribution to rebuilding the country. One of these centers of excellence – called Plasma-Spin Energy – will be established in cooperation between the Max Planck Institute of Microstructure Physics in Halle and the W.N. Karazin Kharkiv National University. The center of excellence will probably be located in Kharkiv. The researchers aim to produce components for spintronics using plasma techniques. Unlike conventional electronics, spintronics uses the spin of electrons rather than their charge to create more efficient electronic devices. ***www.mpg.de/21108595***

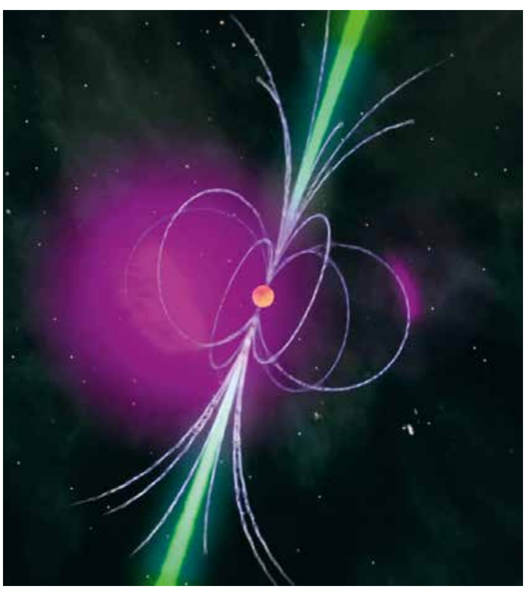


PHOTO: NASA/FERMI/CRUZ DEWILDE

Cosmic lighthouse: The illustration shows a neutron star emitting radio waves (green) from its magnetic poles. As a radio pulsar like this one rotates, it appears to glow periodically when viewed from Earth.

STARGAZING FROM THE COMFORT OF YOUR COUCH

Einstein@Home harnesses the otherwise wasted computing power of the PCs of over 15,000 volunteers, making it one of the largest citizen science projects of its kind in the world. Since 2009, Einstein@Home has analyzed over 150,000 observations from the Arecibo Radio Telescope, identifying a staggering 60 billion pulsar candidates hidden in the data. Using a new algorithm, researchers at the Max Planck Institute for Gravitational Physics have reduced this number and created a database of 50,000 particularly promising candidates for rapidly rotating neutron stars. For each of these potential new pulsars, the research team has produced a series of graphs of the measurement data. As part of the new "Pulsar Seekers" citizen science project, hosted on the Zooniverse platform, volunteers can now classify the graphical representations of the Einstein@Home results to discover the actual pulsars in them. ***www.mpg.de/21023035***

OUTSTANDING! ✶

PHOTO: CHRIS KETTNER

TOBIAS ERB

The Director at the Max Planck Institute for Terrestrial Microbiology in Marburg has been awarded the EUR 2.5 million Gottfried Wilhelm Leibniz Prize. He is being honored for his research into the metabolic pathways of microorganisms, particularly those involved in photosynthesis. Erb studies microbial enzymes, modifies their properties, and uses synthetic biology to construct metabolic pathways that convert CO_2 more efficiently than their natural counterparts. His work is opening up new ways of producing sustainable raw materials from CO_2 by using light.

PHOTO: MPI FOR BRAIN RESEARCH

MORITZ HELMSTAEDTER

Moritz Helmstaedter, Director at the Max Planck Institute for Brain Research in Frankfurt, will also receive a Leibniz Prize. He is being honored for his pioneering work in neuroscience. Helmstaedter has developed tools and techniques that provide insights into the densely packed neuronal networks of the brain. He is one of the founders of connectomics, which reconstructs thousands of neurons and their synaptic connections. Research in this field fundamentally improves our understanding of how circuits in the mammalian brain are organized and how they function.

IN BRIEF

PHOTO: YONI KELBERMAN / MPG

Patrick Cramer at the Yad Vashem Holocaust Memorial in Jerusalem, with other members of the Max Planck delegation in the background.

MAX PLANCK DELEGATION IN ISRAEL

It was a visit during difficult times. There should have been reason to celebrate this year. The Minerva scholarship program, which promotes Israeli-German scientific exchange, is celebrating its 50th anniversary. But because of the barbaric terrorist attack by Hamas and the terrible war in Gaza, the planned event was canceled. Nevertheless, a small delegation from the Max Planck Society and the Minerva Foundation, led by President Patrick Cramer, traveled to Israel at the end of November to express solidarity with long-standing colleagues at Israeli universities and the Weizmann Institute of Science. It was the first and so far only visit by an international research organization to Israel since October 7. At the Van Leer Jerusalem Institute, the delegation met with the presidents and vice-presidents of Israeli universities and research facilities, as well as the directors of the Minerva Centers. They brought with them offers of scientific support, as research is hardly possible in Israel at the moment. The Max Planck Society and the Minerva Foundation are therefore helping Israeli researchers to continue their projects at Max Planck Institutes in Germany or to hold conferences that are no longer possible in Tel Aviv, Haifa, or Jerusalem. The delegation also visited the Yad Vashem Holocaust memorial and laid a wreath in memory of the persecuted scientists of the Kaiser Wilhelm Society.

SUCCESSFUL IN EUROPE

They want to develop a new mathematical language, explore the regenerative abilities of the axolotl brain, search for habitable worlds beyond our solar system, and work on transmitting odors over the internet. In the call for tenders in the ERC Synergy Grants 2023, 37 projects were selected for funding out of a total of 396 applications from across Europe. Four grants totaling around EUR 40 million were awarded to research teams from the Max Planck Society. In addition, four Max Planck projects were awarded Consolidator Grants, each worth around EUR 2 million. These grants are awarded to researchers who recently completed their doctorates and have promising scientific careers ahead of them. The diverse range of research topics have included giant viruses, origami DNA for optimizing essential enzyme functions, microorganisms as biofuel sources, and reconstructing prehistoric neighborhood structures using ancient DNA.

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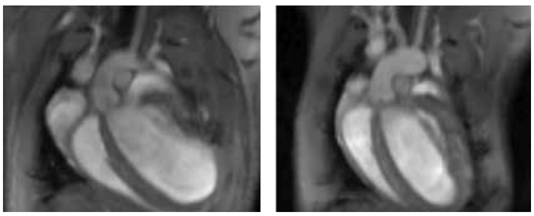
A HEART CAN BE REPAIRED



Mouse heart about one month after a heart attack: In mice with a functioning Cpt1b gene, the ventricle is enlarged and the muscle tissue is damaged (left). In contrast, the hearts of animals without a functional Cpt1b gene have fully regenerated after the heart attack (right).

PHOTO: MPI FOR HEART AND LUNG RESEARCH

Because heart muscle cells cannot divide after birth, the human heart loses almost all of its ability to repair damage. This is why a heart attack in adults usually causes permanent damage to the heart muscle. When cells lose their ability to divide, their energy metabolism also changes. Instead of getting energy from sugar, they rely mainly on fats. Researchers at the Max Planck Institute for Heart and Lung Research have now successfully restored the hearts of adult mice after a heart attack. They focused on a gene called Cpt1b that is essential for the burning of fatty acids. Mice in which Cpt1b was deactivated in heart muscle cells showed almost no scarring in the heart muscle a few weeks after a heart attack. The hearts of these animals were able to beat almost as strongly as before the heart attack. Deactivating the gene causes heart muscle cells to revert to an immature state, allowing them to regenerate. Inhibitors that block the action of Cpt1b may be an option for new therapies. **www.mpg.de/20981292**

HUMANS AND BATS

Bats are commonly thought to carry viruses that can be transmitted to humans. A team of researchers at the Max Planck Institute of Animal Behavior has analyzed studies of viruses from more than 160 African bat species. Apart from the Egyptian fruit bat, which can carry Marburg and Sosuga viruses, they found no evidence that African bats carry viruses that are dangerous to humans. Transmission of viruses from bats to humans in Africa has only been confirmed in two cases. Despite research to the contrary, bats are still considered to be disease carriers. This can be fatal for these animals, as it increases their already growing persecution by humans. The decline of bats in Africa is also having a dramatic impact on nature, as bats carry tree seeds and help reforest previously deforested areas. **www.mpg.de/21135641**

EXOMOONS PLAYING HIDE-AND-SEEK

Just as planets are thought to orbit most of the stars in our Milky Way, moons around these exoplanets should be no rarity. Finding them, however, is even more challenging than finding exoplanets and resembles a game of hide-and-seek. Both planets and their moons can be detected using the transit method. When such a celestial body passes in front of its star or planet, as seen from Earth, it slightly dims its light. However, when an exomoon accompanies the planet, the effect is easily lost in the noise within the data. Various analyses have confirmed the existence of moons to varying degrees. So far, only two of the more than 5,300 known exoplanets, namely Kepler-1625b and Kepler-1708b, have shown potential evidence of moons. However, a team from the Max Planck Institute for Solar System Research and the Sonneberg Observatory has re-analyzed the data using an algorithm specifically designed for exomoons. They haven't found any evidence yet, but the game of hide-and-seek continues. **www.mpg.de/21217437**

Illustration of an exoplanet orbiting a sun-like star.

PHOTO: NASA/JPL-CALTECH

PHOTO: PAUL-ANTOINE LIBOUREL, LYON NEUROSCIENCE RESEARCH CENTRE, FRANCE

Breeding Adélie penguins on King George Island, Antarctica.

MICROSLEEP

Penguins have perfected what some people wish for in their hectic daily lives: the ability to doze off for a moment and regenerate in the process. An international team, including the Max Planck Institute for Biological Intelligence, recorded the brain activity of Adélie penguins during the breeding season and discovered that these birds sleep for an average of only four seconds at a time, but can enter such a microsleep up to around 600 times per hour during the breeding season. Over the course of the day, they accumulate up to twelve hours of slow-wave sleep, the typical bird sleep pattern. During this sleep, they may alternately doze off in one hemisphere of the brain or the other, or both hemispheres may sleep together. They can also sleep while floating in the sea, but then almost exclusively with both hemispheres. Especially at the edge of a colony, there is a risk that nest robbers stealing eggs will take advantage of penguins sleeping with both hemispheres. However, the measurements show that penguins at the edge of a colony do not sleep longer or more often with only one hemisphere than those in the center of the colony. The unusual sleeping behavior of the penguins appears to be a result of disturbance and aggression from conspecifics rather than fear of predators.

www.mpg.de/21169426

STAR NURSERY WITHOUT UV DISASTER

Although the sun's UV radiation can cause sunburn and, in the worst cases, skin cancer, it hasn't prevented life on Earth. But the situation is different on many planets in the universe. In the vicinity of more than half of all star systems and their planets, possibly including our own solar system, there were or are particularly massive stars. During their short lives, these stars bombard many planets with intense UV radiation. Complex molecules, and therefore life, were thought to be unlikely to form there. A team led by María C. Ramírez-Tannus from the Max Planck Institute for Astronomy set out to test this assumption by studying the birthplace of planets in a truly inhospitable environment – the star-forming region NGC 6357, a region 5500 light-years away. To their surprise, the researchers discovered water, carbon monoxide, carbon dioxide, acetylene, and silicate dust in the material reservoir of the gas and dust disk known as XUE-1. These are all key molecules for the formation of Earth-like planets and, in part, for the origin of life – despite the enormous radiation from neighboring giant stars. Earth-like planets could therefore form under much harsher conditions than researchers previously thought.

www.mpg.de/21124740

Illustration of a star-forming region with a planet-forming disk in the foreground and a massive star in the upper left.

PHOTO: MARIA CRISTINA FORTUNA (WWW.MARIACRISTINAFORTUNA.COM)

FASTING IN OLD AGE

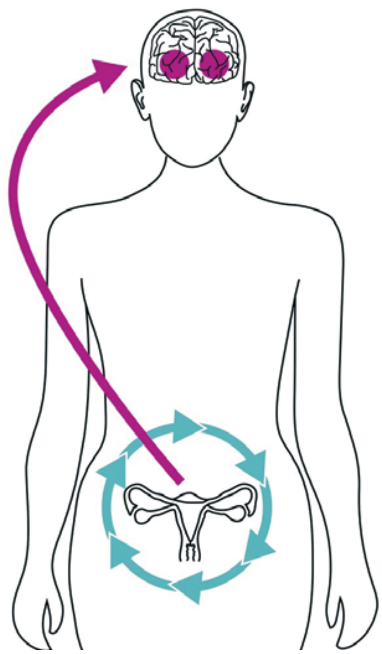
Diets that alternate between fasting and eating keep the metabolism flexible. In this way, intermittent fasting promotes health and increases life expectancy. However, studies in different animal species have shown that the effect of such diets declines with age. Researchers at the Max Planck Institute for Biology of Ageing have now found out why. They prescribed fasting periods for killifish of different ages and studied the response of the fish's fat tissue to the end of the fast. In contrast to young fish, fasting puts the fat tissue of older animals into a permanent dormant state. This leads to a shutdown of energy metabolism, a reduction in protein production and tissue non-renewal. This negatively affects the energy balance of the whole body. A subunit of a cellular energy sensor called AMP kinase plays a central role in this process. It is less active in older fish than in younger ones. This molecule may also influence the ageing process in humans, as people with higher levels of the AMP kinase subunit tend to be healthier in old age. The researchers are therefore looking for molecules that activate the subunit and promote health in old age.

www.mpg.de/21105996

A CYCLE IN THE BRAIN

Fluctuations in female hormone levels affect the brain. A team of researchers at the Max Planck Institute for Human Cognitive and Brain Sciences has found that some brain regions grow and shrink during the menstrual cycle. The team took blood samples and performed magnetic resonance imaging of the brains of 27 participants at six different times. The researchers found that during periods of high estradiol and low progesterone, which are typical around ovulation, some regions of the medial temporal lobe of the cerebral cortex expand. These areas of the brain are important for aspects of long-term memory and spatial perception. The exact neurological changes responsible for the growth of these regions are still unclear. However, part of the increase in volume could be explained by an increase in the number of synaptic connections between nerve cells.

www.mpg.de/20964081



During the menstrual cycle, brain regions in the cerebral cortex of women grow and shrink.

GRAPHIC: MPI FOR HUMAN COGNITIVE AND BRAIN SCIENCES

COLLECTIVE APPROACH FOR BETTER DIAGNOSES

Medical diagnoses become much more accurate when the expertise of several doctors is combined. A diagnosis is correct 76 percent of the time when the judgments of ten medical experts are combined. When one person makes a diagnosis alone, it is correct only 46 percent of the time. This has been shown by an international team, including scientists from the Max Planck Institute for Human Development, using more than 1,300 medical cases from a global database. In medicine, pooled assessments can save lives – in the United States alone, around 250,000 people die each year as a result of medical errors, many of which occur during diagnosis. Until now, multiple expert opinions could only be evaluated efficiently if they were standardized. However, this is rarely the case with medical diagnoses. The team is using artificial intelligence, among other methods, to combine the opinions of different experts. The researchers are currently working on implementing their development in medical practice.

www.mpg.de/20991718

5,000,000

deaths per year could be avoided by transitioning away from fossil fuels.

ENERGY TRANSITION SAVES MILLIONS OF LIVES

A rapid phase-out of fossil fuels wouldn't just slow climate change. It could also prevent 5 million deaths worldwide each year from air pollution. This is the conclusion of an international team including researchers from the Max Planck Institute for Chemistry. The researchers assessed the impact of air pollution, particularly fine particulate matter and ozone, and its effects on health. They attributed both total mortality and disease-specific deaths to specific emission sources. They found that about half of fossil fuel deaths were from cardiovascular disease, which is primarily caused or aggravated by particulate matter.

www.mpg.de/13275159

PHOTO: MPI FOR MULTIDISCIPLINARY SCIENCES/ MIQUEL VILA-FARRÉ

Flatworms can regenerate body parts to varying degrees. This may be related to the way the species reproduce.

HEADLESS, BUT SEXY

In Greek mythology, if you cut off the head of the monster known as the Hydra, two new ones grow in its place. Some species of flatworms are also masters at regenerating body parts. In general, very few animals have the ability to regenerate body parts, even though it would be a survival advantage. Researchers at the Max Planck Institute for Multidisciplinary Sciences have found an explanation for why some species have developed the ability to regenerate while others have not. A key factor is a cell signaling pathway called Wnt. When the pathway is "on", an animal forms a new tail; when it is "off", it forms a head. Wnt signals also control the formation of testes and egg yolk. In sexually reproducing flatworms, the Wnt signaling pathway must be active in order to produce eggs and sperm. However, this comes at the cost of their ability to regenerate, as the worms cannot survive without a head. By contrast, asexually reproducing flatworms must be able to regenerate body parts because they split into two parts, each of which grows into a complete new organism. Thus, flatworms may have evolved the ability to regenerate for the purpose of asexual reproduction by division rather than for wound repair.

www.mpg.de/20977630

EUROPE UNDER HEAT STRESS

Extreme heat waves and droughts that were virtually impossible less than 20 years ago were expected to become more common by the end of the century due to human-induced climate change. However, new calculations by a team including researchers from the Max Planck Institute for Meteorology suggest that these extremes could occur earlier than expected. According to their findings, a natural climate variability, in which the surface temperature of the North Atlantic Ocean fluctuates over several decades, amplifies the effects of global warming. As a result, the likelihood of extreme heat waves and droughts in the next two decades has increased to ten percent. By 2050, there is also a ten percent chance of extreme heat waves occurring in two consecutive years.

www.mpg.de/mpr-2023-042

PHOTO: DEBBIE FROM PIXABAY

Monk parakeets originate from South America. In recent decades, birds that escaped from the zoo trade have established new populations in European cities.

PARROT TALK

"We can do everything except speak standard German," the Swabians say of themselves. At least when it comes to dialect, some parrots may feel the same way. Researchers from the Max Planck Institute of Animal Behavior in Konstanz and the Max Planck Institute for Evolutionary Anthropology in Leipzig have studied monk parakeets, which have spread across Europe over the last 50 years. They recorded the birds' vocalizations in eight cities in Spain, Belgium, Italy, and Greece and analyzed them using a novel statistical method. Their analyses showed that the parakeets modulate the pitch of their calls differently in each city. However, within each city, the calls did not differ. This suggests that the dialects of monk parakeets in Europe may have evolved as individuals imitating their conspecifics made small errors that accumulated over time and differed from city to city. The researchers had previously discovered that each parakeet may have a unique voice. It might be the case that monk parakeets, like humans, recognize each other by voice.

www.mpg.de/21165360

RISKY PAYDAY

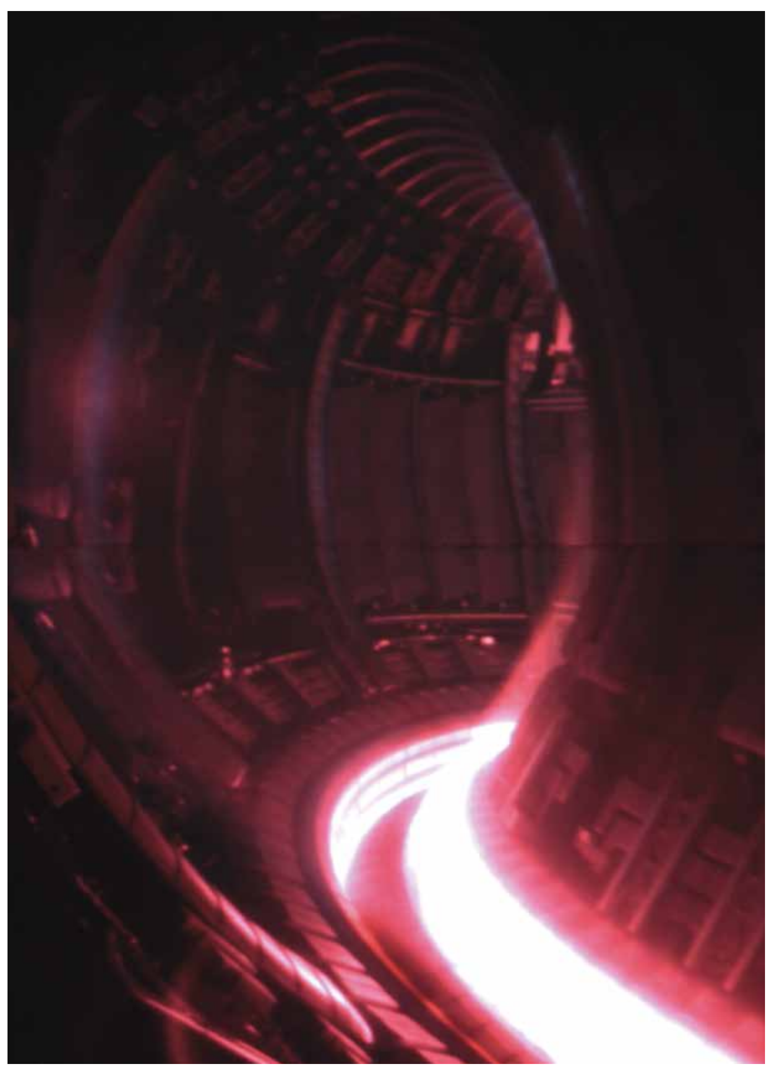
An international study, involving Peter Eibich, a scientist at the Max Planck Institute for Demographic Research, has found that individuals receiving state social benefits or low pensions tend to take higher risks shortly before their income is paid out. This behavior was observed among socially disadvantaged pensioners in both the USA and Japan. Risk-taking behaviors include taking out loans, engaging in gambling activities like the lottery, or smoking. To gauge risk tolerance, the research team analyzed survey responses regarding preferences between a job offer with a steady, guaranteed income versus one with varying probabilities of higher or lower salaries. By correlating this data with the timing of the surveys, the researchers were able to observe changes in risk-taking behavior around payday. The results indicate that, in both the USA and Japan, where individuals generally exhibit lower risk-taking tendencies, those with very low incomes display an increased willingness to take risks as their funds run short before payday and they become stressed as a result. Shortening the intervals between payment dates could potentially assist payment recipients in better managing their finances, thereby reducing stress levels and the associated propensity for higher risk-taking behaviors.

www.mpg.de/20938976

ENERGY RECORD IN NUCLEAR FUSION

At the Joint European Torus (Jet) in the UK, a European team, including scientists from the Max Planck Institute for Plasma Physics in Garching, has released the largest amount of energy ever produced by a fusion experiment. During a 5.2 second plasma discharge, they generated 69 megajoules of energy from 0.2 milligrams of fuel. This surpasses their previous record from 2021, where they attained 59 megajoules in 5 seconds. However, the energy required to ignite the plasma still exceeded the energy produced by the fusion process itself. Achieving a positive energy balance will only be possible with significantly larger fusion facilities, such as Iter. The record-breaking discharge was one of the last experiments at Jet, as the facility ceased operations at the end of 2023 after four decades.

www.mpg.de/21522737



Plasma discharge #104,522: The energy record was achieved in this Jet experiment.

