02 | 2023

MAX PLANCK
Research

75 YEARS OF THE MAX PLANCK SOCIETY
Monitoring the Earth's Vital Signs

PSYCHOLOGY
Artificial Intelligence on the Couch

LEGAL STUDIES
When States Sink

WORLD SHAKING

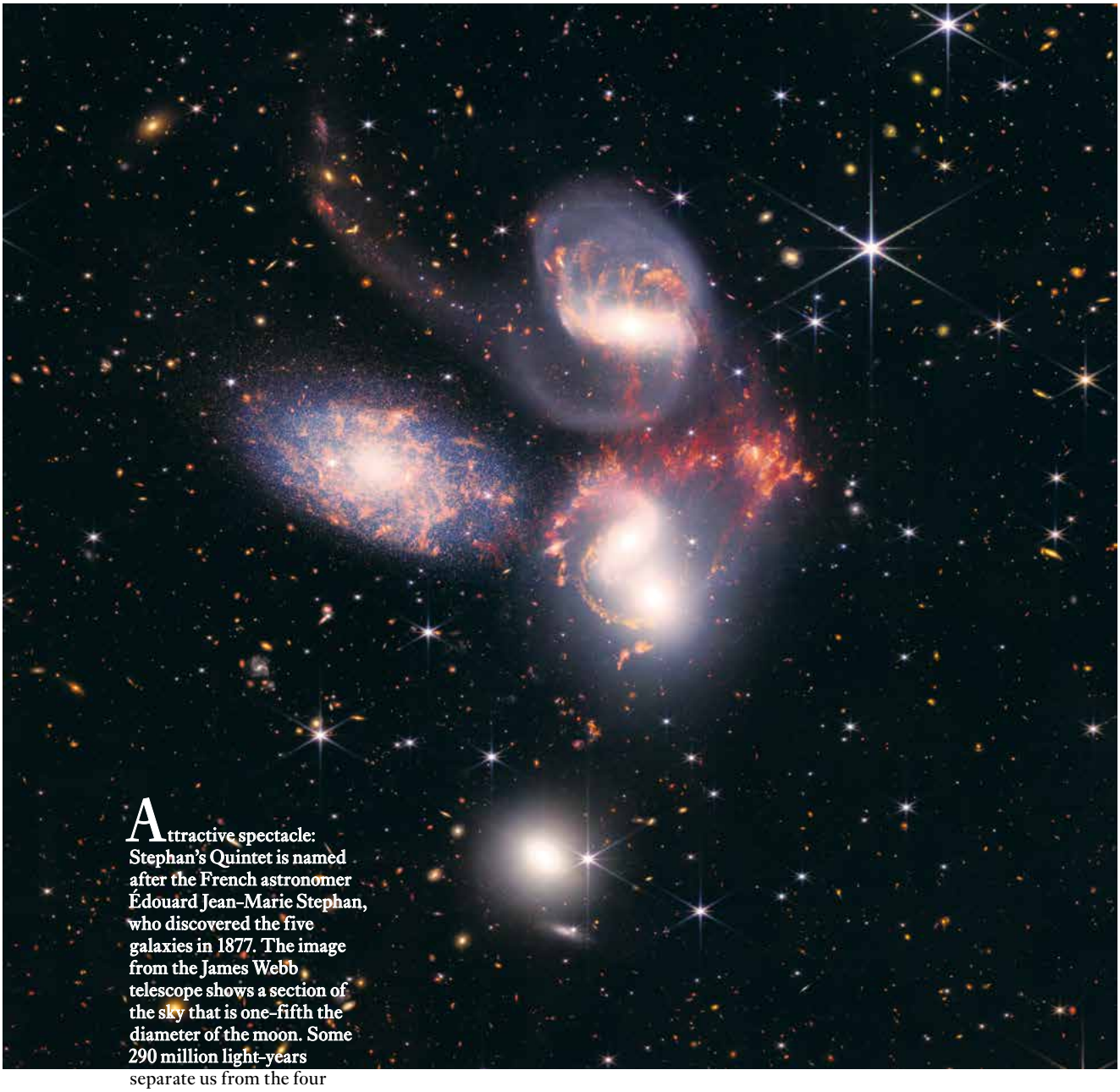


IMAGE: NASA, ESA, CSA, AND STSCI

2

Attractive spectacle: Stephan's Quintet is named after the French astronomer Édouard Jean-Marie Stephan, who discovered the five galaxies in 1877. The image from the James Webb telescope shows a section of the sky that is one-fifth the diameter of the moon. Some 290 million light-years separate us from the four galaxies stacked to the right of the image's center. Their luminous arcs indicate a dynamic interaction due to their mutual attraction. The galaxy that is visible left of center is in the same section of the sky, but it is only about 40 million light-years away from us.

EDITORIAL

Dear Reader,

The view of the night sky has always given us a sense of wonder; since ancient times, we have also used it as a way to tell time and as a navigational aid. Above all, however, it determines our view of the world and of ourselves. Thanks to astronomical discoveries, the location of humankind in the cosmos has increasingly shifted from the center to the edge. It is now evident that even our solar system only has a peripheral existence within the Milky Way: there are countless planets like ours in the universe – indeed, there are countless galaxies.

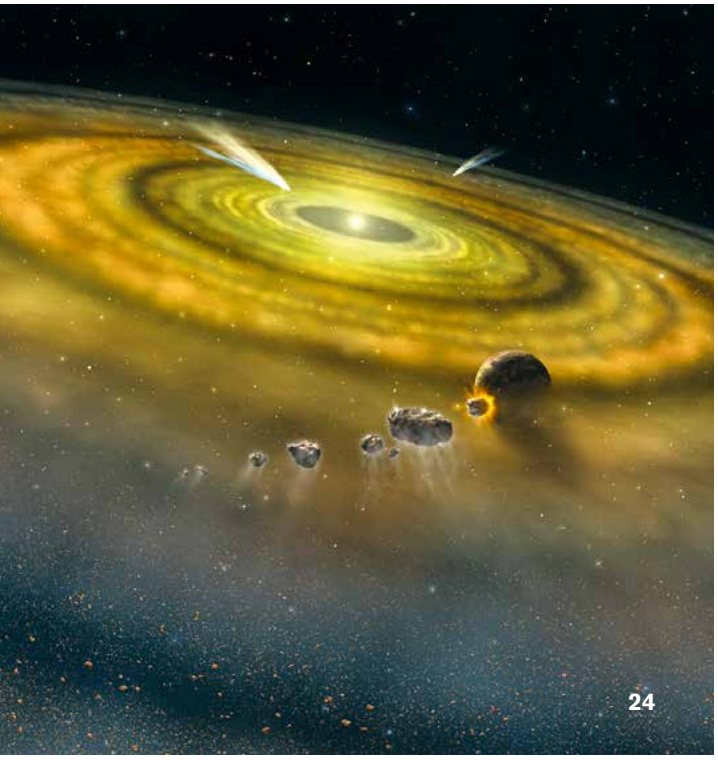
Among these, even our solar system still poses many unanswered questions. For instance, scientists are looking into the specifics of how the Earth and nearby planets were created. Where did the building material come from? Why did they form at different rates? And why did the Earth, in particular, have the conditions necessary to support the development of life?

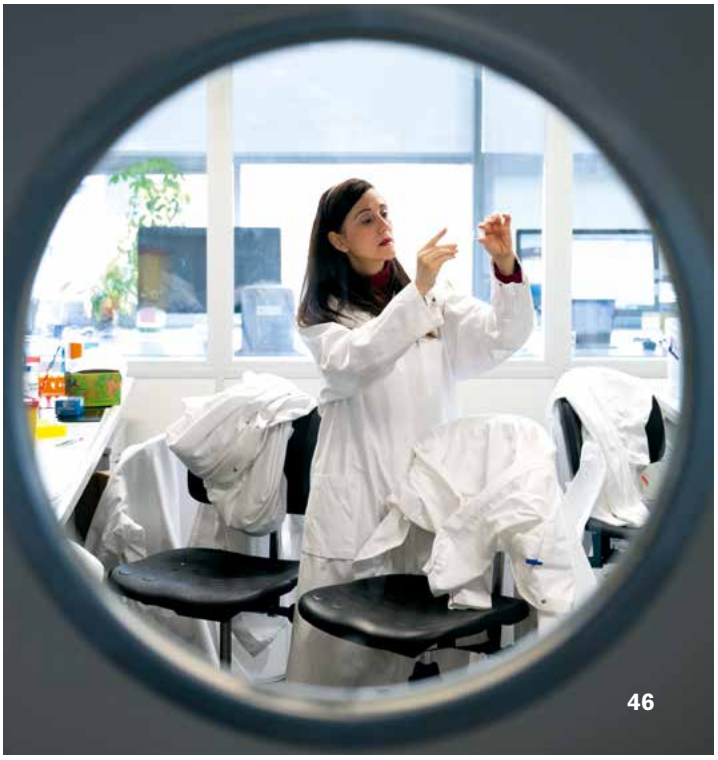
While these questions can be investigated in our immediate vicinity (on a cosmic scale) many other targets of astronomical research are located in far-off galaxies; they astound with their barely conceivable dimensions and characteristics, such as black holes with millions of times the mass of the Sun. Sometimes, two black holes can even be found orbiting each other in a single galaxy. Modern telescopes make it possible to get a picture of these systems and the processes that take place within them.