PHOTO: UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ELECTRONIC MUSIC WITH A HUMAN RHYTHM

Electronically generated rhythms are often perceived as sounding too artificial. New software is changing that perception by allowing producers to create rhythms that sound more natural in computer-produced music. Research conducted at the Max Planck Institute for Dynamics and Self-Organization and at Harvard University forms the basis for new and patented methods of electronically generated rhythms imitating deviations of musicians, which follow fractal patterns. The process, which produces natural-sounding rhythms, has been licensed to Mixed In Key LLC, whose music software is used worldwide by music producers and DJs. A product called Human Plugins, which uses this technology, has now been launched.

www.mpg.de/21479985

A software called human plugins generates rhythms with deviations of human musicians.

IMAGE: MIXED IN KEY

Two grams of paclitaxel are needed to treat one cancer patient. To obtain this amount, ten tonnes of yew needles must be processed. Laboratory synthesis of paclitaxel involves numerous complex steps and is therefore still more costly than extraction from trees.

PHOTO: ALPSDAKE / CC BY-SA 3.0

SYNTHESIS OF ANTI-CANCER AGENT ELUCIDATED

Paclitaxel, a commonly used chemotherapeutic agent in the treatment of cancer, is synthesized by yew trees with the help of various enzymes. However, until recently, many of the molecules and the genes involved in the biosynthetic pathway remained unknown. Researchers at the Max Planck Institute of Molecular Plant Physiology in Potsdam have now successfully identified all the missing enzymes required by yew trees to produce paclitaxel. By equipping tobacco plants with both the previously known and newly discovered genes, similar amounts of paclitaxel can be produced as in yew tree. This breakthrough suggests the potential for genetically modified plants or microorganisms to be utilized in the production of this chemotherapeutic agent. However, some of the enzymes currently do not function effectively in bacteria. This may be due to the fact that many of these enzymes are bound to membranes, but bacteria possess different membranes compared to plants. As a result, the enzymes in the single-celled organisms may not find each other. Nevertheless, it may be possible to adapt the synthetic pathway so that it also functions effectively in bacteria. The discovery holds promise to help produce the anti-cancer drug more efficiently in future.

www.mpg.de/21255442

LAW AT THE BORDER

Admission criteria, distribution plans, or asylum procedures at the EU's external borders: the adopted EU asylum reform aims to clarify many aspects. Ulrich Becker and Constantin Hruschka call for effective and legally secure border procedures.

Shortly before Christmas, the European Council, the European Parliament, and the European Commission agreed on asylum procedures at the EU's external borders. At the time of going to press, the details of how these will be implemented had not been finalized. Since the summer of 2023, border procedures have been increasingly discussed as a possible means of combating human smuggling and relieving the burden on national authorities. This is also driven by the desire of EU member states to better control immigration and speed up decisions on access for asylum seekers.

Border procedures – i.e., recognition procedures for persons seeking international protection carried out at a border – are not entirely new. They have been part of asylum policies in many countries for more than 30 years. In Germany, such procedures have been in place at international airports since 1993. If it is established that a person who does not fulfill the conditions for entry is clearly not in need of international protection, they are refused entry, and the airline that transported the person is obliged to return them to the point of departure; in practice, however, this is of little significance due to the prohibition of airlines transporting passengers without a visa or other legal entry permit to the country of destination.

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VIEW POINT

ULRICH BECKER AND CONSTANTIN HRUSCHKA

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Ulrich Becker is Director of the Max Planck Institute for Social Law and Social Policy in Munich. As an expert in constitutional and European law, he focuses primarily on the characteristics and development of social law and migration-related issues.

Constantin Hruschka's research interests include responsibility sharing in refugee protection. He recently advised the European Committee of the Regions on its position on reform proposals.

Now that border procedures have been extended, expectations are high, but they point in very different directions. Some see these procedures as an essential building block to curb irregular migration. Others consider them to be an abdication of responsibility and fear an erosion of asylum rights, as the assessment of protection claims at the border would inevitably lead to human rights violations. In the face of these conflicting positions, a sober examination of the legal requirements can help to assess the potential and requirements of border procedures.

QUOTAS REDUCE THE NUMBER OF ASYLUM CASES

What can border procedures be used for? First, it is important to understand why procedures are necessary, and second, where these procedures should take place. The need for procedures stems from the fact that, after the First World War, countries agreed not only to admit people from other countries because they were needed in their labor markets, but also to offer them protection. This admission of people is a humanitarian act that has gradually been codified into legally binding rules, notably through the 1951 Geneva Refugee Convention (GRC), which became universally applicable by virtue of the 1967 New York Protocol. However, it also involves a distinction between people fleeing their homeland: namely between those who meet the criteria for refugee status as defined in the GRC and those who do not. The purpose of this distinction is debatable, even considering the fact that the criteria for protection have now been broadened to include human rights – but there are good reasons to maintain it. The consequence is that procedures are needed to determine eligibility for protection.

However, the number of asylum procedures can be reduced by granting certain groups of people a (temporary) right of residence without individual assessment. For example, such temporary protection procedures have been implemented for refugees from Ukraine for the first time on the basis of EU law. This approach is not new and has been used in Germany since 1956. It could, in principle, be applied to other groups, such as those threatened by specific armed conflicts, and would contribute to the relief of other procedures.

The need for procedures leads to the second point and the question of where these procedures should take place. Germany is part of the EU's single market, which allows not only the free movement of goods but also, within the Schengen area, the free movement of persons without controls at internal borders. To support this, the Common European Asylum System was created on the basis of various EU laws and, since the Treaties of Amsterdam and Lisbon, on a contractual basis.

It can be argued that this system does not work well, partly because of overlapping competences between the EU and member states. But it does provide a legal framework for refugee policy. While internal border controls can be reintroduced in exceptional cases, they do not allow for the direct return of asylum seekers to the EU's neighboring states. Moreover, in a common space, there must be common decisions on the admission of people from other countries. Border procedures must therefore be carried out at the EU's external borders if they are to control access effectively.

What kind of control can border procedures develop? First, asylum border procedures should make it possible to refuse entry to people who do not meet the criteria for international protection. Such refusal of entry can only take place upon assessment of established protection criteria, as the asylum procedure is legally carried out before entry. However, even if the asylum procedure were to take place on the receiving country's own territory, procedures close to the border would offer the prospect of better controllability, faster procedures, and successful deportation/repatriation. Second, border procedures should ensure that people are not allowed to enter if they do not need protection on the other side of the border, because a third country is willing to take responsibility for assessing the need for protection and for granting protection in case of a positive assessment. The required assessment program has a different focus: it still maintains the prohibition of "pushbacks", i.e., refusals without an individual assessment of protection needs, yet it does not assess the circumstances of flight in the country of origin, but rather the circumstances of protection in the third country.

PUSHBACKS WITHOUT ASYLUM PROCEDURES ARE AND WILL REMAIN PROHIBITED

The question remains as to how border procedures should be organized. With regard to protection in third countries, it is necessary that third countries are willing and able to offer protection to threatened persons in two respects: protection against return to the country of origin and protection against human rights violations in third countries. Under these conditions, the GRC does not generally prohibit the involvement of third countries. This is the background against which the UK entered into an agreement with Rwanda, but also the reason the UK Supreme Court declared this agreement unlawful in the fall of 2023. Third countries must provide a guarantee that refugees will be protected from human rights abuses. Indeed, other attempts to completely outsource asylum procedures to third countries have largely failed – think of Australia's efforts with boat transfers to Papua New Guinea and Nauru, or the US's attempts to reach

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similar agreements with Guatemala and Honduras. It remains to be seen what will be achieved by the recent agreement between Italy and Albania, according to which people rescued in distress at sea will be processed by the Italian authorities in Albania – similar to the US's Remain in Mexico program. The legal uncertainties involved and the foreseeable difficulties in achieving even the planned maximum of 3000 admissions per month in Albania raise serious doubts as to whether this will be anything more than a symbolic act.

SWIFT SWITZERLAND: FULL ASSESSMENT WITHIN 100 DAYS

It will therefore remain necessary to carry out a full program of assessment of protection needs at the EU's external borders. This means two things: providing a procedure that meets the legal requirements, and the possibility of legal stay arrangements to carry out this procedure. The procedure must be fair in accordance with general human rights standards, with effective legal protection, and decisions should be taken within a reasonable period of time and with a reasonable expenditure of resources. The protection needs claimed by refugees must be genuinely assessed. In order to reduce the length of the procedure and increase the likelihood of repatriation in the event of a negative protection assessment, short procedural deadlines should be established and respected. However, this should not be at the expense of ensuring effective legal protection. Legal protection against decisions must at least include access to full information and an independent review body. An appeal against the decision should have a suspensive effect on the execution of deportation. That means the ordered deportation will only take place after a judicial decision on the obligation to leave.

Expeditious and, at the same time, lawful procedures therefore place high demands on the resources invested in them. As the example of Switzerland shows, it is advisable to provide refugees with counseling and legal representation in order to complete most procedures within 100 days; accommodation must be humane, and families, people with disabilities, children and young people, victims of violence, and the sick must be given special support. Refugees may be housed in proximity to the border, but this must not involve deprivation of liberty. The EU Court of Justice and the European Court of Human Rights have dealt with this in several cases, although the specific requirements have not yet been clarified. However, it can be assumed that the detention of persons at the border is only allowed for a limited period of time and must serve the actual conduct of the procedure; furthermore, the circumstances of the conduct of the procedure must not hinder it in practice.

It is in the light of these broad legal requirements that the EU's current reform plans can be assessed. They are currently being negotiated between the participating institutions ("trilogue") and are expected to be adopted by spring 2024. The proposed border procedures could be applied to inadmissible cases (e.g., applicants from safe third countries) and for accelerated processing of applications, with a maximum duration of 12 weeks. These proposed procedures would be deemed mandatory, inter alia, for applications from persons coming from a country where the average EU-wide asylum recognition rate is at 20 percent or less and, generally speaking, would apply to an upper limit of up to 30,000 applications. In times of crisis, however, it should be possible to extend and increase the maximum duration of border procedures to 20 weeks. The last point in particular is viewed critically.

THE RULE OF LAW IN PRACTICE IS THE KEY

In principle, the proposals allow for a lawful organization of border procedures. Ultimately, it will come down to adhering to these requirements in practice. This practical reservation also applies to the solidarity measures aimed at achieving a fairer distribution of the persons admitted on the basis of their need of protection. On the one hand, EU member states would have the possibility to buy themselves out from such admissions obligations; on the other hand, financial commitments are a first approach as long as there is no prospect of enforcing EU-wide admission quotas. This is particularly relevant given that the introduction of legal border procedures is resource-intensive and the EU as a whole must take responsibility for it.

In conclusion, border procedures can be regulated in a lawful manner and can contribute to a more effective distinction between those in need of protection and other potential arrivals, as required by refugee law. However, they are not a panacea; they do not reduce the number of refugees, nor do they contribute to a meaningful overall responsibility-sharing approach. Multilateral agreements with third countries will remain indispensable and, above all, addressing the root causes of forced displacement and migration is crucial. None of this is new. But it is important, and the time has come once again to bring it to mind.

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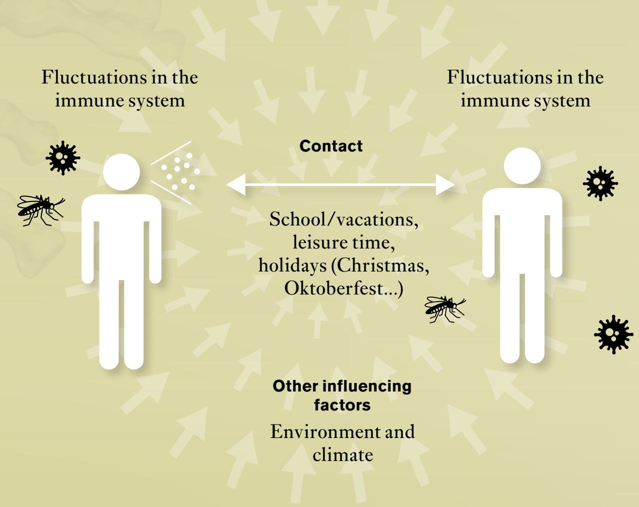
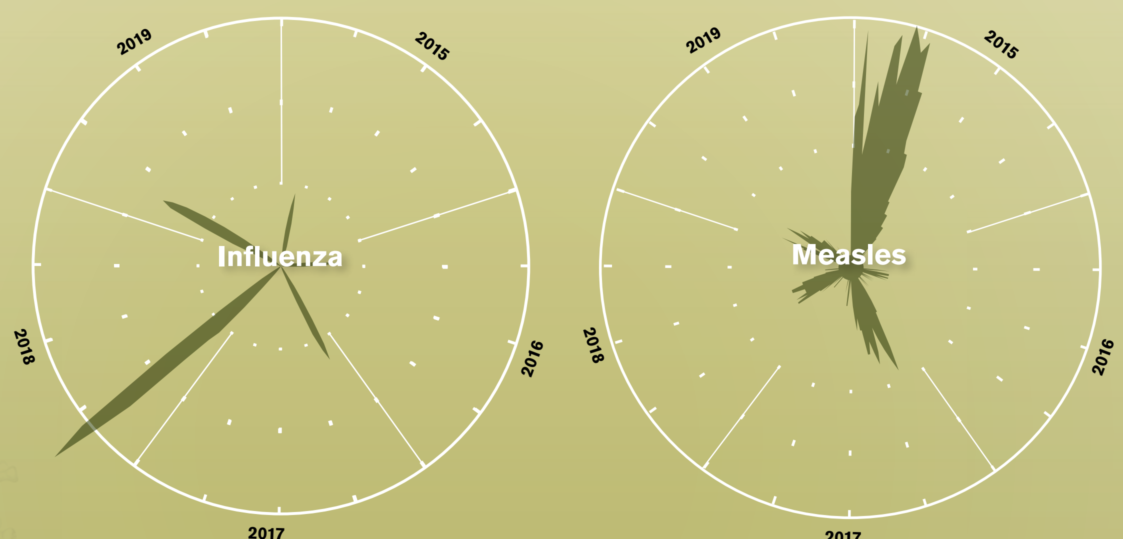
PEAK SEASON FOR VIRUSES

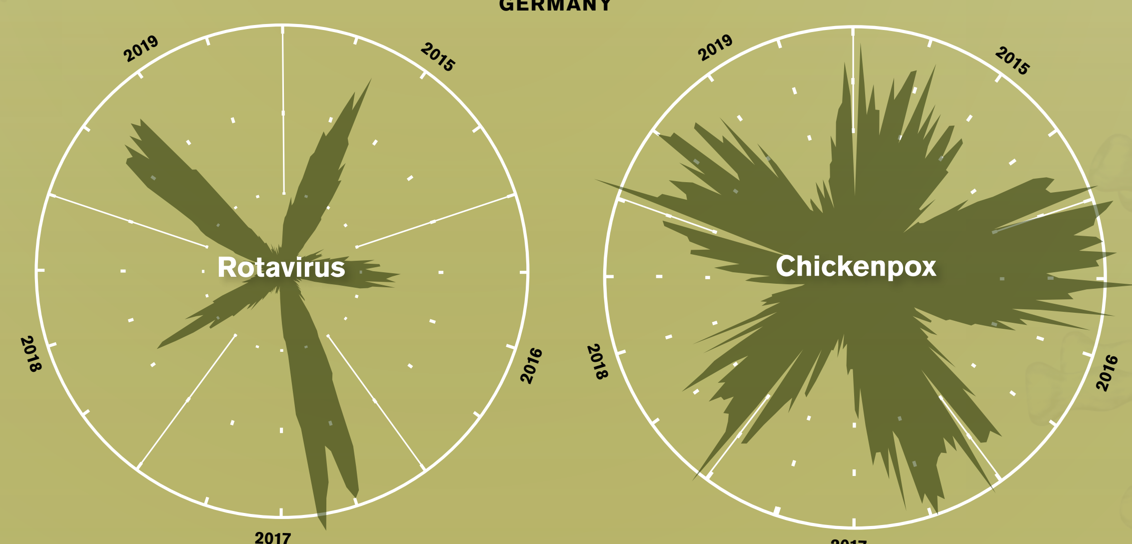
In temperate latitudes, many viral infections occur more frequently in winter. Despite the fact that there are no seasons in the tropics, many infectious diseases still occur there with uneven distribution throughout the year. The period in which a wave of infection reaches its peak depends on several factors, for example on seasonal temperature fluctuations or changes in contact rates among susceptible people. Researchers at the Max Planck Institute for Infection Biology have managed to decipher the seasonality of chickenpox in Colombia. Their findings can help with the development of vaccination programs.

TRIGGERS FOR WAVES OF INFECTION





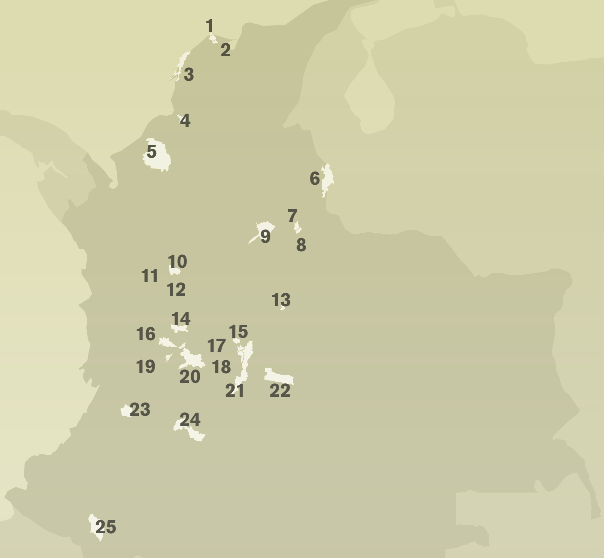
FREQUENCY OF INFLUENZA, MEASLES, ROTAVIRUS, AND CHICKENPOX IN GERMANY

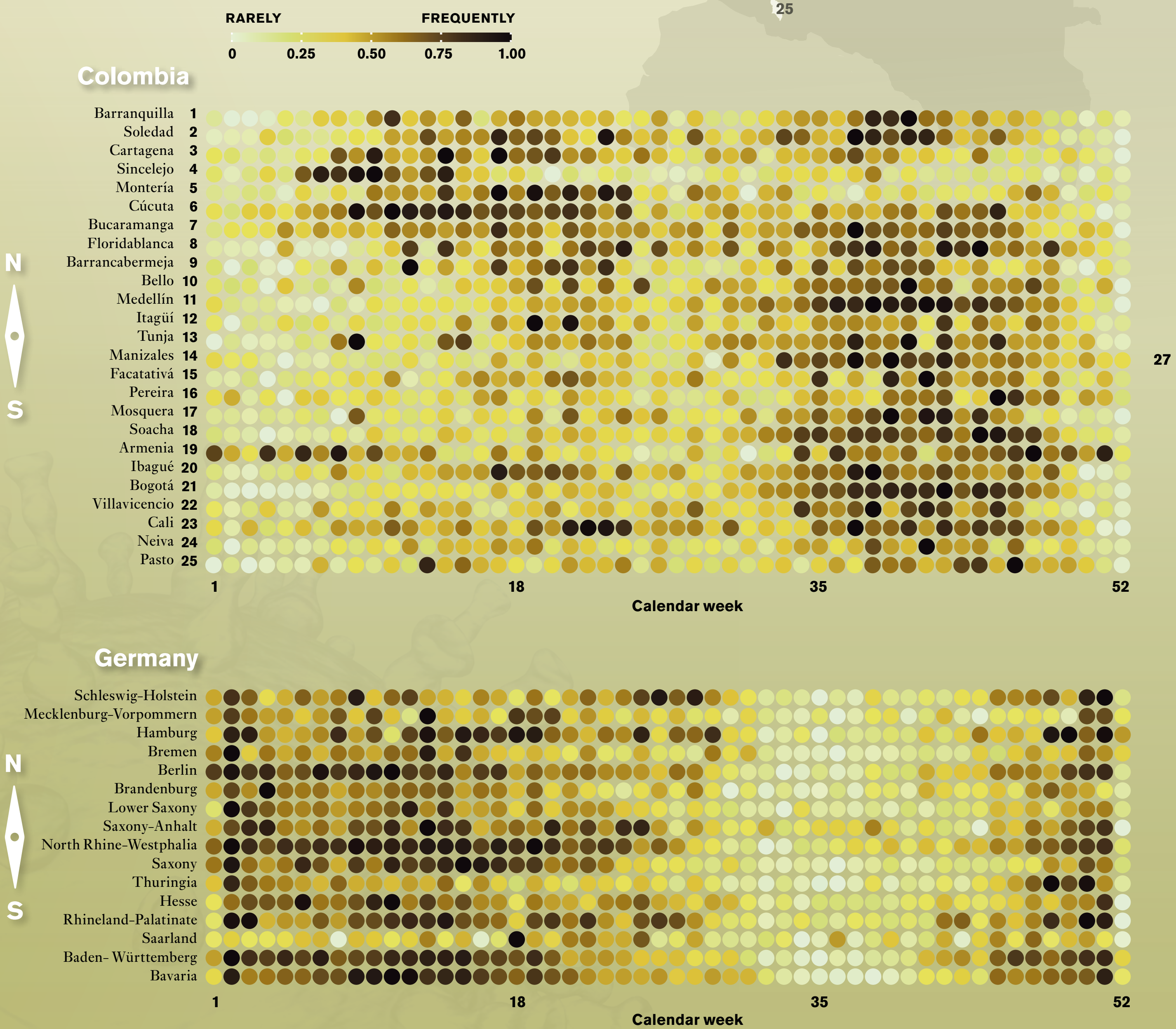


GRAPHIC: GCO BASED ON BARRERO GUEVARA ET AL., 2023

CHICKENPOX IN COLOMBIA AND GERMANY

In Colombia, chickenpox occurs more frequently in April and October. The South American country does not have seasons like in Germany; instead, humidity fluctuates throughout the year. In the north, the first few months of the year are dry, then humidity rises and remains high until the end of the year. In the south, meanwhile, it increases at the start of the year and decreases again towards the end of the year. The researchers suspect that chickenpox is more easily transmitted during the dry months and during the school term. In communities in the north of the country, the wave is therefore higher in April than in October, while in the south it is the other way around. In Germany, meanwhile, the chickenpox season peaks around the same time in all federal states.