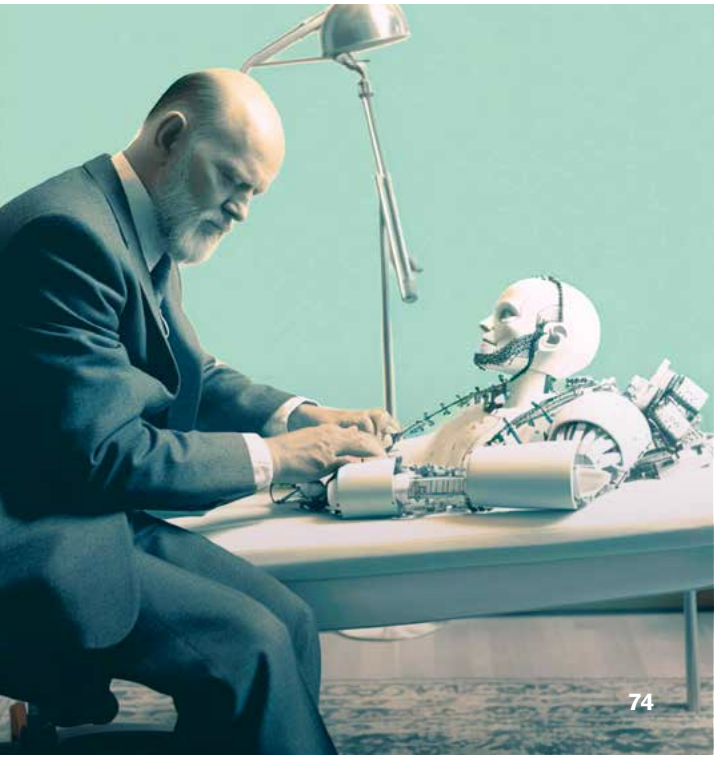
Even in places where you might assume more existential issues prevail – such as Madagascar, a country with one of the lowest gross domestic products in the world – fascination with the cosmos still takes hold. Since the prospect of serving as the location for the antennas of a large international telescope has arisen, many locals have developed a passion for astronomy. This passion could encourage young people to study science or technology, which in turn could contribute to the country's development.

It seems then that astronomy holds many surprises, and not just in space. In the spirit of this, we wish you an exciting read!

Your editorial team







IMAGES: NASA/FUSE/LYNETTE COOK (TOP LEFT); SVEN DÖRING FOR MPG (TOP RIGHT); MIDJOURNEY AI IMAGE | GESINE BORN | BILDERINSTITUT (BOTTOM LEFT); MARIO TAMA/GETTY IMAGES (BOTTOM RIGHT).

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Planets were formed by the agglomeration of dust into solid bodies.

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Meritxell Huch does not just skip lunch for research.

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Psychological tasks expose the weaknesses of ChatGPT.

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Climate change could soon cause island states to sink into the sea.

CONTENT

TWO AND A HALF MILES UNDER THE SEA

With a depth of roughly 4,000 meters, the Arctic Ocean is far deeper than Jules Verne once imagined. And it is an extreme habitat that even today we know little about, one that is cold, dark, and covered with ice, with a floor almost entirely lacking in organic material to serve as a substrate for microorganisms. Could life possibly exist here?

Deep sea islands of life are known to form around what are called black smokers: hydrothermal vents caused by underwater volcanoes at sites where tectonic plates collide. These vents are abundant in extremely hot, oxygen-free water, which dissolves large quantities of iron, manganese, and copper, as well as sulfur compounds, hydrogen, and methane. When the hot water mixes with the surrounding cold, oxygen-rich seawater, the minerals precipitate, creating gray-black columns of "smoke." Hence the name black smoker.

Many different biotopes can form on the smokers, including species that only exist here. Bacteria use sulfur and hydrogen in particular as an energy source, which forms the basis for a biodiverse food chain: tube worms, crabs, mussels, and even certain fish.

For a long time, researchers were convinced that the Arctic Sea had neither volcanoes, nor hydrothermal sources. But in the early 2000s they were discovered on the Gakkel Ridge, a mid-oceanic ridge stretching from Greenland to Siberia. The black smoker Enceladus, shown here, is located in the Aurora Vent Field on the westernmost peak of the Gakkel Ridge. During an expedition aboard the research vessel Polarstern, a group from the Max Planck Institute for Marine Microbiology conducted an in-depth study of bacteria of the genus *Sulfurimonas*. The study uncovered a new species whose genome contains clues that might help explain the ecological connection between this highly specialized habitat and the open ocean.