Our infographics were recognized with the Creative Communication Award in 2023.

FOCUS

BELOW ZERO

ILLUSTRATION: TOM BJÖRKLUND

A member of what is termed Gravettian culture. It began around 32,000 years ago and lasted around 8000 years. Although these people manufactured stone tools that look similar to those found in many parts of Central Europe, they clearly lived in largely isolated populations. The artist's depiction is inspired by archaeological finds in Arene Candide cave (Italy).

ICY TIMES

TEXT: THOMAS TRAPPE

The last Ice Age has shaped human life in Europe for thousands of years. Driven from Central Europe by low temperatures during glacial periods, *Homo sapiens* repeatedly reconquered previously uninhabitable regions during interglacial periods. Johannes Krause and his team at the Max Planck Institute for Evolutionary Anthropology in Leipzig are studying these migrations.

Over 40,000 years ago, a hyena attacked and killed a woman and dragged her into a cave called Zlatý kůň near her home in the present-day Czech Republic. Her fate would have been forgotten, had archaeologists not discovered her remains in the middle of the 20th century. Bite marks on the bones attest to the drama to this day. The bones had lain largely unnoticed in an archaeological museum in Prague since the 1950s. Then, in 2021, they revealed a secret much bigger than the circumstances surrounding the victim's death: they provided evidence that modern humans must have come to Europe much earlier than previously assumed.

The find also revealed how difficult it was for *Homo sapiens* to permanently conquer a continent that yielded repeatedly to ice and snow. With the help of a discipline called archaeogenetics, researchers are able to analyze the genome of bones dating back thousands of years and recount the history of migration in Ice Age Europe. The resulting picture is of a continent in which Neanderthals and modern humans made repeated incursions, only to vanish time and again when the harsh climate proved too much for them.

Johannes Krause, 43, is one of the world's leading archaeogeneticists. As a doctoral researcher, he helped Svante Pääbo decode the Neanderthal genome, an achievement for which Pääbo received the 2022 Nobel Prize in Medicine. Since then, Krause has become the Director of the Max Planck Institute for Evolutionary Anthropology. The work he contributed to has taught us much, including the certainty that all humans living outside present-day Southern Africa carry within them an average of two percent Neanderthal DNA. With the help of DNA from a tiny finger bone, Krause also managed during his postdoc with Svante Pääbo to discover the Denisovans, a hitherto unknown species of archaic human.

Cold and warm by turns

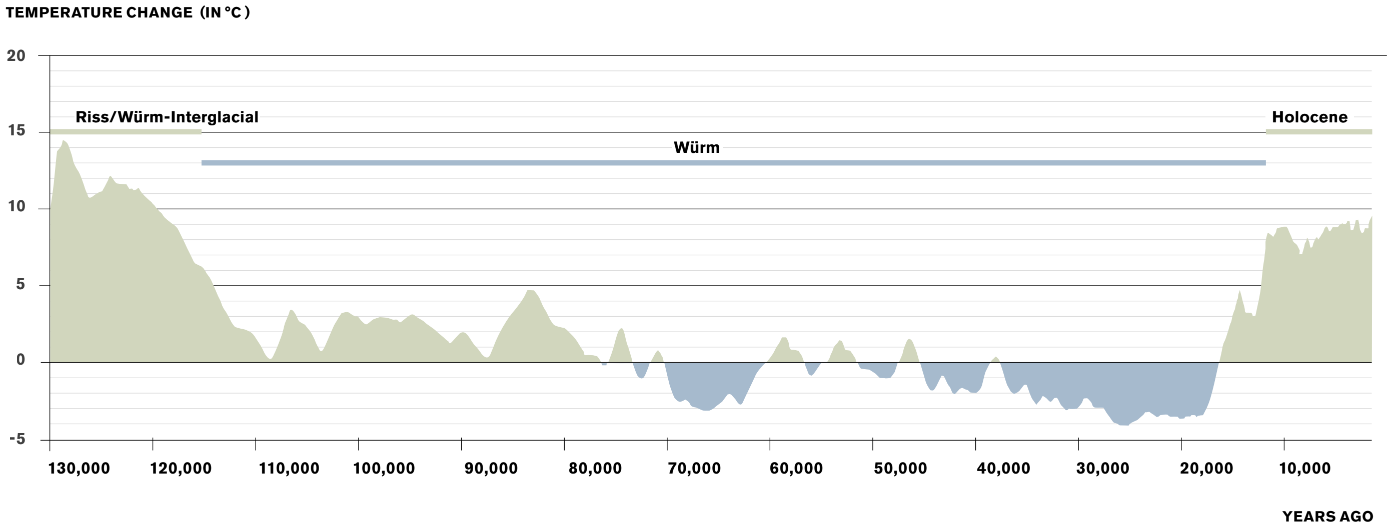
The results of archaeogenetic research show that it took modern humans multiple attempts to gain a permanent foothold in Europe. *Homo sapiens* migrated from the south to the north whenever the climate permitted.

"Anyone unable to cope with the new living conditions vanished."

JOHANNES KRAUSE

PHOTO: SVEN DÖRING

Johannes Krause's research has made enormous contributions to our knowledge of early human history. Genes and the family relationships derived from them show scientists the migratory movements of Neanderthals and modern humans in the Ice Age.



GRAPHIC: GCO BASED ON SCHINTGEN, T.V., MOECK, I.S. GEOTHERM ENERGY 9, 25 (2021)

Temperature changes in Antarctica, as reconstructed based on ice cores: Following the interglacial period from 130,000 to 115,000 years ago, termed the Riss-Würm Interglacial Stage in the Alpine region, temperatures dropped by more than ten degrees in Antarctica within 10,000 years. At the height of the glacial period 24,000 years ago, known as the Würm Ice Age in the Alpine region, temperatures fell by up to 4 degrees. A new interglacial period called the Holocene began 11,500 years ago and persists to this day.

And each migration was a new start. That's because the Pleistocene that began 2.5 million years ago and lasted until around 11,500 years ago was never consistently cold. Instead, the weather alternated between glacial (ice ages) and interglacial periods. These fluctuations arose due to changes in the Earth's orbit around the Sun, which changed the Earth's distance from the Sun and hence the global temperature. Average global temperatures at the height of several interglacial periods even exceeded present-day averages. "The reality is that today we're only living in the interglacial period between ice ages," says Krause. Each climate shift also caused changes to flora and fauna. This often involved a radical disruption of natural resources, sometimes wiping out whole populations. To further complicate matters, *Homo sapiens* in Europe, western Central Asia, and the Middle East shared their habitat with another type of human: the Neanderthal. Before modern humans arrived in this region, Neanderthals had survived for around 400,000 years under a broad range of climate conditions, managing to make their way both in the cold steppes and in the forests of the interglacial periods.

The woman from Zlatý kůň cave is one of the earliest known modern humans *(Homo sapiens)* in Europe. Genetic analysis of her bones reveal that her ancestors must have arrived on the continent more than 45,000 years ago – at least 2000 years earlier than previous research had assumed. Clearly those humans were unable to gain a permanent foothold, as they left no traces in the genome of later human populations. Her descendants must have died off at some point, bringing an end to the lineage from Zlatý kůň.

The redating of presumably the first wave of modern human migrants thanks to the find leads Krause to question an interpretation that remains common today, namely that *Homo sapiens* is responsible for the extinction of the Neanderthal around 39,000 years ago. "Both populations clearly lived alongside each other for thousands of years," says Krause. What is more, the two types of humans interbred, as evidenced by the presence of Neanderthal DNA in our genome today. Krause speculates that the disappearance of the Neanderthals and the first modern humans in Europe may be attributed in large part to a natural disaster: the eruption of a supervolcano. An eruption of the Phlegraean Fields near Vesuvius during that period hurled massive quantities of ash into the atmosphere and blotted out the Sun. Temperatures in large swaths of Europe and as far afield as present-day Russia dropped several degrees as a result. A shortage of light and a thick layer of ash might have stunted the growth of vegetation in large parts of Europe, depriving many animals of their food supply, including the Neanderthals and the descendants of the woman from Zlatý kůň cave. Furthermore, ashfall would probably have poisoned the drinking water in many areas.

"In my view, this volcanic eruption is the most convincing explanation for why not only Neanderthals, but also early modern humans disappeared during this period," explains Krause. *Homo sapiens* had a chance to resettle, however. Just a few years ago, Krause and his team examined human remains that had been found in Kostenki in western Russia. The analysis indicated that this individual had once been buried in the ashes of the Italian supervolcano, and hence must have lived in the region after the eruption. The genetic traces obtained from the bones can be found in later Ice Age humans and even modern Europeans today.

The preconditions for resettling Europe were far from comfortable, as a new intense glacial period began more than 30,000 years ago. Survival became increasingly difficult for humans and animals. Genetic analysis shows that the population shrank massively in that period. This presented an opportunity for migrants who probably came from Eastern Europe. Specialists have named these and subsequent populations based on where they were found. Migrants from the east, for example, are called the Věstonice people after an archaeological site in the Czech Republic. In Central Europe they came across the Fournol, a group that at the time had resided primarily in Western Europe, as far south as the Iberian Peninsula. The Věstonice people had already developed techniques enabling them to hunt mammoths and other large mammals that had adapted to life on the cold steppes covering Central Europe more than 30,000 years ago, driving away animals native to Western and Central Europe. For example, the cave hyena, so deadly to humans, went extinct during this period. "What happened then is typical of the Ice Age as a whole," explains Krause. "Climate fluctuations changed flora and fauna, and anyone unable to cope with the new living conditions vanished. That presented opportunities for better-adapted populations." The glacial period reached its apex 24,000 years ago. Only a few plants and animals were still able to survive in Central Europe. Steadily advancing glaciers in Northern Europe and the Alps drove the Fournol people to the extreme southwest. During the coldest period, they found a homeland on the Iberian Peninsula with humans who already lived there, a region isolated from the rest of the continent by the glaciated Pyrenees. The Iberian refuge offered protection for thousands of years, while human life remained impossible elsewhere in Europe. People would not return to Central Europe until 5000 years later, or 19,000 years ago, when the glaciers finally began to thaw.

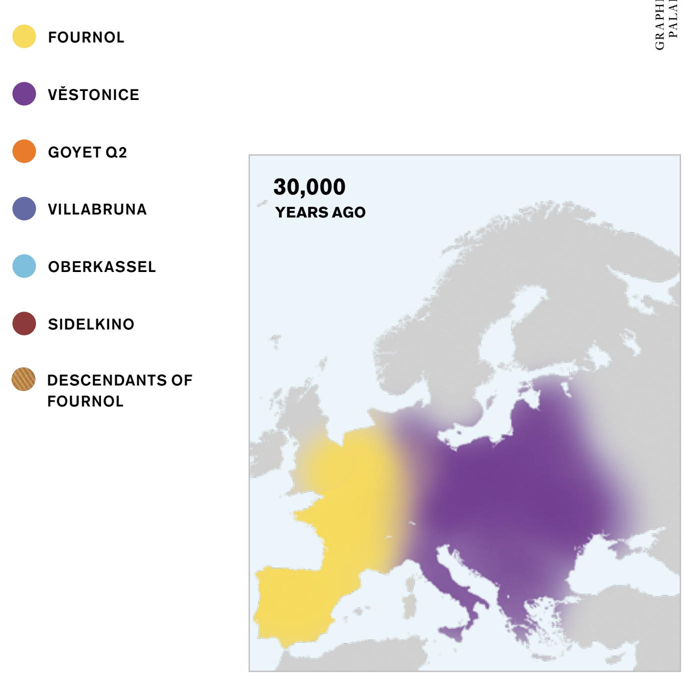
In March 2023, Krause's team published evidence that, contrary to prior assumptions, there were no humans living in Italy at the height of the glacial period. Not until temperatures began to rise did modern humans migrate from the Balkan region along the Adriatic to present-day Italy. The forests thriving there offered the newcomers good living conditions. Today they are called Villabruna people.

Around 14,500 years ago, an interglacial period lasting around 2000 years began. Temperatures rose quickly and the Villabruna people began to spread from Italy to large parts of Europe. They drove out the descendants of the Fournol people, who had survived south of the Pyrenees during the height of the last glacial period and had resettled Central Europe from there. The

SUMMARY

The first known migrants of the species *Homo sapiens* came to Europe 45,000 years ago. However, a volcanic eruption on the Italian Peninsula 39,000 years ago brought an end to this – until recently unknown – first settlement. The Neanderthals went extinct during this period as well.

Humans weathered the height of the last glacial period 24,000 years ago on the Iberian Peninsula and in the Balkans. Central Europe and the Italian Peninsula, by contrast, were unpopulated. With temperatures rising again, humans returned 19,000 years ago, setting out from the Iberian Peninsula. At around the same time, humans migrated from the Balkan region to present-day Italy. Descendants of those migrants spread out across Central Europe around 14,500 years ago and remain part of our genetic heritage to this day.



GRAPHIC: GCO BASED ON POSTH, C., YU, H., GHALICHI, A. ET AL. PALAEOGENOMICS OF UPPER PALAEOLITHIC TO NEOLITHIC EUROPEAN HUNTER-GATHERERS. NATURE 615, 117–126 (2023)

Fournol only managed to survive on the Iberian Peninsula. "We can still see traces of this upheaval today in the genome of people from that period." Our analysis shows that the genes of humans coming from Italy dominated the genetic makeup of people in modern-day Germany, France, and Great Britain after only 500 years. The genes of what researchers refer to as Oberkassel people still comprise part of Europeans' genetic heritage today.

"The climate shift 14,500 years ago probably played a decisive role in this wave of migration," says Krause. As temperatures rose, forests pushed north, gradually replacing the steppe vegetation of the Ice Age. Smaller and faster forest animals required new hunting and gathering techniques, as well as knowledge regarding edible mushrooms and plants of the forest – skills mastered by the newcomers of Villabruna from their time on the already forested Italian Peninsula and Balkans.

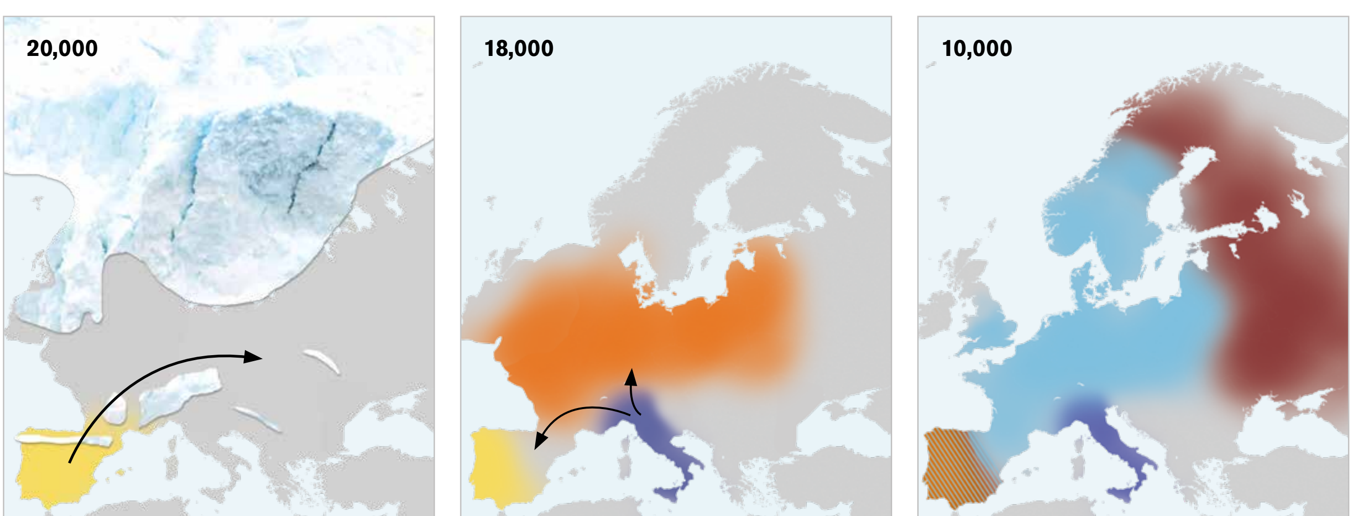
Farmers from Anatolia

Next came farmers from Southern Anatolia, who migrated to most parts of Europe starting around 8000 years ago and interbred over time with the Indigenous Oberkassel people that still practiced hunting and gathering. Ötzi, for example, was a direct descendant of these migrants from Anatolia. This conclusion was reached in a study published by Krause and his team in 2023. The "Iceman," who died in the high mountains over 5000 years ago, apparently belonged to a group living in extreme isolation in the Alps, an exception to Europe's settlement history. But the study didn't stop with those migrants. Krause's team discovered another component in the gene pool of modern Europeans: around 5000 years ago, members of a nomadic tribe arrived from the region north of the Black Sea. They must have quickly become the dominant group, as "steppe genes" still account for around 30 percent of the genetic makeup of many Europeans today. Did another drop in temperature occur? Or were the newcomers not peaceful migrants, but conquerors? There is no evidence for either claim. Instead, it may be that large swaths of Central Europe were devoid of people at the time. DNA traces of plague bacteria in bones from the period indicate that one of the first plague epidemics in history eradicated large parts of the population, clearing the way for the next wave of migration.

Even if climate had nothing to do with what seems to be the last large scale migration to Europe, it has exerted an enduring influence on the settlement of the continent for thousands of years. *Homo sapiens* was climate's victim and beneficiary, by turns. Today, humans once again face decisive changes. Temperatures are rising faster than at any point in the past 10,000 years, which have seen the flowering of human culture. The cause is not variations in the Earth's orbit, but large-scale emission of greenhouse gases. Instead of an ice age, humanity is now facing a heat age. Survival will become difficult if not impossible in many regions. And so climate will once again shape the migration history of humankind.

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

Prehistoric DNA enables researchers to reconstruct the genealogy of modern humans in Europe. The populations named after archaeological sites were genetically separated from each other time and again. However, migratory movements repeatedly ensured that genes were exchanged (black arrow). Glacier coverage is depicted only at the time of maximum glaciation. The coast of Europe looked different during the last glacial period than it does today because the sea level of the Mediterranean was lower.



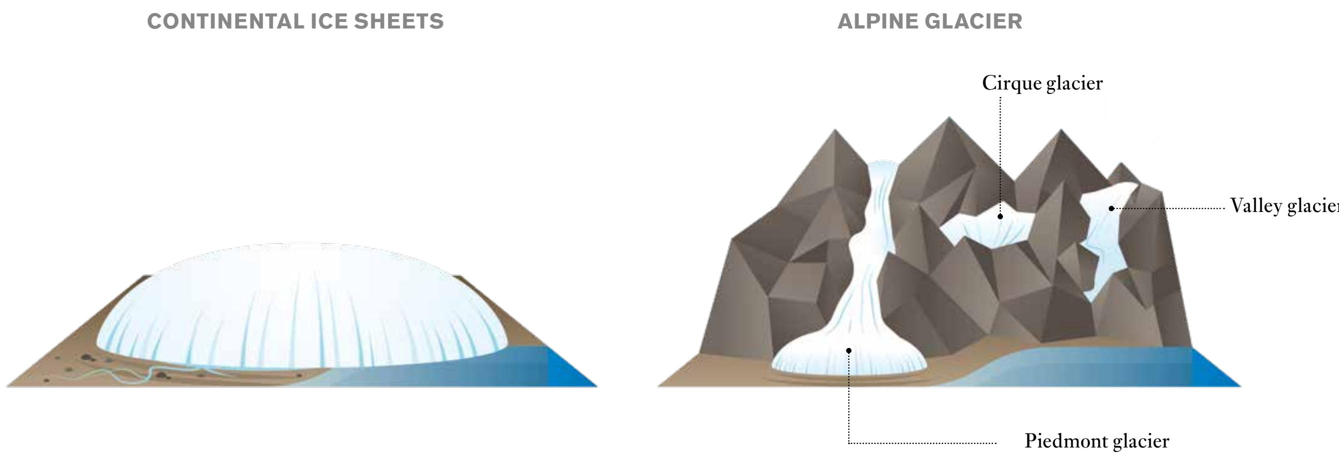
Fading splendor: The ice sheets of Greenland and Antarctica are shrinking. For example, ice is breaking from the glaciers of the Mogens Heinesen Fjord in southwestern Greenland and ending up in the ocean.

PHOTO: BENOIT LECAVALIER

THE BIG MELT

TEXT: KLAUS JACOB

Climate change is melting the ice sheets of Greenland and Antarctica and causing sea levels to rise. This could be a disaster for island states and coastal cities. How much the ice sheets shrink also depends on feedback effects between the ice sheets and the climate system. Marie-Luise Kapsch and Clemens Schannwell are studying these effects at the Max Planck Institute for Meteorology.