ON LOCATION

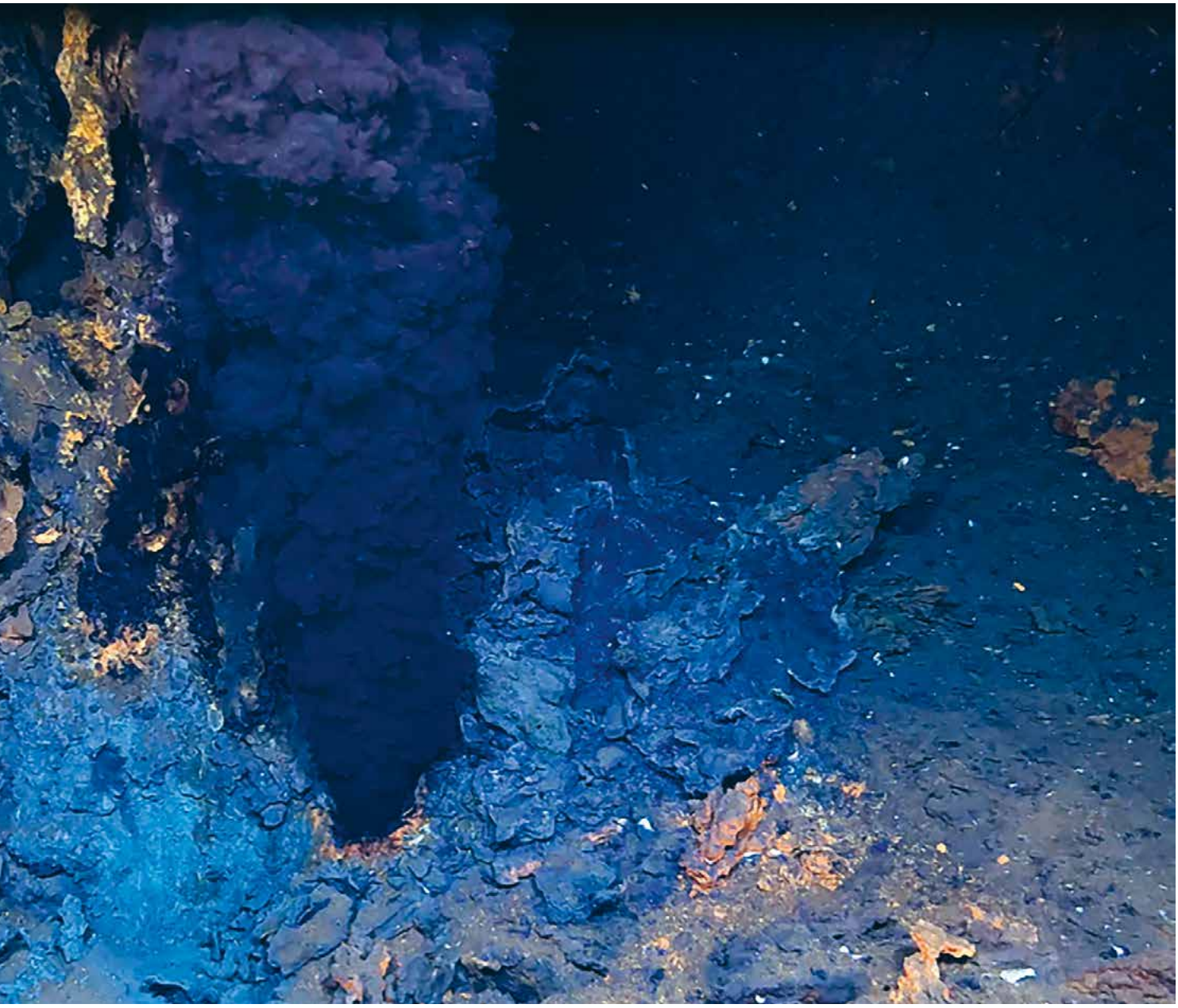


PHOTO: HACON CRUISE 2021, REV OCEAN

PROMOTING EXCELLENCE IN AFRICA

The Max Planck Society and the Alexander von Humboldt Foundation for Africa are planning three Max Planck-Humboldt Research Units, which entails the search for three Research Group Leaders at African institutions. The Max Planck Society will grant the leaders research resources of 150,000 euros per year for five years. The research groups will cooperate with a Max Planck Institute of their choice and jointly train young scientists. "We are not funding a research topic, but rather supporting young talent who will bring their own approaches and topics," said former Max Planck President Martin Stratmann at the opening of the program, explaining the main features of the model that the Max Planck Society has already been using for some time on other continents. The goal is for very good researchers, who will become more visible by leading these research groups, to attract talented young researchers. This creates positive feedback loops – and thus nuclei for scientific excellence in Africa.

www.mpg.de/20343908 (in German)

PHOTO: ILJA C. HENDEL / SCIENCE IN DIALOGUE

A LOOK INTO OUTER SPACE

This time, the "MS Wissenschaft" has the universe on board and will be traveling on rivers and canals in Germany and Austria until the end of September 2023.

With the motto "Our Universe," Science Year 2023 is an opportunity for a number of Max Planck Institutes to present themselves and their research to the public. Two exhibitions are traveling through Germany this year: the "MS Wissenschaft," a floating science center, and the Universe on Tour exhibition, a mobile planetarium complete with exhibition tent. Both will be making stops in around 40 cities across the country until the fall. The exhibitions are diverse: in the mobile planetarium, visitors can immerse themselves in the universe via live shows projected in 360 degrees. Local astronomical research institutions, including Max Planck Institutes, will report on their current research following each show. On the "MS Wissenschaft," 30 interactive exhibits invite visitors to discover outer space.

www.mpg.de/20280458 (in German)

HONORED*

PATRICK CRAMER

PHOTO: DAVID AUSSERHOFER/MPG

The Director at the Max Planck Institute for Multidisciplinary Sciences and new President of the Max Planck Society has been honored with the Shaw Prize. Patrick Cramer shares the top distinction with Eva Nogales from the University of California, Berkeley. Both have contributed significantly to the structural biological elucidation of gene transcription, one of the fundamental processes of life. The Shaw Prize is awarded annually in the life sciences, mathematics, and astronomy and each award is presented with one million US dollars in prize money.

ERIN SCHUMAN

PHOTO: G. LAURENT

With the Brain Prize 2023, the Lundbeck Foundation is honoring the pioneering work of Erin Schuman, Director at the Max Planck Institute for Brain Research in Frankfurt, as well as Christine Holt, University of Cambridge, and Michael Greenberg, Harvard Medical School. The researchers have revolutionized our understanding of how neurons regulate the production of the brain's many thousands of proteins. The Brain Prize is the world's most important neuroscience research prize, with prize money of around 1.3 million euros.

IN BRIEF

PHOTO: PICTURE ALLIANCE / SWEN PFÖRTNER

Patrick Cramer (left), the new President of the Max Planck Society, symbolically took over from Martin Stratmann (right) by donning the chain of office.

PATRICK CRAMER IS MAX PLANCK PRESIDENT

At the Annual General Meeting of the Max Planck Society in Göttingen on June 22, 2023, Patrick Cramer took over the presidency from Martin Stratmann. Cramer paid tribute to his predecessor's achievements in fostering female researchers and up-and-coming scientists, among other things. He said that Stratmann had given Germany and Europe fresh perspectives with projects such as Cyber Valley, the Max Planck Schools, the Dioscuri Excellence Programme for Eastern Europe, and the Agency for Leap Innovations (Sprind) proposal. Cramer also outlined three fields of action for the coming years in his inaugural address. One of his key ambitions is to attract employees to science and the science-support sector and nurture them once there. He emphasized that paying attention to and appreciating people in all their diversity is crucial in this regard: "Everyone who shares our values is welcome," Cramer stated. Another area of focus is the ongoing development of Max Planck Society's international strategy under challenging circumstances. He said that it is important to look for new partners in Asia, Africa, and Latin America and to meet them on an even footing. And the third major field, according to the new President, is the responsibility of research to carry out its work in a way that is as ethical and environmentally friendly as possible, and to make the findings obtained freely accessible. Cramer also asserted that science needs to be more involved in societal debates.

www.mpg.de/20499257

MILLIONS RAISED FOR PROXIMA FUSION

Proxima Fusion is the first spin-off from the Max Planck Institute for Plasma Physics. The start-up was founded by former scientists and engineers from the Max Planck Institute as well as MIT and Google-X. The team's goal is to create a high-performance stellarator by the 2030s. A high-performance stellarator is a fusion device that harvests energy from the fusion of atomic nuclei by trapping a high-energy ionized gas, called plasma, in a ring-shaped magnetic field. Proxima Fusion's work builds on the Max Planck Institute for Plasma Physics' Wendelstein 7-X stellarator, by far the most advanced device of its kind. The start-up has now completed its pre-seed fundraising of 7 million euros. This will make it possible for the team to take the next steps towards the creation of a fusion power plant.

www.mpg.de/20380035 (in German)

BLOOD PRESSURE AND THE PSYCHE

Psychological factors can complicate the treatment of hypertension. As a large-scale study by the Max Planck Institute for Human Cognitive and Brain Sciences has shown, morbidly high blood pressure is often associated with symptoms of depression. This is consistent with observations from clinical practice, which note that sufferers of the condition feel tired and fatigued and do not take their antihypertensive medication because it also affects their mood. On the other hand, the study also shows that people with only specific elevated sub-values feel better overall and are more emotionally stable. This is because higher blood pressure also lowers the threshold for pain, both physically and mentally. Both phenomena complicate hypertension therapy. As a result, the researchers are calling for future treatments to take better account of the interactions between psychological and physical factors.

www.mpg.de/20162308 (in German)

On the safe side: when great apes have to choose between a transparent cup containing a grape and an opaque cup containing a possibly larger reward, most of them choose what they can see.