Types of glaciers: The ice sheets of Greenland and Antarctica together contain around 33 million cubic kilometers of ice. That is eight times more than the amount of water contained in the Mediterranean Sea and around 99 percent of the ice masses on land. In the mountains there are piedmont glaciers, which flow from a valley into the lowlands, where they spread out in a ring shape. Valley glaciers move downward through a valley. Although they account for less than one percent of the global ice mass, they include the best-known Alpine glaciers, such as the Aletsch Glacier. Cirque glaciers are found in shaded, kettle-shaped depressions and can therefore occur at lower altitudes than other glaciers.

GRAPHIC: ADOBESTOCK

So much for "eternal ice." The poles are melting and temperatures in the Arctic are rising between two and three times faster than the global average. Warmer temperatures are breaking up sea ice, allowing more and more ships to traverse the Northwest Passage, the sea lane connecting the Atlantic and Pacific through the Arctic Ocean. They're also causing the ice sheet covering Greenland to suffer considerable losses – with global consequences. When glaciers melt, the sea level rises. The severity of the situation became clear on August 14, 2021: on that day, the highest-altitude weather station in Greenland reported rain. This had never happened before, for as long as scientists have been recording weather data at that station – 3216 meters above sea level. The ice melted over the entire island. At the peak of the heatwave in 2021, the ice sheet lost about 12 billion tonnes of mass, or roughly 12.5 cubic kilometers, in a single day.

On the other side of the globe, where over half the freshwater on Earth is stored in ice, the situation looks just as precarious. Some 168 billion tonnes melted in the hot summer of 2019 alone, as indicated by the Ice Sheet Mass Balance Intercomparison Exercise (IMBIE). According to those calculations, the Antarctic and Greenland ice sheets lost a total of 7560 billion tonnes of ice between 1992 and 2020, the equivalent of a cube with sides measuring 20 kilometers. This melt caused the sea level to rise by 21 millimeters, whereby Greenland contributed to the majority of the melt, by around 13.5 millimeters. Within this period, water expansion due to warming contributed even more to rising sea levels than glacial melting – it amounted to around 35 millimeters. The ratio between the contribution of ice melt and thermal expansion to sea level rise could reverse, however.

The aforementioned changes affect around 300 million people worldwide living in regions that lie less than one meter above sea level. Cities with over a million inhabitants, such as New York, Jakarta, or Amsterdam are in danger. Adding even further to the danger, climate change is making storms more violent and driving waves deeper inland, so that every centimeter of sea level rise may effectively be doubled. It is therefore crucial to develop reliable forecasts of how the sea levels will change in the coming decades and centuries and how large ice sheets respond to climatic changes. To this day, however, many questions remain. First and foremost, the rate at which the ice sheets melt can only be predicted to a low degree of certainty, in part due to a lack of long-term data from the Earth's cold zones. In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) predicts that by 2100, the sea

SUMMARY

The ice sheets of Greenland and Antarctica are shrinking due to progressive climate change. As a result, the sea level will likely rise as much as one meter by 2100, according to the *Sixth Assessment Report* of the IPCC. Conventional climate models do not yet account for slow changes in the ice sheets. Researchers at the Max Planck Institute for Meteorology have developed a model that can calculate the long-term dynamics of ice sheets and their interactions with the climate system. The interplay of climate and ice sheets can lead to instabilities beyond which an ice sheet melts away irreversibly. These tipping points are still being investigated, but one such threshold may have already been exceeded in West Antarctica.

level will probably rise between half a meter and a meter compared to 1900, depending on how greenhouse gas emissions develop. However, the predictions do not factor in feedback effects between ice sheets and the climate system, and so the true scope of the situation is not yet fully understood.

A team at the Max Planck Institute for Meteorology, including researcher Marie-Luise Kapsch, has expanded a climate model to factor in changes in the ice sheets in both the past and future – which they use to describe and understand the changes in the climate and ice sheets during the last glacial cycle.

A team led by Jason E. Box of the Geological Survey of Denmark and Greenland has projected how much ice will disappear in Greenland alone by the turn of the century and how much the sea level will rise as a result if the melting continues at the rate it has in the past two decades. The researchers calculated it at around 27 centimeters, nine centimeters more than the upper limit designated by the IPCC. If the projection is based on the summer of 2012, which set a record for melting, the result is as high as 78 centimeters – from Greenland alone. The forecasts do not yet account for progressive warming, which may soon make the record-setting summer of 2012 look like just another year.

PHOTO: TOM PINGEL FOR MPG

To understand how ice sheets and climate interact, it is helpful to examine the last glacial period, commonly referred to as the last Ice Age. It started around 115,000 years ago and ended around 11,500 years ago. During the peak of the last Ice Age, a phenomenon occurred that caused significant fluctuations in sea level: ice sheets became unstable and led to abrupt changes in the climate. Hartmut Heinrich, a marine geologist and climatologist from Germany, found the first evidence of such events early in his career. While studying sediments from the floor of the Atlantic in 1988, he stumbled across deposits that clearly came from North America. He could find only one rational explanation: icebergs had drifted across the Atlantic and melted, shedding the rock material trapped inside them. A peculiar aspect of these findings was that that the sediments did not trickle down continuously throughout the last glacial period, but had been deposited in spurts. Evidently, large quantities of ice from the Laurentide ice sheet, which covered much of North America during the last glacial period, had repeatedly slid into the Atlantic over a short period of time. Such periods are now termed Heinrich events. These events also affected the climate in neighboring regions: the freshwater that was added to the oceans through the melting of icebergs modified ocean currents and thereby the transfer of heat around the globe. These events show that, even before humans interfered with the climate, thresholds existed beyond which massive changes to the climate would occur. The ice sheets could become unstable in the future as well. Instabilities like these have become known to the public as tipping points. It remains unclear whether such tipping points might be reached in the near future, and if so, what part of the Earth system might be involved, e.g., the Amazon rainforest, the Siberian permafrost, or the ice sheets. The possible effects of exceeding them is still a subject of research among climatologists (see the interview on p. 74).

Compromise in the climate model

When seeking to determine the future climate, scientists rely on computer models, which are depicting more and more aspects of reality. It stands to reason that changes in the ice sheets would factor into the equations used within the models. But this is where computers reach their limits. The problem is that although the climate changes relatively quickly, ice sheets move slowly and often require several millennia to respond to external changes. Running complex climate models over such long periods even exceeds the capabilities of today's supercomputers. Furthermore, changes in the ice sheets and the consequences that result in response to changes in ice sheets are hard to incorporate into conventional climate models. For that reason, researchers have thus far been forced to represent the shape of the ice sheets as constant within models. That seemed like a good approximation, because noticeable changes take anywhere from decades to centuries to occur. However, observations in recent years have shown that even small changes in ice sheets can have substantial effects, particularly on the local climate.

Meteorologist Marie-Luise Kapsch, who studies the role of ice sheets in the climate system at the Max Planck Institute for Meteorology in Hamburg, has therefore developed a model with her colleagues that accounts for changes in the ice sheets. Its resolution is lower than that of standard climate models in terms of both space and time – "A compromise," Kapsch concedes. Nevertheless, the model can be used to compute several millennia. Similar difficulties confront researchers investigating possible tipping points in the Earth system.

Global warming releases ice brakes

No one can predict the future without first examining the past. After all, a model's ability to reflect reality must be tested over a time period for which abrupt climate events are reasonably well known. The Max-Planck model has even managed to simulate/reproduce Heinrich events – that is, the collapse of ice sheets. However, the initial situation during the last Ice Age was different than today. An ice sheet several kilometers thick covered North America and North Eurasia, and the sea level was more than 100 meters lower than today. A collapse consistently occurred when the burden of the ice became too large – when the ice buckled under its own weight, so to speak. The thick ice caused the underside of the glacier to melt, which acted as a lubricant, setting gigantic ice flows in motion. The large quantities of freshwater that reached the Atlantic as a result cooled the North Atlantic and adjacent regions. The Atlantic circulation came to a halt, precipitation fields changed, and the jet stream took a different path.

Ice losses similar to Heinrich events are possible today, says Kapsch, but on a much smaller scale. Other factors currently play the leading role when it comes to ice sheets. It seems as though climate change is loosening the brakes that so far have inhibited the glaciers of Antarctica from flowing into the sea. For example, ice shelves, which are the floating extension of ice sheets and form when land ice reaches the ocean, are thinning in many places. While this does not cause the sea level to rise, it does reduce the force that is holding the ice sheet back. As a result, glaciers flow faster into the ocean. The undulating seabed can provide additional stability to the ice sheet and act as a brake if it comes into contact with the floating ice shelves. In Antarctica, around 700 such undulations are present along the periphery of the ice sheet. Kapsch's colleague Clemens Schannwell has studied several. One particularly interesting finding: these brakes, too, are becoming less efficient. The glaciers are becoming thinner and lighter as they melt. As a result, they lose contact with the seabed sooner and float over the undulations.

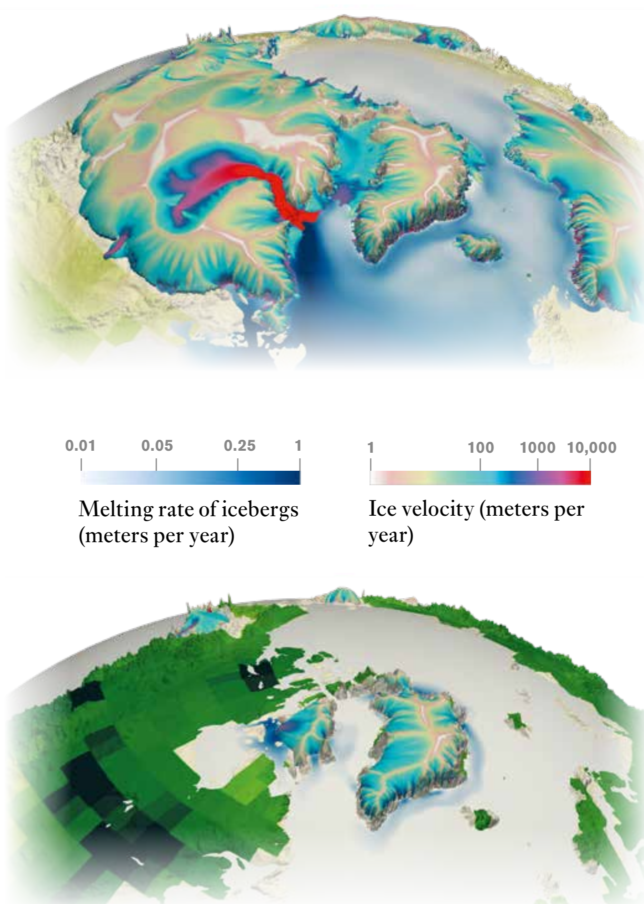
At the same time, the sea level is rising, which amplifies the effect of losing contact with the seabed further inland. And to top it all off, because the heavy ice compresses the Earth's crust, the seabed slopes inland in many areas. As a result, the ocean now gnaws away at the glaciers from underneath. Lately this has caused more and more meltwater and ice to reach the ocean, which raises the sea level, causing even more ice to be lost. "The process is susceptible to a positive feedback loop," says Schannwell. Once the melting process exceeds a threshold value, it may no longer be possible to stop it. "In West Antarctica, we may have already passed the critical point," explains Schannwell. However, the simulation also showed that it will take hundreds or thousands of years before West Antarctica is free of ice. And it has shown that the change occurs in spurts rather than as a continuous process.

"In West Antarctica, we may have already passed the critical point."

CLEMENS SCHANNWELL

Another organization studying changes in the ice sheets is the Potsdam Institute for Climate Impact Research (PIK). It, too, uses an ice model. Researchers at PIK have examined the last interglacial periods, periods that had climate similar to that of today. According to researcher Torsten Albrecht, if the average global temperature rises another 0.5 degrees, the ice masses in West Antarctica may collapse. Albrecht is part of a working group led by Ricarda Winkelmann, who was recently appointed as founding Director at the Max Planck Institute of Geoanthropology in Jena. However, findings like these are beset with serious uncertainties. Small changes to the initial conditions lead to significant differences in the long term. Furthermore, the speed of the changes clearly played a role in the past. There is therefore hope, in Albrecht's opinion, that West Antarctica will remain stable despite exceeding a temperature threshold linked with an expected tipping point – provided humans take countermeasures quickly enough.

Greenland's ice sheet is even more important to Europe than Antarctica's. It, too, could become unstable and vanish. It is hard to determine if and when this tipping point could be reached.



Cold and warm periods compared: At the height of the last glacial period around 21,000 years ago, ice sheets covered large parts of North America and northern Europe (top graphic). Heinrich events, during which large amounts of ice flowed from the North American ice sheet into the sea, can be identified from the high flow velocity of the ice (red). This meant a lot of melt water also flowed into the sea (dark blue). The bottom graphic shows the ice sheets in around 1850, so before human-induced climate change.

GRAPHIC: CLEMENS SCHANNWELL / MPI FOR METEOROLOGY

It would be risky to let it come to that, however. After all, the North Atlantic contains a motor that drives the North Atlantic Current, which is fed by the Gulf Stream. The current is our central heating system, carrying heat from lower to higher latitudes, from south to north, from the Equator to the Pole. Large quantities of freshwater, which flow from the Greenland ice sheet to the North Atlantic, reduce its salinity and density. However, the relatively high density of the North Atlantic seawater is a prerequisite for keeping the North Atlantic Current flowing. If it were to weaken or stop altogether, the climate would change fundamentally, especially in Europe. The average temperature here could fall several degrees in the long term if heat were no longer supplied from the West Atlantic. Measurements by a team from the PIK and other research institutes indicate that the overturning circulation in the Atlantic has already slowed. However, it appears very unlikely that the North Atlantic Current will stop, even as climate change advances.

By contrast, at high latitudes today one can already observe several striking feedback effects that are amplifying climate change and ice loss. One of these feedback mechanisms is the connection between loss of sea ice and temperature increase. Without ice, the Sun's energy is no longer reflected back into space. Instead, it warms the water. The result: temperatures in the far north are rising between two and three times faster than the global average. Another mechanism depends on the height of the ice sheets. The highlands are colder than the valley, as every mountain climber knows. When ice melts, however, its surface gets lower and lower, where higher temperatures are present. This intensifies the melting process itself.

Anyone who studies ice sheets has to contend with all these complex connections and dependencies within the climate system. Sea ice and temperature, ice loss and rising sea levels – the gears are interlocked. Feedback effects and tipping points pose major threats to the stability of our climate. Researchers from the Potsdam Institute for Climate Impact Research and other institutes have studied how the individual tipping points interact – with worrying results. They warn of a domino effect, in which one irreversible change triggers the next. A cascade of tipping points like that could start with the ice sheets on Greenland and West Antarctica. The currents in the Atlantic would be the next to change, which in turn would affect the Amazon rainforest, and finally the climate of the entire world. A study by a team led by Ricarda Winkelmann shows that the risk of this happening increases dramatically even when the temperature rises between 1.5 and 2 degrees Celsius, the upper limit designated by the Paris Climate Accords. And the more global warming advances, the more likely such a scenario becomes. Humanity should do everything it can to prevent it.

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

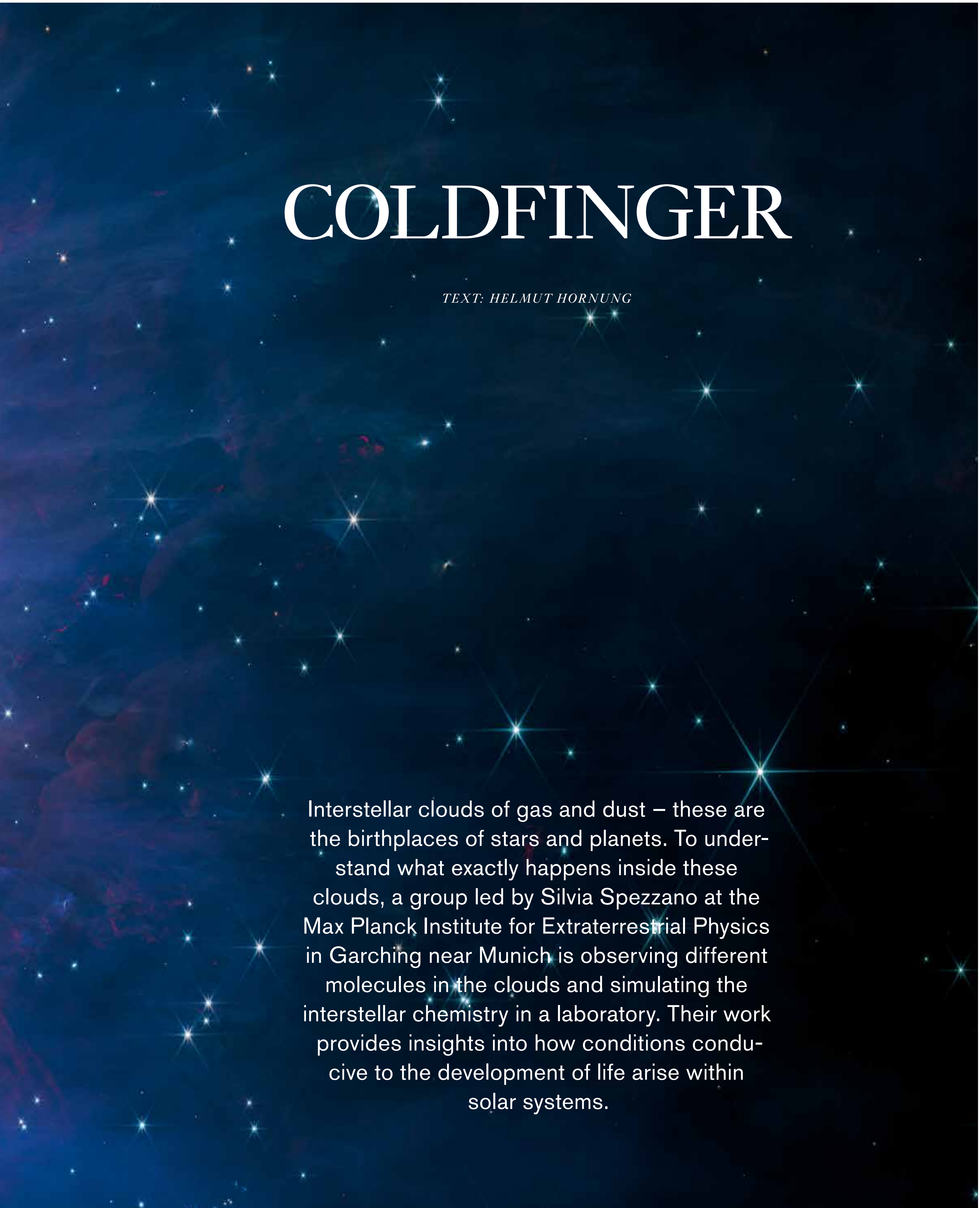
GLOSSARY

HEINRICH EVENT
is the term for the episodic and rapid loss of large masses of ice from the North American ice sheet during the last glacial period/Ice Age.

TIPPING POINT
is a threshold value such as temperature that, when exceeded, leads to irreversible changes in the climate system.

Creation and destruction: This photograph from the James Webb Space Telescope shows the infrared light that can be seen behind the curtain of the Orion Nebula, revealing the gas and dust structures where stars are born. Remnants of a star that exploded 500 to 1000 years ago can be seen in the left part of the image.

PHOTO: NASA, ESA, CSA/SCIENCE LEADS AND IMAGE PROCESSING: M. MCCAUGHREAN, S. PEARSON, CC BY-SA 3.0



COLDFINGER

TEXT: HELMUT HORNUNG

Interstellar clouds of gas and dust – these are the birthplaces of stars and planets. To understand what exactly happens inside these clouds, a group led by Silvia Spezzano at the Max Planck Institute for Extraterrestrial Physics in Garching near Munich is observing different molecules in the clouds and simulating the interstellar chemistry in a laboratory. Their work provides insights into how conditions conducive to the development of life arise within solar systems.

The path to the birthplace of stars leads through the Munich subway via the 6 train to Garching Research Center Station. From there it's only a few minutes' walk to the Max Planck Institute for Extraterrestrial Physics. An elevator ride will take you to the basement, where the astrochemical laboratory is housed. "Here we reproduce the conditions that prevail in interstellar clouds," explains Silvia Spezzano. The chemist studied in Bologna and, after a year at Harvard, earned her PhD at the University of Cologne. Since 2015 she has conducted research at the Center for Astrochemical Studies (Cas) at the Max Planck Institute under the directorship of Paola Caselli.

Many of the objects studied at the Cas can be spotted in the sky with the naked eye. Take the Orion constellation, for example, which stands high in the southern firmament with its characteristic belt of three stars. On a clear winter night, a diffuse little cloud shimmers in the "scabbard" that hangs diagonally below the belt. Located approximately 1350 light years from Earth, this structure contains massive clouds of hydrogen gas, which are gathering under their own gravity and forming new stars. But to find out what's happening here on a small scale, to learn how stars really form, you have to look very closely, like Spezzano. In photos from the giant telescope, the Orion Nebula shines magnificently in saturated red. This is thanks to young, hot stars, whose radiation energy enables them to strip electrons, at least temporarily, from the hydrogen atoms that dominate star-forming regions. When the electrons bond once again with atomic nuclei, a characteristic red light is emitted.

This nebula, which is visible to the naked eye, is embedded in a much larger complex, designated OMC-1. Spezzano and her team are studying that molecular cloud, which only appears at longer wavelengths, in the infrared or radio spectrum. Like all dark nebulae, it is extremely cold, with a temperature just a few degrees above absolute zero (minus 273.15 degrees Celsius). It contains around one percent dust, a whole lot of hydrogen, and plenty of other molecules. The latter tell researchers a great deal about the processes occurring in the clouds, but the molecules are also an important prerequisite for the development of life in a solar system. Conditions on Earth are wholly different from those that prevail in the universe. And that goes for dark nebulae, too. "Astrochemical researchers have to conceive of a whole new form of chemistry," says Spezzano.

SUMMARY

The building materials of stars and planets lie in large and very cold interstellar dark clouds, which consist primarily of gas and a pinch of dust. These dark nebulae contain many molecules, the analysis of which offers insights into how the clouds develop. With the aid of spectroscopy and laboratory experiments, researchers investigate the chemical processes in dark nebulae and the development of stars and planets.

Dark nebulae exist everywhere in the Milky Way. They gather a relatively large quantity of material in a small space and absorb the light of the stars behind them, like a thick curtain. To 19th-century scientists, they appeared to be "holes in the sky". The photographs taken by Max Wolf around the turn of the last century show many of these dark nebulae. Wolf, an astronomer and pioneering astrophotographer from Heidelberg, was responsible for the development of, among other things, a statistical tool for determining the distances of these nebulae from Earth and their respective dimensions.

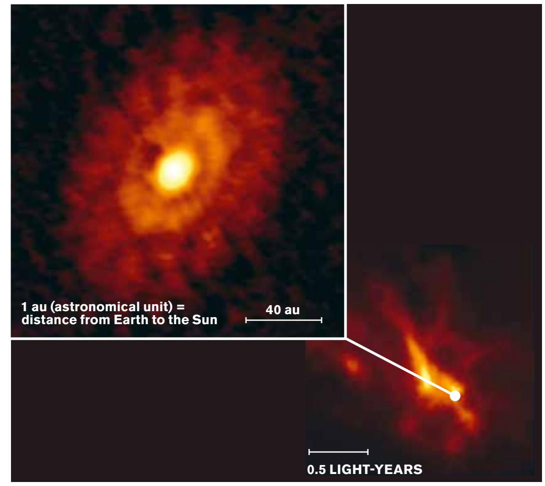
In the 1960s, researchers began using radio telescopes to probe deep into such clouds in search of specific molecules; the most common, after hydrogen, is carbon monoxide. For the first time, one could therefore observe how dark nebulae are structured and the processes that take place inside them before a new star is formed. Today, the clouds are known to contain approximately 300 other types of molecules. Among the most complex are fullerene and dimethyl ether. Spezzano is especially fascinated by the fact that a large number of organic molecules have been discovered in the universe, including amino acids and fatty acids. "All of them are ingredients of life. And they are already present in the clouds where stars and planets are formed."

She relies on spectroscopy to detect the molecules. It enables her to identify individual substances by means of a kind of fingerprint in the electromagnetic radiation of molecular clouds. Spezzano is interested in radio waves with very short wavelengths – in the millimeter range. She studies them with telescopes, such as the 30m Antenna on the Pico del Veleta in Spain's Sierra Nevada mountains and the Northern Extended Millimeter Array (Noema) observatory on the Plateau de Bure in the French Alps. In the radio spectrum, individual molecules reveal themselves by certain energies they radiate due to their rotation. This allows Spezzano to determine, among other things, how bright an astronomical molecular cloud shines at which wavelengths. Many of the thin lines found in the spectrum are characteristic of known molecules, which can be identified using an online catalog.

The lines, or fingerprints, allow researchers to determine the number of molecules of a specific kind in the cloud, the temperature of the gas, its density, and how it moves. The width of the spectral lines tells Spezzano that different parts of the cloud are swirling at speeds of several kilometers per second. The dynamics of the molecules yield information on whether the cloud is collapsing under its own gravity or drifting apart. This ultimately decides whether or not a star will form in the cloud of gas and dust.

Cold fingers

To understand this, a detailed visualization is required of the processes that occur when a star is born. Whereas simple models are based on spherical birth clouds, the matter actually seems to gather in small filaments, which permeate the gas like thin fingers. The Herschel Space Observatory observed filaments like these a few years ago. The structures are clearly the real delivery rooms of stars. How they form has yet to be explained. At an early stage, with no stellar core at the center, the cloud remains rather spread out. When a critical mass is exceeded at one position and gravity wins the upper hand against the outward-oriented thermal pressure of the particles, the cloud begins to collapse under its own gravity, the particles hurtling towards each other.



GRAPHIC: MPE/D. SEGURA-COX; HERSCHEL DATA FROM ESA/HERSCHEL/SPIRE/PACS/D. ARZOUMANIAN

Star cradle: A gas cloud in the constellation Ophiuchus contains thin, finger-like filaments of cold molecular gas (lower right), in which fresh material flows to the densest regions (bright yellow). Star embryos mature in some of these nodes. The section appears to be about a quarter of the size of the full Moon in the sky and was photographed by the Herschel Space Telescope using infrared photography. In the center of a filament, the Alma telescope network captured a baby star, IRS 63 (upper left). Planets may be forming in its disk of gas and dust.

"The ingredients of life are already in the clouds."

SILVIA SPEZZANO

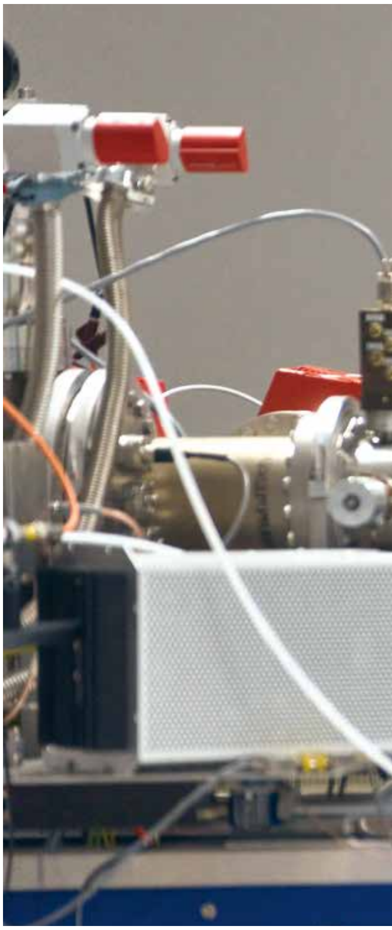
What happens next in the star birth process? It takes a mere million years or so for a mature star to emerge from a molecular cloud. These are relatively fast processes, when compared with the lifetime of a star like our Sun, which lasts around 10 billion years. It all begins with diffuse clouds of interstellar material. Gravity and extremely low temperatures cause the clouds to come together and ultimately disintegrate into even denser fragments containing around 100,000 molecules per cubic centimeter. By comparison, the Earth's atmosphere contains 10 trillion molecules per cubic centimeter – a lot denser and hence much warmer than interstellar gas. The resulting pre-stellar cores are 0.3 light years in size, with temperatures of minus 263 degrees Celsius. If gravity makes the cores unstable, they collapse again and form protostars, which are initially embedded deep in a thick shell of gas and dust. The dust consists primarily of tiny particles of graphite and silica, which have one ten-thousandth of the diameter of the dust particles found on Earth. Many molecules form in the vicinity of the protostar. In addition, material flows from the cool mother cloud to the center of the core, where the material becomes even denser until a disk forms, which feeds the young protostar in the center. Researchers at the Max Planck Institute for Extraterrestrial Physics and the Institute Radio Astronomie Millimétrique in France observed how this works some time ago. They used the Noema antenna system to study a protostellar binary system in a molecular cloud in Perseus (stars often form in pairs) and observed a radiant bridge of matter connecting the outside of the shell with the inner region. Thanks to this "conveyor belt", the mass, density, and temperature of the star-embryo constantly rises. "The molecule that enabled us to discover this cosmic conveyor belt has the structural formula HCCCN, meaning it has three carbon atoms," says Max Planck Director Paola Caselli.

Astronomers often observe disk-shaped regions surrounding protostars. Theoretical models indicate that these would offer good conditions for the birth of planets. And in fact, research shows that they begin growing while the central sun is still maturing. "We used to think that the stars mature first and then, so to speak, become mothers of planets, which don't come until later. But now we see that protostars and planets develop together from childhood like siblings," says Dominique Segura-Cox, who previously worked at the Max Planck Institute for Extraterrestrial Physics. At the Atacama Large Millimeter Array (Alma) observatory in the Chilean Andes, her group obtained a detailed picture showing a protostellar disk with multiple holes and dust rings around star IRS 63, which is less than 500,000 years old and far from finished; it will continue to gain mass. Once the temperature in its core rises to around 10 million degrees, nuclear fusion will begin. Hydrogen will convert to helium, and a new sun will shine in outer space.

To obtain an overall picture of the growth of stars, the group at Cas in Garching is studying more and more clouds at various stages. Many such objects were observed and classified in the 1980s. "In the universe there are delivery rooms with and without babies, so to speak, that is, dark nebulae with and without stars," says Spezzano. In both cases, researchers are registering the fingerprints of dozens of different molecules in the spectra. But there are differences; some clouds contain molecules that aren't found in others. The amount of a given substance can also vary. The reason: as already stated, the astronomers are observing each cloud at a different stage of development. Spezzano cites methanol as an example. In clouds without stars, the temperatures in the center are low. The chemistry is on ice, so to speak, and gaseous methanol can only be found in low quantities. When a star shines in the cloud, by contrast, the central temperatures are correspondingly higher. The ice melts, the previously bonded methanol is released, and large quantities become visible and measurable.

Interstellar molecules in the lab

"We are trying to combine the pieces of several puzzles into an overall picture," says Spezzano. This results in an interesting finding: "A protostar radiates energy, which affects its environment. We should really expect that this would completely annihilate the molecular inventory within the cloud. But this is not the case at all. Instead, many of the molecules survive the radiation and are embedded in the developing planets. "It was the same around 4.6 billion years ago, when our planetary system was born. That's why roughly half of the water in our glasses is older than the Sun," says Spezzano. The rest of the water originated later, during the star and planet formation process. Occasionally, the spectra indicate molecules that are not recorded in any catalog. "We call these initially unknown fingerprints 'U-lines', 'U' signifying unknown," explains Spezzano. Researchers can then work backwards, generating previously unknown molecules under extreme conditions in the lab, measuring their spectral signature, and matching them with a U-line. For example, in cooperation with colleagues from Italy, researchers from the Cas discovered propargylamine in a cloud near the center of the galaxy. This molecule has a complex chemical formula, HCCCHNH, and is exceptionally unstable. It is extremely difficult to isolate on Earth under normal conditions. By contrast, it remains quite stable at the very low densities and temperatures typical of interstellar media, which the team led by Spezzano use for their laboratory research. This species of chemical plays a fundamental role in the formation of amino acids, which are among the most important building blocks of life. Another match was made by Spezzano's student Judit Ferrer Asensio. She discovered deuterated acetaldehyde (for chemists: CHD-2CHO), first in the lab, then in a molecular cloud. This



Waiting for the measurement: Silvia Spezzano converses with a colleague during an experiment. On the left side of the photograph can be seen part of a vacuum chamber, where she studies how ions and molecules integrate with each other in regions where stars are born. The tests are run under space-like conditions at a maximum of minus 268 degrees Celsius.

PHOTO: FABIAN VOGL FOR MPG

"Half of the water in our glasses is older than the Sun."

SILVIA SPEZZANO

shows how important lab work is; alongside observation and theory, it is the third pillar of research at the Cas. A glass tube measuring 3 meters in length is the beating heart of the Cas Absorption Cell (Casac), one of several spectrometers in the basement of the Institute. The system studies the spectral fingerprints of molecules in the gas phase. They can also be created in plasma inside the glass cell. The spectroscopic equipment records wavelengths between 0.3 and 4 millimeters. In another room stands an instrument called Cas-Ice. An ice machine called Coldfinger lowers the temperature of molecules to a maximum of minus 268 degrees Celsius. Researchers use Cas-Ice to study different mixtures of frozen substances in the infrared portion of the spectrum. Among other things, the instrument allows for a direct comparison with observations of cosmic ice made using the James Webb Telescope.

In 2023, the space telescope registered sulfur dioxide in the atmosphere of a planet for the first time. The spectral lines of the molecule get wider as the pressure increases. This could, for example, be attributable to the presence of other molecules, such as hydrogen, water, nitrogen, or oxygen. In the lab, Spezzano's team injects this molecule into an artificial atmosphere and compares the varying line widths of sulfur dioxide with the measurements from the James Webb Telescope. "In the future, this method will allow us to recreate the complex atmospheres of smaller Earth-like planets," says Spezzano. At the heart of such experiments lies a fundamental question, one that not only interests Spezzano, but that lately has guided the entire field of astrochemistry: how does life come into the world? ***www.mpg.de/podcasts/kaelte (in German)***

Silke Britzen moves between two spheres. As a scientist at the Max Planck Institute for Radio Astronomy, she analyzes the epitome of darkness. That is to say, she studies black holes with telescopes that nearly span the globe. As an artist, she paints pictures bursting with color. Her approach to both research and painting is unorthodox.

TEXT: FINN BROCKERHOFF

When Silke Britzen looks up at the starry night sky, she doesn't think about her work – and that's despite having spent nearly 30 years as an astronomer exploring the riddles of space. "I can still just enjoy the sight and marvel at its aesthetic beauty. The black holes and astrophysical jets I study daily are far, far away then," says Britzen, a scientist at the Max Planck Institute for Radio Astronomy in Bonn.

What fascinates her about the universe is its vast, invisible secrets – things that literally lie in darkness. Britzen's desire to understand the universe began in her early childhood. "My mother loves to talk about how I would pepper her with questions about the starry sky before I could even speak correctly."

One of the first sources of information that helped quell her growing thirst for knowledge was Cosmos, an American documentary series presented by astronomer Carl Sagan that was broadcast on German television in 1983. "I was immediately engrossed. When I saw it, I went to my physics teacher and asked if we could cover astronomy in class. She agreed, but only on the condition that I prepare the classes myself." And so Britzen prepared a two-hour teaching unit about the solar system and presented it to the class. "I think for me it was the first small step towards becoming an astronomer." At the time, she wished she could have spent hours questioning an astronomer about the universe. "Before long, I had already read the few astronomy books available at the local bookstore, and unfortunately at the time there weren't any lectures that made astronomy comprehensible to amateurs.

That's partly why, for several years now, Britzen has offered a lecture entitled "Black Holes and the Questions of Modern Astrophysics" as an associate professor at the University of Heidelberg. The many fascinating aspects of black holes and their important role in our universe are a central focus of this lecture. Aside from the basics, she talks about current astronomical research projects and also about her everyday life as a scientist. Her goal is to make the work of astronomers more tangible and accessible, both for an interested lay audience and for young people toying with the idea of studying the subject or even planning a future career in research. "As a child I would have been really excited by an event like that."

→

VISIT TO

SILKE BRITZEN

PHOTO: CHRISTOPH SEELBACH FOR MPG

Focused: Whether painting or researching, Silke Britzen has a keen eye for detail.

Another great passion had been growing alongside astronomy in 15-year-old Britzen for some time: art. "I grew up painting and have always loved experimenting with colors." When her biology homework called for drawings of songbirds, for example, she would use the opportunity to try out different artistic techniques.

Recognizing Britzen's talent, her art teacher gave her additional private lessons and encouraged her to study art. However, her fascination with the cosmos was unyielding. "I love painting. But what could be more exciting than exploring the universe?" An important factor in Britzen's decision not to study art was the gigantic Effelsberg radio telescope, with a dish 100 meters in diameter. "When I read about it in a book, it became my big dream to work with such a fantastic telescope and peer into the depths of space." Her mind was made up. She moved from her hometown of Irrel in Rhineland-Palatinate near the Luxembourg border to Bonn to study physics, astronomy, and mathematics at the University of Bonn.

Although she had decided against studying his subject, her art teacher showed his respect for her decision by allowing Britzen to analyze Van Gogh's Starry Night and Caspar David Friedrich's Two Men Contemplating the Moon in her final oral examination in the subject. "That really moved me at the time," recalls Britzen. She also credits the art lessons for a skill that plays a very decisive role in her career today: "To be able to paint, you have to learn to see." For example, Britzen's art teacher had her paint different types of apples – in such a way that you could recognize later which was a Gold Reinette and which a Belle de Boskoop. According to Britzen, the ability to see subtle differences in structures, shapes, and colors is a gift that is often needed in astronomy. "There is so much information hidden in the massive datasets from radio telescopes that you have to look very carefully to avoid missing something." She also believes that engaging with art can open the mind and create new connections. "This leads to creative ideas that can help you make progress in science."

No wonder, then, that art is still an important part of Britzen's life. She paints whenever she has time, preferably outdoors, in nature. There she can draw inspiration from the colors and lighting conditions, which she then works into

PHOTO: CHRISTOPH SEELBACH FOR MPG

Contrast program: In the control room of the Effelsberg telescope, Britzen demonstrates how aesthetic images from science and art can be. The photograph of black hole M87* on the screen beside her is a product not simply of creativity, but also of data analysis.

her art in a partly abstract manner. "My paintings don't necessarily have to be realistic. I'm much more interested in creating something beautiful and capturing the moment." For that she needs one thing above all: a whole lot of color. "The crucial thing for me is how I apply the paint. For example, I've painted the Port of Hamburg several times to capture the light effects there." Britzen learned the different techniques she uses to apply oil, acrylic, and watercolors to canvases for her paintings by taking classes at the Art Institute while studying physics in Bonn. "It helped me clear my head and was an important counterbalance for physics."

Meanwhile, she was getting ever deeper into astronomy. In her diploma thesis, Britzen focused on an observation method known as radio interferometry at the Max Planck Institute for Radio Astronomy. In this method, researchers aim radio telescopes that are far away from each other at a single astronomical object. By correlating the data, they are able to reconstruct an image of the object they are studying. "This method is both elegant and highly effective. It allows us to peer into faraway galaxies at extremely high resolutions by creating a virtual radio telescope the size of the Earth – an idea I found unbelievably attractive." Later, in her doctoral thesis, Britzen used this observation technique to study variable processes in the cores of active galaxies.

After defending her dissertation in April 1997, Britzen traveled to the Dutch village of Dwingeloo for a post-doctoral research residency at the Netherlands Institute for Radio Astronomy (Astron). And there, too, she very quickly found an opportunity to develop her artistic side by enrolling at an institute for graphic art techniques in Groningen and studying various printing techniques with a group of Dutch artists. "I would let the finished prints dry on the back shelf of my VW Scirocco as I drove back to Astron."

Up to that point, Britzen's scientific work had focused almost entirely on the study of astrophysical jets. These gigantic streams of matter are ejected by supermassive black holes from the center of galaxies at nearly the speed of light and can measure thousands of light years in length.

The focus of Britzen's research shifted, however, when she attended a Munich astronomy conference in 2008 dedicated to the processes in the immediate vicinity of these massive monsters. Up to that point she had only dealt with black holes to better understand the phenomenon of jets. "But at the conference it became clear to me that it's much more exciting to think the other way around, that is, to draw conclusions about the properties of supermassive black holes from the characteristics of jets, since the latter couldn't even exist without the former."

"I love painting. But what could be more exciting than exploring the universe?"

With this small but decisive change in perspective, Britzen's scientific career really took off. From 2017 to 2019, she contributed to the very first image of the shadow of a black hole – from the first batch of data collected with the Event Horizon Telescope (EHT) straight through to publication of the image. "When I heard that the EHT would be taking pictures of the center of galaxy Messier 87 at an unprecedented resolution, I immediately wanted in. I simply wouldn't have been able to stand it if a colleague was sitting next to me in the office with the data and I wasn't able to contribute," says Britzen with a laugh.

Although the black hole (M87*) in the center of Messier 87 extends more than 35 billion kilometers, the researchers' effort can be compared to

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PHOTO: CHRISTOPH SEELBACH FOR MPG

attempting to photograph the letter O printed here from a distance of 25,000 kilometers. "We knew that the resolution of the EHT would just barely suffice to make the black hole's shadow visible in the midst of a photon ring of glowing plasma at a distance of 54 million light years." More than 300 scientists evaluated the data from the EHT, and four teams prepared the images independently of each other – and Britzen was part of one of them. "We weren't allowed to communicate with each other during that period, to keep us from influencing one another." Thanks to complex simulations based on theoretical models, all the participants already had quite a specific idea of what they should expect to see in the images under the best of circumstances. "But we couldn't know if reality would match our expectations." When the researchers finally compared their results and practically all the images had a dark spot in the center with the ring of the surrounding plasma visible around it, the cheers and relief were overwhelming, recalls Britzen. "I still get goosebumps now, just thinking about it."

In Britzen's own words, the image of the shadow of M87* was the most exciting project of her career up to that point, but there is a phenomenon that fascinates her even more. "I was always interested in whether there are galaxies with two supermassive black holes at their center." She had already found initial evidence of this in the results of her diploma thesis. One indicator that such binary black holes exist is the fact that some astrophysical jets are bent, explains Britzen. "A jet bent in that way is hard to explain with just a single black hole. In the meantime, theoretical astrophysics has come to assume that in cases like these there must be two black holes orbiting each other." Her current research therefore involves searching for signs of such pairs of black holes in one new galaxy after another. "The work gets more and more exciting, because the data is constantly getting better over time, and I have an increasingly accurate idea of what I should look for when evaluating it. There are many days when I would just as soon never leave the Institute again." The primary goal of her work is to find binary black holes whose shadows can be photographed like that of M87*. "The problem is that all the candidates so far are too distant to resolve with the EHT." Britzen hopes that this will change with the next generation of the Event Horizon Telescope. The next-generation EHT, or ngEHT, should achieve an even higher resolution and even allow for continuous shooting. Furthermore, 2037 should see the launch of LISA (Laser Interferometer Space Antenna), a gravitational wave interferometer, which could make it possible to detect the merger of two supermassive black holes from the resulting gravitational waves. "But the convergence and merger takes place on a time scale of millions or even billions of years." Locating two black holes that are merging in the next few years is therefore like finding a needle in a haystack. Yet, that is precisely part of what Britzen enjoys so much about her work. "Combing through astronomical datasets for weeks and months to my heart's content and rooting out the best candidates is the part of my job I find the most fun."

That's why Britzen was thrilled to accept a position at the Max Planck Institute for Radio Astronomy in October 2003, after a research residency in the

Impressive dimensions: Towering behind Silke Britzen is the Effelsberg Radio Telescope, one of the biggest telescopes in the world. The dish alone consists of a metal framework weighing 1950 tonnes and covers an area the size of a football field.

Netherlands and her habilitation in the field of astronomy at Heidelberg University. "The research conditions here are simply fantastic. To be able to work so independently, yet be so well networked with the scientific community is worth a great deal, especially since I work without a permanent team." Instead, she cooperates with specialists from all over the world on each project.

At the moment, Britzen is finding more signs of binary black holes than ever before. "I'm having practically the best research year of my life." Dropping her pen at 6 PM and heading home for the evening is not an option for her. "I literally carry the work in my head wherever I go. And then I'll be taking a walk or shopping, when all at once a solution hits me." Only when the brushes, paints, and canvases come out does science take a back seat – at least for a little while. "Black holes against a black background don't really inspire me artistically, because no light or information escapes from them," says Britzen. And so she has no problem separating art from science when painting. "The photographs we've taken with the Event Horizon Telescope are fantastic. But it's also all the information we have. To simply imagine what might be there and paint that would strike me as frivolous." Consequently, Britzen much prefers to draw inspiration for her art from things here on Earth. "And then later when my mind shifts away again a few million light years into space, I find I'm more open to new ideas."

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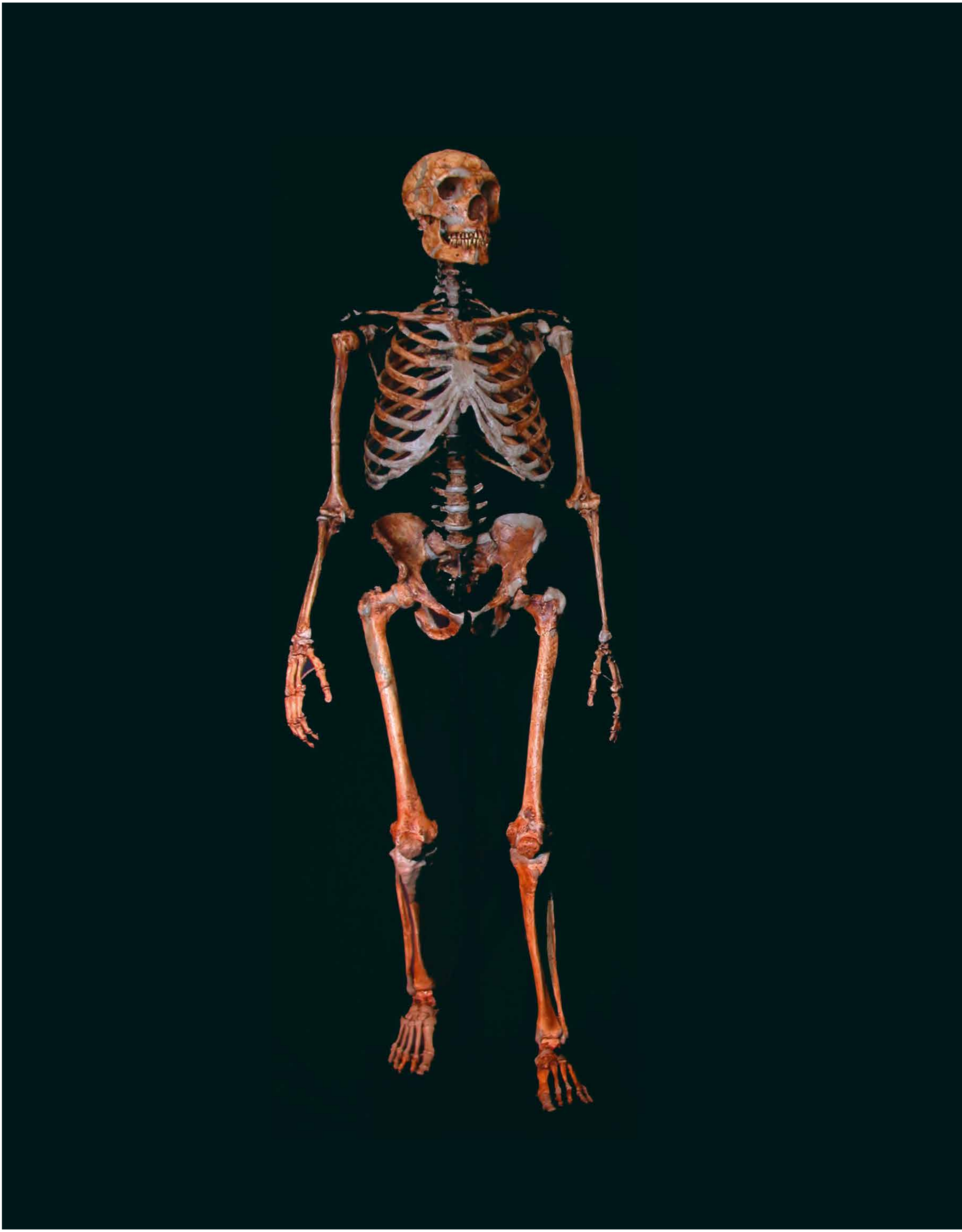
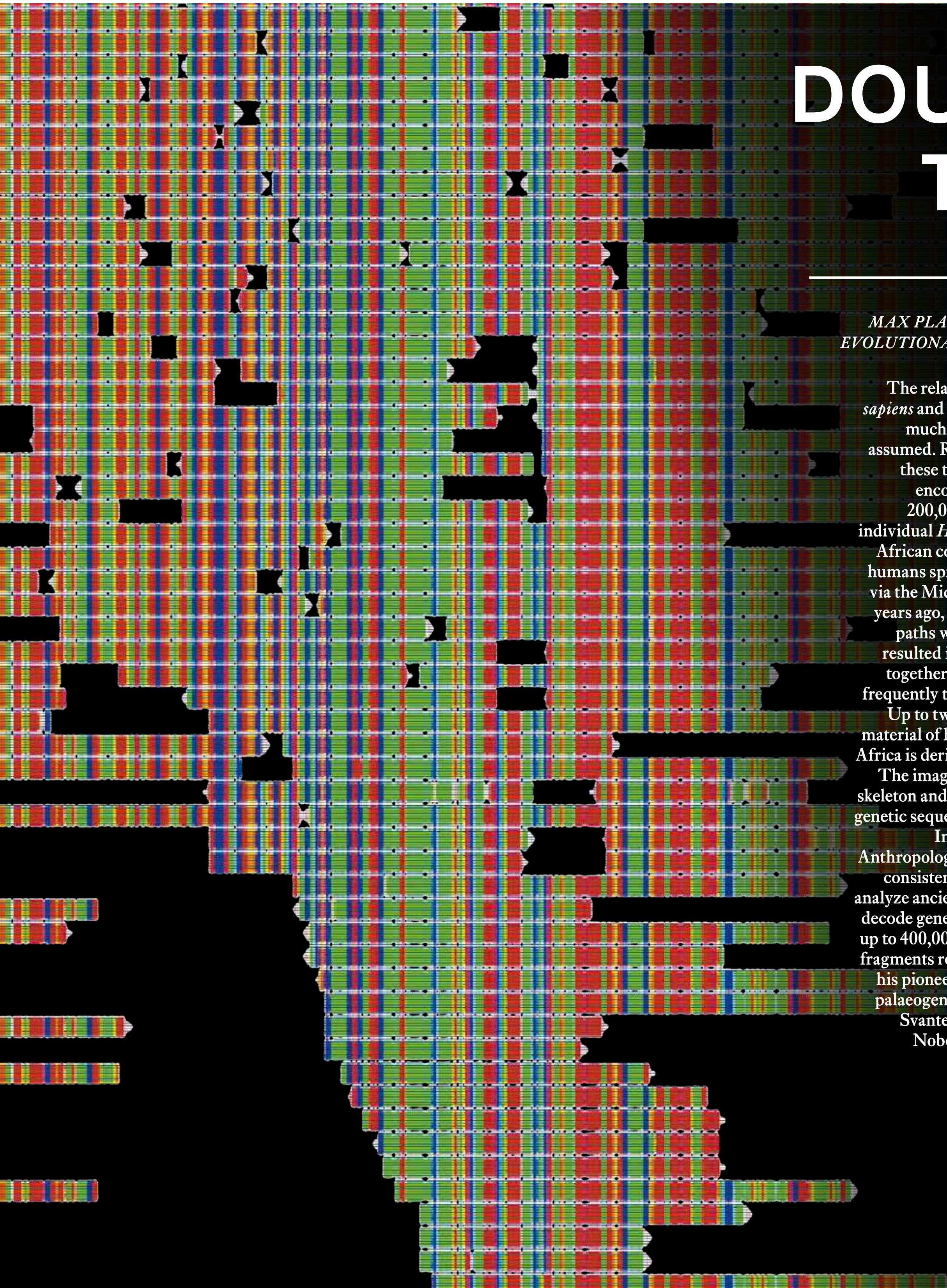


PHOTO: AMERICAN MUSEUM OF NATURAL HISTORY – IAN TATTERSALL



DOUBLE TAKE

MAX PLANCK INSTITUTE FOR EVOLUTIONARY ANTHROPOLOGY

The relationship between *Homo sapiens* and Neanderthals goes back much further than previously assumed. Recent studies show that these two types of human first encountered each other over 200,000 years ago, after some individual *Homo sapiens* had left the African continent. When modern humans spread to Europe and Asia via the Middle East around 50,000 years ago, they once again crossed paths with Neanderthals. This resulted in them having children together – which occurred more frequently than commonly thought. Up to two percent of the genetic material of human beings outside of Africa is derived from Neanderthals. The images depict a Neanderthal skeleton and part of this individual's genetic sequence. At the Max Planck Institute for Evolutionary Anthropology, palaeogeneticists are consistently refining methods to analyze ancient DNA. They can now decode genetic material dating back up to 400,000 years, even when only fragments remain. In recognition of his pioneering work in the field of palaeogenetics, Institute Director Svante Pääbo was awarded the Nobel Prize in Physiology or Medicine in 2022.

PICTURE: MPI FOR EVOLUTIONARY ANTHROPOLOGY

75 YEARS

IMAGE: ABBERIOR INSTRUMENTS

PATENT SOLUTIONS

TEXT: ROLAND WENGENMAYR

Finding applications for scientific discoveries that hold promise for medicine and technology is the goal of Max Planck Innovation. The agency for technology transfer was a global pioneer in helping researchers patent and license inventions and found startups. Its history includes many successes, a financial crime thriller, and a major crisis.

An invention for new insights: The STED microscope depicts details of cells at a resolution previously thought impossible. Here it makes the tubulin filaments (yellow) and actin (blue) of a cytoskeleton visible in great detail, thus contributing to a better understanding of their role in cellular locomotion. Max Planck Innovation helped market the invention.

They are two of the most important inventions from the Max Planck Society: discoveries made by Axel Ullrich, Director at the Max Planck Institute of Biochemistry in Martinsried until 2016, are the reason people can survive kidney cancer today. And developments from a team led by Jens Frahm at the former Max Planck Institute for Biophysical Chemistry (Karl Friedrich Bonhoeffer Institute) have reduced from hours to minutes the amount of time patients have to lie still in MRI machines. Not only do both inventions contribute to progress in medicine, but the corresponding patents are among the most lucrative in the history of the Max Planck Society (MPG). Sutent® brought in EUR 165 million during its term, while the Flash technique Frahm helped develop earned EUR 155 million.

An ever increasing number of researchers at the MPG are contributing to patents or founding companies. However, technology transfer requires professional knowledge to succeed, because international patent registrations and company formations are complicated. That's where Max Planck Innovation GmbH (MI) in Munich comes in. After all, transferring technology to the economic sector from basic research at the Max Planck Institutes is a very unique challenge. It often involves completely new technologies, and developing them to the point of market readiness is like running a marathon. A scientific discovery that could lead to a new product must be patented as soon as it is made. "We might be 15 years away from market readiness," confirms Jörn Erselius, Managing Director of MI. The primary goal of basic research is to publish results in scientific journals, but a patent can't simply be registered later, because after publication the inventions are no longer patentable. As a result, with a patent term of 20 years, the inventors and the Max Planck Society are often left with only a few years to profit from licensing income. But Erselius emphasizes that MI is primarily concerned with benefiting society. "Of course

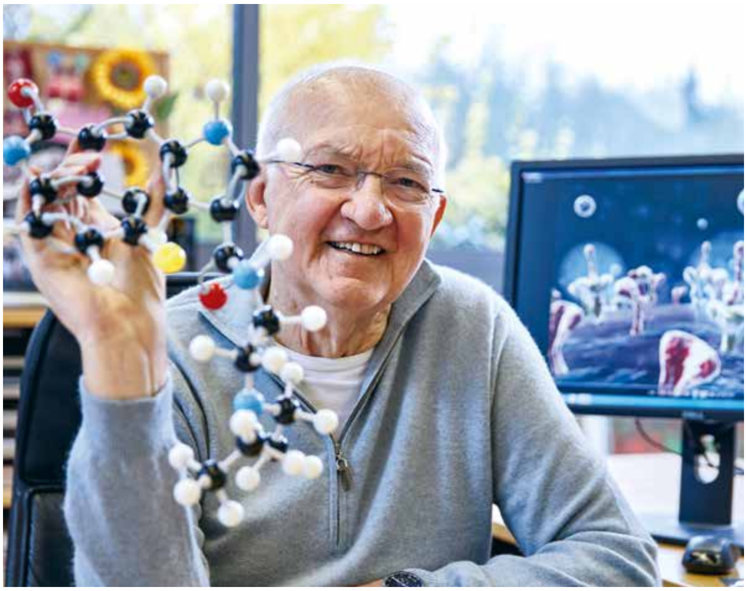


PHOTO: HEINZ TROLL

A basic researcher with an eye for applications: Axel Ullrich holds up a model of the substance Sunitinib, which causes some cancer cells to die off. It was developed based on findings from his group. Since 2006, Pfizer has marketed the active ingredient in the drug Sutent®.

we also want to earn money for the Max Planck Society, but we're more concerned with what becomes of the technologies."

The social benefit of technology transfer was known as far back as the 1970s. That decade saw the founding of Garching Instrumente GmbH, the precursor to Max Planck Innovation. Jaromír Balcar studied this early phase as a guest scientist at the Max Planck Institute for the History of Science. By international standards, the research organization was very early out of the gate with regard to technology transfer, explains Balcar. Especially compared to the U.S. "There were small technology transfer organizations at individual American universities, but the boom didn't come until the Bayh-Dole Act." The Act came into effect in the U.S. in 1980 and gave universities the right to market their inventions.

Balcar explains that the idea of founding an organization for technology transfer arose at the Max Planck Institute for Plasma Physics (IPP) in Garching. Because plasma research aims to generate energy from nuclear fusion, it breaks new ground technologically and develops new devices. This offers potential for the industry, which is why the IPP considered marketing as far back as 1967. Though initially hesitant, the MPG was likewise attracted to the idea of a central agency that could support the Institutes when registering patents. However, the question arose whether commercializing research results was compatible with the organization's public-benefit status. "It was a sore point," emphasizes Balcar. As a result, the MPG consulted the Bavarian state government to determine the most suitable legal structure. The Garching Instrumente Gesellschaft zur industriellen Nutzung von Forschungsergebnissen mbH, or GI for short, was founded on March 20, 1970.

The managing directors were Ernst Guilino, a physicist from the IPP, and Gunther Hoeltz, a businessman with industry experience. Together they built a company with 35 employees. Not only did it market patents from the Max Planck Society through licenses, but it also manufactured devices that had been developed at the Institutes. The equipment division was very important to both directors, because it brought in revenue immediately. With patents, however, it took many years before the money started flowing in. The external impact of Garching Instrumente in international professional circles was enormous. Before long, the directors were being invited to deliver lectures at European and American research facilities. "They were considered pioneers in the transfer of findings from basic research," explains Jaromír Balcar.

However, the device business was so unprofitable that a crisis occurred at the end of the 1970s. It would have spelled the end of Garching Instrumente, if a political wind favorable to technology transfer had not blown from the realm of science. The former Federal Ministry of Research praised the activities of the MPG as "exemplary." The latter therefore decided to downsize Garching Instrumente and continue it solely as a patenting and licensing agency. After restructuring, the portfolio of patents and licenses, which had been growing steadily since the 1970s, yielded enough income to cover the debts within a few years. Business didn't always go smoothly, however.

SUMMARY

Since 1970, the Max Planck Society's agency for technology transfer, known today as Max Planck Innovation GmbH, has commercialized knowledge and inventions from Max Planck Institutes and helped researchers patent and license inventions and found startups. The cancer drug Sutent®, which is based on a discovery at the Max Planck Institute of Biochemistry, earned a record-setting EUR 165 million in licensing income for Max Planck Innovation, while the Flash technique for improved MRI imaging earned EUR 155 million.

The mid-1980s even saw the beginnings of a real-life financial crime thriller involving the aforementioned Flash technology. The problem with magnetic resonance imaging (MRI) at the time was that patients had to lie still in the tube for a very long time for an image. A team in Göttingen led by physicist Jens Frahm overcame this disadvantage. Bernhard Hertel at Garching Instrumente helped register the Flash method for a patent as quickly as possible. Just how wise that was would become clear that very same year. “It must have been in August 1985, at a conference in London,” Hertel recalls. “General Electric had already implemented the procedure in a showroom model there!” A patent dispute began in the U.S. and Europe and would go on for seven years. To the industrial giant’s surprise, the MPG could not be intimidated. Drawing on the internal competence at the Max Planck Society, it won an initial trial. After that, the big manufacturers gave in: first Siemens, then Philips, and eventually General Electric. From the mid-90s onward, licensing income flowed bountifully for the Max Planck Society.

“We’ve made it our motto to be trendsetters in technology transfer in Germany.”

JÖRN ERSELIUS

Just a few years earlier, a paradigm shift had occurred in the organization’s approach to technology transfer. “Up to that point, no Max Planck scientist had been allowed to participate in the founding of a company,” says Erselius. The reasoning behind this was to avoid possible conflicts of interest. That changed in 1988, when Axel Ullrich was appointed Director of the Max Planck Institute of Biochemistry in Martinsried. The biochemist was a pioneer in the production of genetically engineered insulin and had optimized the procedure at the American company Genentech. That was the big breakthrough in the industrial production of human insulin.

In consequence, Ullrich knew the American ethos with regard to founding companies, and he only agreed to accept the appointment if allowed to found and participate in companies as a Max Planck scientist. “And so the spell was broken,” says Erselius. In Martinsried, Ullrich’s team discovered a class of kinases that, among other things, play a role in the blood supply of tumors. Garching Instrumente initially contacted the now-defunct pharma giant Hoechst and other pharmaceutical companies in Germany, reports Erselius, “but none wanted to cooperate.” As a result, Ullrich’s team partnered with New York University to found the startup Sugen in San Francisco. Based on Ullrich’s research, Sugen developed the active ingredient Sunitinib for a cancer drug now marketed by Pfizer under the name Sutent®. In 1993, shortly after Sugen began, a company was finally founded in Germany. Under the name Evotec, it, too, was active in the life sciences industry. Its primary driving force, with support from GI, was Manfred Eigen, Director of the Max Planck Institute for Biophysical Chemistry (Karl Friedrich Bonhoeffer Institute) in Göttingen. In 1967 he had already received a Nobel Prize in Chemistry at 40. The founding was based on a high throughput method Eigen had developed to efficiently test the biological effects of countless substances in an evolutionary process. It speeds up the search for new pharmaceutical agents, for example. Today, Evotec has more than 5000 employees worldwide and is based in Hamburg.

The 1990s saw a boom in life sciences, which accounted for around 70 percent of all spin-offs at the time. That’s according to Ulrich Mahr, who is responsible for spin-offs as Deputy Managing Director of MI. As the dot-com bubble burst at the end of the millennium, however, it became harder to find investors for biotech startups. “Today, this area accounts for around 50 percent of total investment,” says Mahr. Other startups were founded, for example, in the field of physics. Two Nobel Prize winners come into play again here: Theodor Hänsch, Director at the Max Planck Institute of Quantum Optics in Garching, and Stefan Hell, Director at the Max Planck Institute of Biophysical Chemistry in Göttingen, which in 2022 became part of the new Max Planck Institute for Multidisciplinary Sciences.

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THE RESEARCH PROGRAM “HISTORY OF THE MAX PLANCK SOCIETY”

From 2014 to 2022, independent historians reconstructed the development of the Max Planck Society between 1948 and 2002, placing the history of the MPG within the contemporary history of the Federal Republic in the context of European and global developments.

Theodor Hänsch, who was awarded the Nobel Prize in Physics in 2005, had developed a laser technique he dubbed the “frequency comb.” This method allows light frequencies to be measured optically. It had never been possible before, because light oscillates very quickly. To market the frequency-comb technique, Hänsch founded Menlo Systems in Planegg in 2001 with his two former doctoral researchers, Ronald Holzwarth and Michael Mei. Now numbering almost 200 employees, the company quickly established itself on the market for ultra-precise measurement. Its customers include metrological institutes around the globe, for example, the National Metrology Institute (Physikalisch-Technische Bundesanstalt) in Braunschweig.

High resolution microscopy technique

Stefan Hell achieved a breakthrough much like Theodor Hänsch’s – one that had long been considered impossible. The physicist, who received the Nobel Prize in Chemistry in 2014, did away with the Abbe diffraction limit. Formulated by Ernst Abbe in 1873, this law asserted that the wavelength of light limits the resolution of optical microscopes. And because it is much larger than an individual molecule, it should not be possible to observe the latter with light microscopes. In life sciences, molecules are labeled with fluorescent dyes, so that their activities in living cells can be observed. The microscope images remained blurry due to the diffraction limit, however. Hell managed to circumvent this limit using quantum physics and specially shaped laser light. This technique facilitates images of the molecular inner workings of a cell with hitherto unrivaled sharpness. On the basis of this invention, Hell founded two companies in the early 2010s with physicist Gerald Donnert as managing director: Abberior Instruments manufactured supermicroscopes that worked with lasers, and Abberior produced new fluorescent dyes. “With their own shareholder capital, both companies established themselves in a market where they had to compete against major players such as Zeiss, Leica, and Olympus,” says Mahr.

Up to this point, technology transfer has clearly been dominated by men. However, female scientists have been closing the gap ever since. One example is chemist Katharina Landfester, Director of the Max Planck Institute for Polymer Research in Mainz. She holds around 60 patents and has developed, for instance, a refined method for manufacturing tiny nanocapsules. These are useful, for example, in viticulture, where they can ensure that fungicides are applied in precise and environmentally friendly doses. Another area of application is the targeted transport of medicinal agents in the body. Landfester is working on this with Mainz-based vaccine developer Biontech, among others.

The agency for technology transfer has changed its name twice in more than fifty years. In 1993, the misleading term “Instrumente” was removed from the name and the company was renamed Garching Innovation GmbH. Technologien aus der Max-Planck-Gesellschaft. In 2006, the company was rechristened with the name it still holds, Max-Planck-Innovation GmbH. By that time, the MPG had overcome its concerns

OVER 50 YEARS OF MAX PLANCK INNOVATION

1970 Founding of Garching Instrumente GmbH, based in Garching

1985 Registration of Flash patent

1991 First startup with MPG participation: Sugen, Inc. (USA)

1992 First approved drug from MPG research: Miltefosin (Miltex) for treatment of skin metastases from breast cancer

1993 First German startup with MPG participation: Evotec, Hamburg

1993 Name changed to “Garching Innovation GmbH. Technologien aus der Max-Planck-Gesellschaft”

1996 All major medical technology companies have licensed Flash – steep increase in sales

2000 Registration of “Tuschl Patents” for RNA interference

2002 2004 Approval of miltefosine (Impavido) for the treatment of leishmaniasis

2006 Approval of Sutent® as a cancer medicine

2006 Name change to Max-Planck-Innovation GmbH

2007 Founding of Life Science Incubator at Caesar center, Bonn

2008 Founding of Lead Discovery Center (LDC), Dortmund

2018 2019 Approval of Onpattro and Givlaari by Alnylam – first RNAi-based drugs

2020 Total sales exceed EUR 500 million (since founding in 1970)

2020 Approval of Oxlumo, RNAi drug

2022 Approval of AMVUTTRA, RNAi drug

2022 MPG’s entrepreneurship reinforced with launch of MAXpreneurs initiative and MAX!mize incubation program

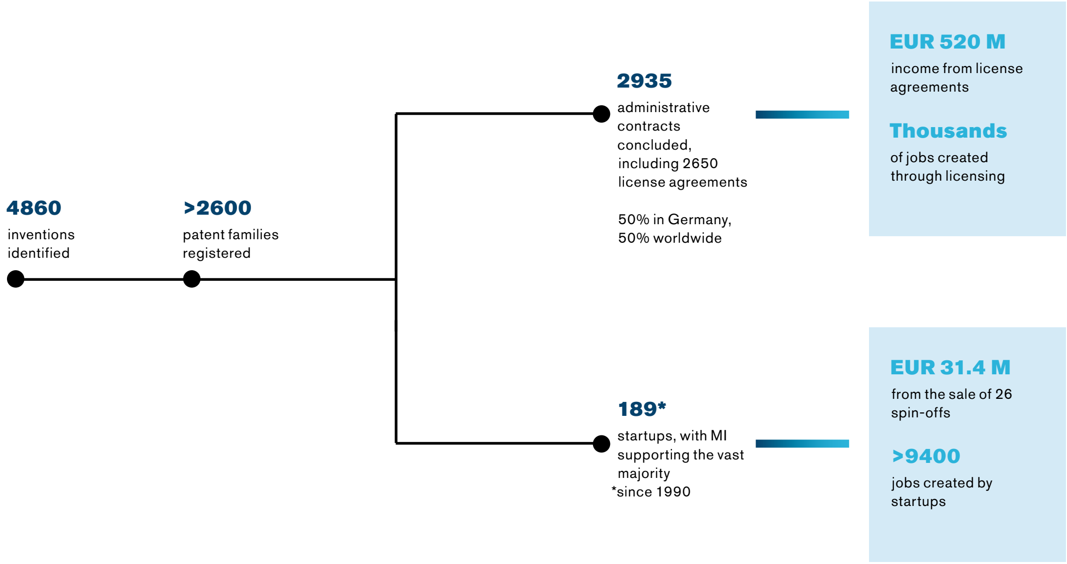
2022 Startup Meshcapade wins the first Max Planck-Startup Award

Maximum support: Dandan Li (left) and Philipp Schmidt (center), who in 2023 founded Quantitative Surgical, a spin-off of the Max Planck Institute for Intelligent Systems, get advice from Carolin Wichmann of Max Planck Innovation (right) as part of the MAX!mize program. The company provides organ models for training surgeons.

PHOTO: KIMBERLY KOBER

about appearing in a company name. From then on, technology transfer would be unmistakably connected with it. In the new millennium, a milestone was set in 2008 with the founding of the Lead Discovery Center (LDC) in Dortmund. This was a response by Axel Ullrich and Max Planck Innovation to the fact that, since 2000, it had become increasingly difficult to interest the pharmaceutical industry in early inventions from basic research. Together they established the LDC, for early drug development with the MPG as a stakeholder. “Lead” stands for the lead structure of an agent. “Such a substance is already optimized,” explains Erselius, “and has exhibited the correct function in animal models.” That reduces the risk for pharmaceutical companies that may be interested. This strategy hardly suffices anymore, however, which is why the Lead Discovery Center in addition began founding startups with support from MI. These companies develop the active ingredients up to the clinical stages, and big companies can then license them later or even purchase the startup. The most recent milestone for MI is the MAX!mize initiative, launched in 2022. This incubation program provides even more intensive support for the founding of companies from Max Planck Institutes. Researchers can apply here with ideas, which then receive support from MI until a company is founded. One important aspect is early contact with potential customers, even while the founders are still developing the business idea. This reality check plays a decisive role in success. And indeed, incubators like these help increase the number of spin-offs. “Five to ten years ago we typically had five to seven spin-offs a year. The numbers fluctuated, of course,” explains Mahr. “Today it’s eight to ten, with an upward trend.” Most of the companies form in Germany, but several highly successful ones were founded in the U.S., where there is significantly more capital for startups. “Roughly speaking, 50 percent of the technologies developed in the Max Planck Society are licensed abroad, and 50 percent stay here,” says Erselius. “We’ve made it our motto to be trendsetters in technology transfer in Germany.” LDC and MAX!mize from Max Planck Innovation is yet one more example.

MAX PLANCK INNOVATION IN FIGURES



GRAPHIC: GCO, BASED ON MAX PLANCK INNOVATION

E-DRIVE FOR LIFE

TEXT: CATARINA PIETSCHMANN

Every living creature has to gather materials from the environment and convert them into the materials it needs to live. Without metabolism, there would be no life on Earth. Tobias Erb, Director at the Max Planck Institute for Terrestrial Microbiology in Marburg, wants to reprogram metabolic pathways so that raw materials can be produced more sparingly and efficiently. His latest coup? A metabolic cycle driven by electrical energy.

Up to a thousand enzymes are working simultaneously in a single cell, manufacturing countless substances in parallel. However, evolution has not always taken the fastest and simplest path. Many metabolic processes occur in stages, with byproducts and waste products emerging at each step. Max Planck researcher Tobias Erb wants to simplify the winding paths. In the future, complex and expensive chemical plants might be replaced by genetically modified microorganisms and plants that use new metabolic pathways to produce important raw materials for humans. As with any journey, the main thing is planning the route. Where do I start, where do I want to go, and what is the shortest path to my destination?

Erb and his team have already found a shorter pathway for photosynthesis – the researchers have paid special attention to this process that is so fundamental to life on Earth. It consists of two reaction cycles. In the first, the "light reaction," energy from sunlight is converted into chemical energy. The second, known as the Calvin cycle, then uses this energy to form carbohydrates from carbon dioxide in the environment. In 2016, Erb and his team recreated the Calvin cycle in a lab. The artificial cycle of 17 enzymes, which the researchers dubbed "Cetch," does the same as its natural model. It converts carbon dioxide into sugar compounds, but is around twice as effective at it. "Furthermore, depending on the choice of enzymes, our metabolic pathway can manufacture not only sugar and starch, but other substances as well, such as antibiotics and proteins," says Erb. Apart from the Cetch cycle, he and his team have since developed additional alternatives to the Calvin cycle. They include the Hopac and Theta cycles, which form different raw materials from carbon dioxide.

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PHOTO: TOBIAS ERB/MPI FOR TERRESTRIAL MICROBIOLOGY

KNOWLEDGE FROM

Artificial chloroplasts could someday provide cells with energy and nutrition. Researchers have filled these 0.09 millimeter droplets with chloroplast membranes from spinach plants (green). They implement the light reaction and drive an artificial reaction cycle that binds carbon dioxide.

Shanshan Luo and Tobias Erb with the reaction chamber for the AAA cycle.

PHOTO: VIRGINIA GEISEL/MPI FOR TERRESTRIAL MICROBIOLOGY

SUMMARY

Researchers are now able to recreate the metabolic cycles of cells in the lab and improve their efficiency.

The Cetch cycle is an artificial metabolic cycle that can fix carbon dioxide and convert it into carbohydrates. Cetch works much more efficiently than the natural Calvin cycle and can provide other raw materials besides sugar.

The AAA cycle can convert electricity into biochemical energy. In the future, the cycle could serve as the interface between electricity and biology and, for example, drive the Cetch cycle for carbon dioxide fixation.

Tailor-made reaction cycles such as these could therefore be used to produce a host of different raw materials. An important ingredient is still lacking, though, without which the enzyme mix cannot do its work: energy! The Sun provides it for the Calvin cycle. In the light reaction cycle, enzymes use energy from sunlight to manufacture the fuel that keeps most life processes running: an energy-rich chemical compound named adenosine triphosphate. Called ATP for short, the molecule provides energy for the Calvin cycle.

Like many reaction cycles in nature, it takes several intermediate steps to form ATP. In the light reaction cycle, an electrochemical voltage builds up along a membrane, and is then used for a protein motor, which generates ATP with the help of mechanical energy. “Electricity therefore flows in photosynthesis, but the charge separation on a membrane is very cumbersome. So, my employee Shanshan Luo and I asked ourselves whether we couldn’t power our synthetic metabolism directly with electrical energy, thus linking electricity and biological systems,” says Erb.

ATP from electrical current

In the summer of 2023, Erb, Shanshan Luo, and the team were able to declare success. They had developed an artificial metabolic pathway that extracts the biochemical energy source ATP from electrical current. The AAA cycle combines electricity with energy generation in living cells. The cycle consists of four enzymes derived from different microorganisms. The first enzyme, aldehyde ferredoxin oxidoreductase (AOR), is the “adapter,” so to speak. The electrons are transferred from an electrode to a soluble carrier molecule, which passes them on to the AOR. At a voltage of 0.6 volts, AOR absorbs two electrons. It can use these to reduce a low-energy acid molecule to an energy-rich aldehyde. The other three enzymes of the cycle then handle the reconversion, that is, the oxidation of the aldehyde into acid. The energy released in the process can be used to form ATP from ADP.

The central enzyme of the cycle, AOR, comes from the little-known bacterium Aromatoleum aromaticum. Researchers at the Center for Synthetic Microbiology of the Philipps-Universität Marburg were the first to successfully cultivate this petroleum-degrading microbe in a lab. Along the way, they stumbled across AOR, which now serves as the central energy converter in the AAA cycle. "It was really a pure accident that colleagues at the neighboring institute were studying precisely the enzyme we needed for the AAA cycle," says Erb.

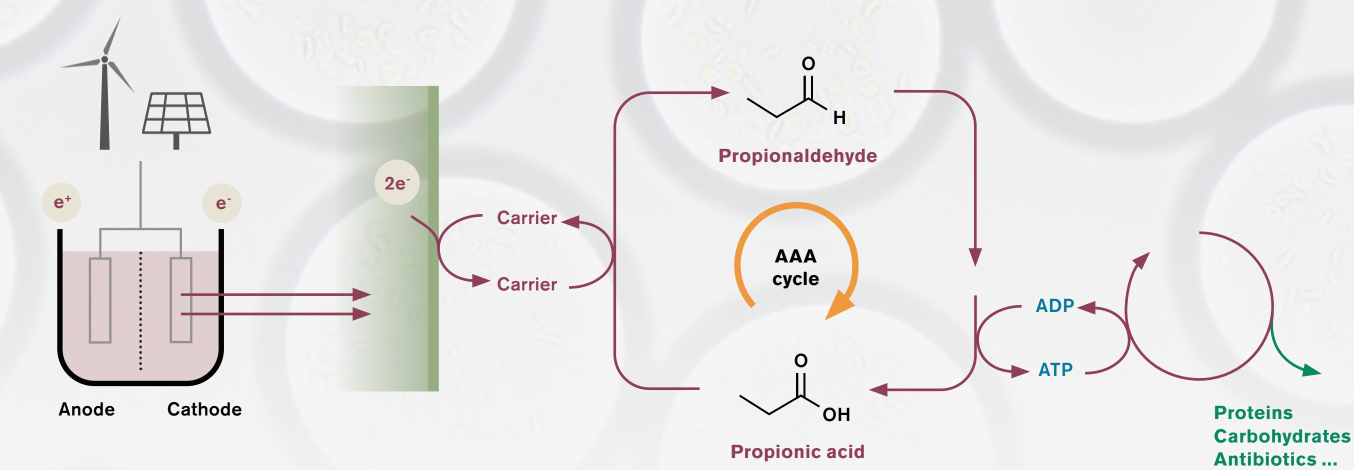
The researcher's success in converting electrical current directly into biochemical energy and then using the latter for chemical reactions is a breakthrough. To demonstrate that they can use it to manufacture more than just sugar molecules, they put the components of the cycle in a reaction vessel together with the necessary building blocks for a protein. "The whole machine rested until the current was switched on," reports Erb. "Then the AAA cycle really started driving production of the protein."

One day it might be possible to use the AAA cycle to drive the production of drugs and other raw materials, but right now it is only possible in small quantities. To make large-scale production possible in the future, the Max Planck researchers are working with colleagues from the Fraunhofer Institute for Interfacial Engineering and Biotechnology in Stuttgart to develop a prototype they can use to manufacture a perfume. Erb sees this as "an example of the interlinking of basic science and applied research."

As in the case of AOR, Erb often finds suitable enzymes in nature. "We start by checking whether there are examples in nature of the reactions we need." Microorganisms in particular are masters of an abundance of all types of metabolic processes. All multicellular animals from worms to humans are alike in terms of metabolism. In microbes, by contrast, completely different types of biochemical process are commonplace. As a result, they can survive in extreme habitats, such as the deep sea or permanent ice.

Enzymes made to measure

When researchers fail to find what they need in the kingdom of microorganisms, they fall back on existing ones, taking enzymes that fulfill tasks similar to what they are looking for and adapting them to their purposes.



An electric drive for cells: Energy generated from renewable sources provides the electrons that drive the aldehyde ferredoxin oxidoreductase (AOR) in the AAA cycle. This enables the AOR to convert low-energy propionic acid into high-energy propionaldehyde molecules. Three additional enzymes catalyze the reverse reaction of aldehyde into acid. The energy released in the process can be used to form ATP and ultimately drive the synthesis of raw materials.

GRAPHIC: GCO BASED ON SHANSAN LUO/MPI FOR TERRESTRIAL MICROBIOLOGY

Mutations change the blueprint of an enzyme in such a way that it can take on a new function. However, it often happens that the researchers seem to have all the ingredients for a functioning metabolic pathway, yet the components get along poorly and inhibit each other. “It’s like when a soccer coach has to form a new team out of famous superstars. If the players don’t work well together, the team won’t win, despite their individual abilities,” says Erb. And so it takes a lot of fine-tuning before the perfect new team is standing on the field. In the meantime, the researchers have managed to build enzyme teams of up to 70 “players” into functional metabolic pathways.

Optimization, not invention

Nevertheless, it is often easier to optimize an existing team; that is, to spice up the natural original of a metabolic cycle, such as the Calvin cycle in photosynthesis. The central molecule in the Calvin cycle is the enzyme rubisco. It binds carbon dioxide, making it usable for the metabolism of plants. “But rubisco works very inefficiently; it only absorbs five carbon dioxide molecules per second. That’s really modest for an enzyme. It also makes a lot of mistakes. In every fifth reaction, it snaps up a molecule of oxygen rather than carbon dioxide,” says Erb. For that reason, he decided against using rubisco in his Cetch cycle and instead replaced it with the enzyme Crotonyl-CoA carboxylase/reductase. The latter comes from a purple bacteria and binds carbon dioxide a hundred times faster than rubisco.

The researchers use automated procedures to find out where a cycle is still stumbling. This means they can analyze the material conversion of 300 variants of a cycle at the same time. A computer varies the concentrations of the different enzymes and evaluates which variants are the most efficient. These are then optimized further.

In principle, the Cetch cycle functions like its natural model during photosynthesis, but none of its 17 enzymes are identical with the ones plants use for carbon fixation in the Calvin cycle. Erb compares this with the invention of aviation. “By studying birds, people learned what laws govern flight and how a wing works. But airplanes don’t look like birds. They don’t have feathers and their wings don’t flap. By the same token, the Cetch cycle is inspired by its biological model, but its structure is fundamentally different.”

But then why didn’t nature come up with the cycles that Erb and his team invented in the lab? One obvious reason is that life depends not just on maximum yield, but also on resistance to environmental influences. The Cetch cycle runs primarily in a lab. On the tundra or in tropical rainforests it would almost certainly have problems. Furthermore, nature is conservative and often tends to develop existing systems further rather than break new ground.

Erb and his team are now hoping to get the artificial metabolic pathways running in real cells. To that end, they are reprogramming the genes of microorganisms and single-celled algae to enable them to produce the necessary enzymes. The Cetch cycle could boost photosynthesis in an algae cell, for example. In photovoltaics, 20 to 30 percent of the Sun’s energy can be converted into electricity, while the cell’s own chloroplasts use only one percent. However, replacing the Calvin cycle entirely with the artificial Cetch cycle would be very challenging, according to Erb. “To do that we would have to remove the key component of plant metabolism, which would massively affect the way the cell functions. A much more promising approach, in my opinion, is not to swap out the entire ‘operating system’ at first, but to help along the natural process with a handful of optimized enzymes.” The team has

PHOTO: MPI FOR TERRESTRIAL MICROBIOLOGY

PHOTO: THOMAS HARTMANN

Tobias Erb wants to create raw materials from simple molecules. To do so, the biochemist relies on metabolic cycles based on models found in nature. They are more efficient and better for the environment than traditional chemical manufacturing processes.

Algae bind carbon dioxide with the enzyme rubisco. But, because the latter works relatively slowly and repeatedly makes mistakes, Tobias Erb's team is experimenting with other enzymes and metabolic pathways to make the reaction more efficient. Equipped with artificial reaction cycles, algae cultures could one day be used as bioreactors for converting carbon dioxide into organic molecules.

already managed to show that this form of optimization works in algae.

In Erb's view, biology today is at the same point chemistry was a hundred years ago. Back then, the world of atoms and molecules had been so thoroughly studied that researchers were able not only to recreate natural molecules, but to synthesize new ones as well: fertilizers, drugs, plastics, and much more. Today's researchers understand the material cycles in cells so well that they are able develop new ones. Biology could now take over the production of chemicals.

Photosynthesis could therefore become central to the future of humanity. Eventually, crop plants with more efficient photosynthesis would form more biomass from carbon dioxide, removing greenhouse gas from the atmosphere in the process. The result would be bigger harvests, with the additional benefit of helping protect the climate. "We need both more urgently than ever. Around 10 billion people will inhabit our planet by the year 2050. Feeding them all would require not only changing our diets and reducing food waste, but also increasing agricultural productivity. And if we can do something to help protect the climate while we're at it, all the better," says Erb. ⟵

Reaching high: The Gilgel Gibe III hydropower plant uses the power of the Omo in Ethiopia. With a height of 243 meters, the dam is one of the tallest in Africa.

PHOTO: FAUSTO PODAVINI

NATURE IN DISPUTE

TEXT: MICHAELA HUTTERER

Extreme mining, huge dams, spreading infrastructure: when economic development endangers the habitat and culture of Indigenous and other local communities, environmental rights appear to offer a solution. But how can such human rights or rights of nature really help? A legal and anthropological research team from the Max Planck Institute for Social Anthropology seeks answers in Mongolia, Ethiopia, Ecuador, and Colombia.

Enkhtuya casts a scrutinizing glance at the long groove in the ground. He has dug a trench, studded with spikes around his yurt and winter camp, deep down into the vast, barren landscape of South Gobi Province in Mongolia. At the edge of the trench, six torn rubber tires are piled up, weighted down with stones, like a guardian calling out to all who pass by: "Stop, no trespassing, this is Enkhtuya's land!" For the cattle herder, both trench and tire pile are signs of resistance against the overwhelming power of Mongolian mining companies like Erdenes Tavan Tolgoi in the South Gobi, a region that had hitherto managed without boundaries for thousands of years.

But life has changed since truck after truck began hauling coal, copper, and other metals to the nearby Chinese border. "Without a barrier, the trucks run over and kill my cattle, and destroy the pastureland," the herder says. A few hundred kilometers away, Uranmandakh has also built a fence around her belongings – made of old metal plates, scrap metal, and pallets. "The mining companies are more likely to pay for the damage if we can show that we have put a fence in place," reports the herdswoman, who is trying to adapt to the new situation.

"This is an experience shared by many nomads I encounter during my field research in the South Gobi," Bayar Dashpurev, a lawyer and doctoral student at the Max Planck Institute for Social Anthropology in Halle, Germany, says. "Since Mongolia declared the extraction and export of mineral resources as its number one economic sector, herders are losing valuable pastureland and access to already scarce water sources, and kilometer-long convoys of trucks are cutting through traditional trails," Bayar reports. From September 2021 to February 2022, the legal scholar investigated how people are fighting back against those damaging the environment in three different locations in South Gobi Province.

His findings: they hardly ever do – at least not by utilizing the legal system. To date, there have been no successful compensation lawsuits and no examples of the court denying a mining permit. Yet Mongolia had already enshrined environmental rights in its constitution in 1992, and strict regulations and standards apply in this area. "The constitution recognizes a right to an intact environment," the lawyer says. Every citizen has "the right to a healthy and safe environment and protection from pollution and ecological imbalance." Taking measures to protect the environment and sustainably use and restore natu-

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ral resources, he says, is the government's responsibility.

But this does not seem to apply in the expanses of South Gobi. Environmental pollution and degradation are progressing, mining licenses are being extended, and the nomadic culture, which has been the essence of rural life for generations, is visibly fading.

However, the nomadic way of life is considered to be particularly resource-saving. "According to the constitution, every Mongolian has a duty to protect the environment. Nomads have been practicing this for thousands of years by tradition," Bayar reports and recounts an old proverb: "Leave everything as you would like to find it again next year." However, people are no longer actively fighting for environmental protection.

Why? Ethnographic studies provide some insights here. In interviews, observations, and research, the scholar examines his theses and identifies patterns. "There are many reasons why people seem to accept the current circumstances," the lawyer says. Lack of knowledge is certainly one reason, he adds, but not the only one. Lack of access? Most certainly. "Many herders told me that they don't go to demonstrations against mining companies because they cannot leave their livestock alone for more than a week," the researcher says. For the same reason, many also tend to avoid court proceedings in far-away urban centers.

At the same time, the lawyer also observes a deep split in local communities. Local residents and newcomers, herders outside and inside affected areas as defined by the mining companies, as well as herders with their own herds, and livestock owners who employ herders on their behalf, cannot find a way to reach a consensus or even a common strategy for litigation.

In addition, the herders' legal standing is weak. Mongolian law does not grant nomads private ownership of land in the Gobi. "Everything belongs to everyone, pastures are public land," Bayar reports. "However, mining companies have extensive rights of use for the extraction of raw materials." How the compensation and coexistence of mining and local residents is to happen has not been legally clarified," he says. And yet practical solutions can be found. The communities have found their own ways to secure their existence: making deals instead of filing lawsuits. In the South Gobi, it is a bargain that rarely takes place in court, but mainly in the halls of the mining companies: residents haggle over compensation for destroyed grazing land, access rights, or infrastructure – making clear reference to environmental rights in order to improve their more immediate circumstances.

Left View: Gezahagn Belewa Akudongole looks at the remains of his farm in the lower Omo Valley in Ethiopia.

Right Self-help: Enkhtuya wants to protect himself from the truck convoys in the Mongolian province of South Gobi by digging a deep trench around his yurt.

PHOTO: ABDULETIF KEDIR IDRIS / MPI FOR SOCIAL ANTHROPOLOGY

Taking stock: Researcher Abduletif Kedir Idris notes down what the community leader reports about the dam. Arez Akurkori Loyalm (on the mat) is one of the few Dassanech who have visited the dam. Gezahagn (in the yellow shirt) translates.

PHOTO: ABDULETIF KEDIR IDRIS / MPI FOR SOCIAL ANTHROPOLOGY

PHOTO: BAYAR DASHPUREV / MPI FOR SOCIAL ANTHROPOLOGY

"Previously, there were no roads, no schools, no electricity, no internet. Mining companies are now providing all of this," Bayar says. With the extraction of raw materials, infrastructure is developing in the region through the process of exchange: pasture for electricity, dust for money, drought for employment – nomadic culture for modern life. And in accepting this exchange, nomads are doing what they have done for a long time: they are adapting – to nature and those who harm it. They create visible signs of ownership where before there were none and negotiate their future – in many cases by sacrificing their cultural identity, according to the researcher. "It's hard to believe, but many of them move to these impact zones on purpose to start a new life."

The extent to which government development programs can harm the local population has also been experienced by the Dassanech in the lower Omo Valley in Ethiopia. Since the government built the Gibe III dam and hydropower plant around 400 kilometers away more than ten years ago, the lives and nature of the community of around 80,000 Dassanech people have been shattered. Like other Indigenous groups, the Dassanech lived in symbiosis with the Omo river in southwestern Ethiopia, which springs in the highlands and merges after 760 kilometers with Lake Turkana in Kenya. The Omo Valley community benefitted from the life-giving cycle of flooding in the rainy season in one of the world's least rainy regions. They followed the drying riverbank's fertile soil to cultivate crops and raise livestock in a special form of agriculture on the wetlands.

"The construction of the Gibe III dam interrupted the flow of the river; the silt that made the soils fertile vanished for more than three years," Abduletif Kedir Idris, a doctoral student at the Max Planck Institute in Halle, reports. The legal researcher is examining how the dam, officially inaugurated in 2014, affects the living conditions of the Dassanech to this day and what they are doing to protect their living environment. It is striking that there are no court proceedings or lawsuits here either. The Ethiopian constitution has recognized a "right to a clean and healthy environment" since 1995, Idris reports. But this cannot be enforced either locally or at a national level.

SUMMARY

Many constitutions recognize human rights to a healthy and clean environment. They promise protection from environmental interference.

In practice, this protection is not always exercised on behalf of those affected and often does not take local conditions into account.

New environmental rights, such as the rights of nature, can enhance nature conservation, but they can hardly be understood without human intervention. Differentiation is important.

The high barrier

"No wonder," says Idris, who is also a lecturer in public law and human rights at the University of Addis Ababa: "The barrier to taking legal action against the State, as the most important economic player and operator of numerous infrastructure projects, is very high in a country with an authoritarian political culture. The rule of law is not something that can be taken for granted here," explains the lawyer. "This is why people don't trust that they will receive a fair judgment in environmental disputes."

For Idris, this is mainly due to the judiciary, which is perceived as not being independent, but also the society's →

understanding of the law and its enforcement. "State authorities hardly exercise any control over each other," the scholar reports. For example, the Commission for Environmental Protection does not issue fines against a State-owned operator for violations. In the case of the Gibe III construction, important means of enforcing environmental rights were left out of the project. "The authority to oversee an environmental impact assessment and approve the dam construction was delegated to the agency responsible for planning and operating the power generation, which is a clear conflict of interest."

In discussions with affected parties, local authorities, operators, experts, and government officials, Idris discovered a lack of control, the absence of a legal hearing, and the deliberate spreading of misinformation. The Dassanech were led to believe that the construction would not negatively affect their livestock or agriculture. They were promised access to electricity, which could power pumps that would be used to irrigate the soil. However, the Dassanech still do not receive any electricity from the hydropower plant. "The electricity is exported to Kenya, Sudan and Djibouti," Idris reports. Instead, the operator has provided the Dassanech with diesel-powered water pumps. But after a short time, the pumps broke down – with fatal consequences for livestock and people.

"You need to understand the importance of cattle to this community. It is not just a form of agriculture, but a source of identity. First and foremost, cattle determine everyday life; ownership of cattle allows people to marry, and many life events, from birth to death, are celebrated with cattle, as sacrifices, in exchange, or as gifts. If a man no longer owns cattle, he is not even entitled to burial rites under tribal law."

For years, the communities waited for water. But when it was suddenly released in abundance, it flooded the remaining grazing fields and washed away the crops. For four years, some of the most fertile Dassanech areas would be under water. "The people are starving and now living on handouts from various aid organizations and the government." The rights listed in the constitution, are of no use to the Dassanech.

Law requires structures

It is no surprise to Dirk Hanschel, Fellow at the Max Planck Institute for Social Anthropology and constitutional and international law professor at the University of Halle, that there is a gap between having a right and being able to enforce it. As head of the group Environmental Rights in Cultural Context, he supervises the field research in Mongolia and Ethiopia. "Legal environmental protection does not mean that the legislator simply sets standards and hopes that they will be as fair as possible to all groups and individuals within the population. Our field studies show that, in many cases, some basic material and institutional conditions must be established before such rights can be effective." Hanschel sees major discrepancies between the great promise of new environmental rights and the realities in some areas acutely affected by environmental degradation. "Constitutional promises often remain largely theoretical, and the actual needs of people particularly affected by environmental degradation are not sufficiently recognized," the scholar says.

That is why his team of lawyers and anthropologists chose several locations in the Global South where severe environmental impacts can be observed. They spent several months investigating how the people react to the impacts, what forms of protest they engage in, how compensation is attempted, and what function the law fulfills there. Using ethnographic methods, the researchers were able to gain deeper insights into the issues and to discover opinions, behaviors, and social rules. This allows them to clarify whether environmental rights play a role in areas where people seek protection from environmental damage and those perpetrating it – even protection from the actions of their own State. In short: do these rights serve the people or do they rather lend themselves to create positive perceptions in the international community, among investors, or potential donors?

"In times when environmental protection is also keeping courts around the world busy, it is particularly important to take a close look at the circumstances in which the law is made, and how it is applied in practice," Hanschel says. A related project funded by the Volkswagen Foundation is taking him to Ecuador at the beginning of the year, where courts and the constitution have created a new form of environmental standards.

Ecuador not only grants rights to those affected by planned mining or forest clearance projects, but also to nature itself, known as Pacha Mama or Mother Earth. In this context, nature is somewhat analogous to the legal

Export through the desert: Convoys of trucks like these transport coal to neighboring China and cut up vital pastureland in Mongolia.

PHOTO: REUTERS/B. RENTSENDORJ

construct of a company which finds its own rights infringed upon and can therefore take legal action. Humans represent the concerns of nature in court on a trustee-like basis.

In the case of Los Cedros, a cloud forest not very far from the capital, the constitutional court has used the rights of nature to affirm the legal personality of the forest. The aim is to provide people being adversely affected by mining activities an additional level of protection to their human rights. In Colombia, by contrast, there is no mention of the legal personality of nature in the constitution. Judges nevertheless granted a river its own rights. "In the case of the Rio Atrato, the Supreme Court in Colombia ruled that the State had to carry out concrete protective measures and designated the State and 'the ethnic communities living in the Atrato basin' as *guardianes* (guardians) of the river," Annette Mehlhorn, member of the research group and post-doctoral researcher at the Institute, reports. Meanwhile, numerous rivers around the world have been recognized as legal subjects: for example, the Colombian section of the Amazon, Rio Cauca, or Rio Magdalena. In New Zealand, the Whanganui River was granted legal entity status in 2017 following a treaty between Maori and the government. Likewise, the Turag River in Bangladesh and the ecosystem in Tamaqua Borough in Pennsylvania, USA are considered legal subjects.

"These many judgments show that the idea of the rights of nature is gaining popularity – also, or perhaps especially, among judges. But that alone is not a 'victory' against environmental destruction or for local communities," Mehlhorn explains. "The precise implications of specific formulations of the rights of nature and their respective effects must be carefully examined." The function of the rights of nature must also be analyzed. What goals are Indigenous groups pursuing when they oppose new mining licenses? Can the Pacha Mama concept be transferred to other regions and communities? After all, there are many different conceptions of nature and Mother Earth. Anthropologists are keenly aware that one-size-fits-all solutions rarely work.

"Environmental rights are an important new tool that can achieve a lot. But at the same time, their impact should not be overestimated," Dirk Hanschel says. "Human rights to a healthy environment depend on their concrete value for people being affected by environmental degradation. And it is difficult to think of nature's own rights without people – whose interests are many and varied." ←

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PHOTO: STEPHEN MAHONY

Secret inhabitants of the outback: Frogs of the genus *Neobatrachus* only come out at night – and then only after heavy rain. The species shown here, *Neobatrachus sudellae*, has an unusual genetic feature: a quadruple set of chromosomes.

Max Planck researchers work with partners in more than 120 countries. Here they write about their personal experiences and impressions. Jozefien Van de Velde from the Max Planck Institute for Plant Breeding Research in Cologne traveled to Australia for two months in search of frogs in the outback. This was no easy task, as her study subjects are nocturnal, hide underground in dry conditions, and only emerge after heavy rain.

The ways in which animals adapt to their environment in order to survive have always fascinated me. For my doctoral thesis, I am researching frogs of the genus *Neobatrachus*, which are found in the arid regions of Australia. To survive periods of drought, they burrow up to one meter underground and surround themselves with a kind of cocoon that protects them from drying out. This allows them to survive for several years if necessary; they only come to the surface to reproduce once there has been sufficient rainfall.

Interestingly, three of the nine known *Neobatrachus* species are polyploid – each of their cells contains four sets of chromosomes. Most animals, including humans, are diploid. In diploid organisms, each chromosome is present in duplicate, once as a maternal copy and once as a paternal copy. Polyploid species often exhibit different characteristics from their diploid relatives. For example, some amphibians with "additional" chromosomes are less sensitive to harsh climates and drought and have therefore been able to colonize mountain or desert regions.

In general, polyploidy is common in plants, which is why my frog project is based at the Max Planck Institute for Plant Breeding Research. I am particularly interested in universal molecular mechanisms: how do the many chromosomes within the cell nucleus coordinate? This coordination is crucial for cell division, during which the genetic material has to be precisely distributed to the daughter cells. To find out which genes play a role in this process, I am comparing diploid and polyploid *Neobatrachus* species.

Our Max Planck research group is collaborating with the Western Australian Museum in Perth and the Southern Australian Museum in Adelaide. Both museums store frozen *Neobatrachus* tissue samples from which I was allowed to extract DNA; I also searched for frogs in the field. In Australia, you are required to take a first aid course to obtain the necessary authorization from the nature conservation authority to catch frogs. After this course, you are well equipped for conducting fieldwork in the outback: for example, the course teaches you how to distinguish between poisonous and non-poisonous spiders and what to do in an emergency after a snake bite. There were many Australians on the course who had been hired as miners.

POST FROM

PERTH, AUSTRALIA

In the field, I worked with Paul Doughty, Head of the Herpetology Department at the museum in Perth. When planning our excursions, we consulted a weather app to ascertain where rain was likely in the foreseeable future, as well as a nature app that reports where various frog species have been sighted. Once we had a location for "our" frogs, we got into Paul's old Subaru and set off. Australia is an enormous country; sometimes we spent the entire day driving. Luckily, we never got bored: Paul knew just as much about his research as he did about his favorite rock bands. In between chatting and driving, we often stopped at the gas station for some instant noodles. Apart from that, I liked to sleep a little on our road trips. Because my research subjects are nocturnal, I had to be fresh in the evening!

A good sense of hearing is required when searching for desert frogs at night. Paul is very skilled at recognizing amphibians by their call. He can even identify individual species when many are calling at the same time. Once he had the right voice in his ear, we set off and searched every little puddle with our headlamps. Thankfully, we found what we were looking for, and I now have enough DNA samples for my analyses. After our forays, I often didn't fall into bed until dawn, by which time I was absolutely exhausted. We mostly spent the night on farms or in hostels that provide beds for seasonal workers. This proved an excellent opportunity to meet and socialize with people from all over the world.

As it was my first time in Australia, I naturally had a look at other representatives of the Australian fauna besides frogs. Quokkas, for example – small marsupials that can be observed on Rottnest Island near Perth. Because they have no natural predators there, they are very curious and trusting. Their facial expressions are their most striking features: they seem to be smiling all the time, so just looking at them puts you in a good mood!

PHOTO: PRIVATE

Jozefien Van de Velde

26, is just as enthusiastic about the whimsical appearance of "her" frogs as she is about their way of life and genetics. Van de Velde comes from Belgium and studied Biotechnology at the University of Ghent. She is currently completing her doctorate at the Max Planck Institute for Plant Breeding Research in Cologne as part of one of the 68 International Max Planck Research Schools.

FIVE QUESTIONS

ABOUT TIPPING POINTS AND CLIMATE ANXIETY

WITH JOCHEM MAROTZKE

Mr. Marotzke, you research the Atlantic overturning circulation. The Gulf Stream is part of this phenomenon and is also driven by the salinity of the water. A recent study concluded that this warm-water heating system for Europe could soon collapse because melting Greenland ice is diluting the ocean. Is the concern that this climate tipping point will be irreversibly exceeded justified?

JOCHEM MAROTZKE: The aforementioned study assumes a very simplified physical relationship, and it is not reliable as a prediction. You really have to draw a sophisticated picture, both here and for other tipping points. The image of a tipping point that people often have in mind is something that topples over and can't rise up again. However, for many of the tipping points that are being discussed, there is still a great deal of uncertainty as to whether they will actually occur.

The public presentation of statistical uncertainties can cause confusion. How do you deal with this?

I admired how Mr. Drosten communicated during the pandemic. Science is complex and rarely black or white, so I prefer to explain how things connect. However, I am aware that I have to be careful when it comes to how I present research findings. That's why, in public lectures, I always outline first what we know for sure, namely that the observed warming is due to humans. Period. We also expect more extreme weather. But it's quite another thing to be absolutely certain in individual cases, such as with tipping points.

How confident do you have to be to take action? There is a consensus in climate research that we have a serious problem.

It certainly isn't wise to wait until you are absolutely sure. How decisions are made under uncertainty is a political question. Of course, you have to trust the climate models. Heavy rainfall and droughts will increase. But when in doubt, it's counter to the scientific code to assume, even for a good cause, that you know more than you really do.

Science and politics often have different values and goals. And the public has expectations of both sides.

Politicians must factor in much more than just scientific knowledge. Rightly so. Good politics ensures a balance of interests in a democracy and has a leadership role, which I appreciate very much. If politics were as strictly consistent as science has to be, it would be incapable of action. However, I hope that politicians will use knowledge more systematically and that there will be more time for discourse. For this to work, both sides must learn to understand each other better.

In the movie Don't Look Up, an asteroid is racing towards Earth. Scientists are doing everything they can to ensure that this threat is taken seriously. Politicians and civil society, however, reassure everyone, "just don't look up!" How do you present unpleasant facts in such a way that society remains capable of taking action?

A positive example: during the pandemic, the authorities reacted decisively and effectively at the beginning; later, there was a switch from crisis mode to risk-management mode. However, climate change is not a crisis that is passing by; it's here to stay. Crisis mode cannot be sustained for long. At the same time, of course, one would have to act much more quickly and decisively to achieve defined climate goals. This is a fine line, also with respect to communication. Do I want to alert people, call for immediate action, or provide the most accurate knowledge possible as a basis for decision-making? The fear that we will exceed 1.5 degrees and then everything will collapse is certainly scientifically unfounded and paralyzing.

Interview: Tobias Beuchert

Jochem Marotzke is Director at the Max Planck Institute for Meteorology.

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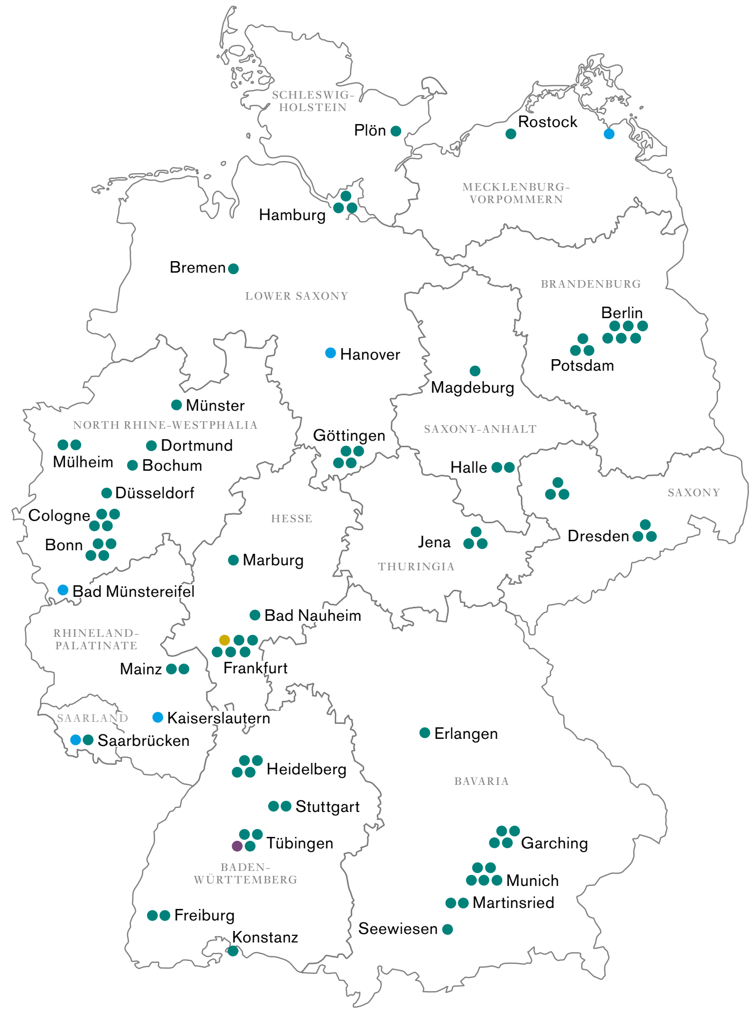

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In internal news: This is the final edition of MaxPlanckResearch that will feature the contribution of our colleague Mechthild Zimmermann, who died far too soon early in December 2023. She was a member of the science editorial team from 2014 and covered a huge range of topics – from legal and socio-political to scientific-historical and art-historical contributions. We will miss her professional competence, her journalistic flair, her sense of style, and her enthusiasm for working in the editorial office. We also feel her loss deeply on a personal level.

The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. (Max Planck Society) comprises 84 institutes and research facilities with approx. 24,000 employees, including some 7000 employed scientists. In 2022, its basic funding by the Federal Government and the Federal States amounted to EUR 2.0 billion. Max Planck Institutes conduct basic research in the natural sciences and the humanities. The Max Planck Society is a nonprofit organization registered under private law as an incorporated association. Its central decision-making body is the Senate, which includes members from the world of politics, the scientific community, and the professional public.

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