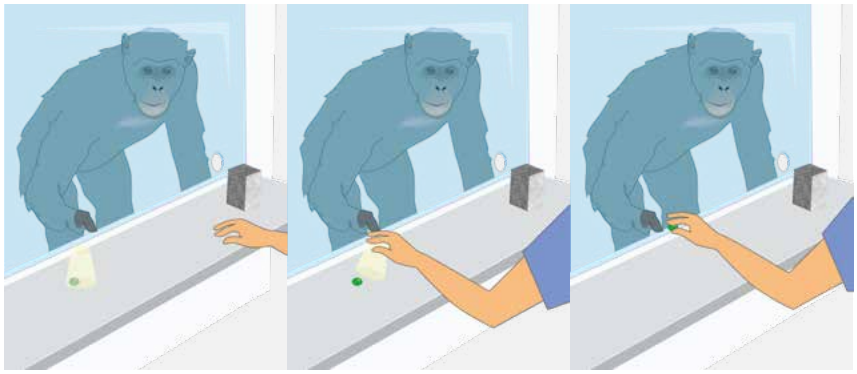


IMAGE: SÁNCHEZ-AMARO, ROSSANO, CC-BY 4.0

CURIOSITY PUT TO THE TEST

Humans are curious and like to try out unknown things. But is the same true of great apes? In an experiment, two researchers from the University of California, San Diego and the Max Planck Institute for Evolutionary Anthropology investigated this question. They gave adult chimpanzees, gorillas, bonobos, and orangutans two upside-down plastic cups to choose from. One cup was transparent and contained a small reward, while a larger reward awaited them in the opaque one. The researchers set a similar task for children between the ages of three and five. On average, children chose the unknown option over the safe reward. In two versions of the study, 85 and 77 percent of children chose the opaque cup at least once compared with 24 percent of the apes. However, once the apes got to see the hidden rewards, they learned to explore the uncertain option in subsequent trials as well.

www.mpg.de/20388599

SCENT PREVENTS CANNIBALISM

When insect densities are high, migratory locusts can transition from solitary to swarming behavior. Cannibalism has long been thought to play a role in the swarming behavior of orthoptera. For example, the threat of cannibalism could cause swarms that frequently wipe out entire harvests in Africa to keep moving on because the animals are essentially fleeing from other members of their own species. Researchers at the Max Planck Institute for Chemical Ecology in Jena have now confirmed this assumption: they discovered that cannibalism among European migratory locusts (Locusta migratoria) increases with the number of swarming animals that are kept in a cage. Of all the scents that orthoptera emit in a swarm, one in particular stands out: phenylacetonitrile. This substance protects its carriers from other orthoptera species because it is the only one with a deterrent effect on them. The team discovered the phenylacetonitrile scent receptor on the surface of olfactory sensory cells after conducting tests on 49 olfactory receptors. The researchers now hope that the locusts will behave more cannibalistically if the scent receptor is inhibited. This might make it possible to dissolve the swarms.

www.mpg.de/20278575

CREATION AIDED BY METEORITES

Iron meteorites that fell to Earth in its early days may have played a central role in the origin of life: fine iron particles rained down when the celestial bodies entered the Earth's atmosphere. In the carbon dioxide-rich urate atmosphere, the metal particles may have catalyzed the creation of the first organic molecules, such as hydrocarbons, acetaldehyde, or formaldehyde. The chemical industry also uses iron as a catalyst for such substances. The substances could then have formed amino acids and nucleobases, which are necessary building blocks of proteins and DNA, respectively, enabling the emergence of life. Researchers at the Max Planck Institute for Astronomy and Ludwig Maximilian University in Munich have now confirmed these assumptions in the laboratory. In a pressure chamber, they generated a mixture of CO_2 and hydrogen gas and used it to simulate the Earth's atmosphere at that time. This consisted mainly of CO_2 and hydrogen and, because of the large quantity of gas, could have had an air pressure many times higher than that of today. As anticipated, the gas mixture reacted to produce a number of complex organic compounds when it came into contact with iron dust, which is very similar to the abrasion of incoming meteorites.

www.mpg.de/20330250

PHOTO: O. TRAPP

A small fragment of the Campo del Cielo iron meteorite. Upon entering the Earth's atmosphere, the surface melted, and the smooth structures formed.

PILLS MADE TO MEASURE

In the future, tablets could be produced in shapes reminiscent of design objects. And this would not just be an aesthetic gimmick; it would also be used to release medical agents into the body in a controlled way. A team from the University of California, Davis and the Max Planck Institute for Informatics in Saarbrücken starts by identifying the form that a pill must take for the active ingredient to be released over a desired amount of time and for the ideal substance level to be reached in the body. The calculated structures sometimes resemble salt crystals, sometimes diatoms, and sometimes even extravagant design objects. It is easy for 3D printers to produce such fancy tablets. However, the calculation technique can also be altered to only produce shapes that can be made with typical pharmaceutical mass production techniques. In contrast to an alternative approach, in which pills are made of various carrier materials with various active ingredient concentrations, it would be much more practical to control the release of an active ingredient solely through a tablet's shape.

www.mpg.de/20687249

PHOTO: MPI-INF

In these pills from the 3D printer, the active ingredient is released over a desired period of time thanks to the fancy shapes.

PHOTO: ADOBESTOCK

Even during the long period of rest in winter, a brown bear is protected from thrombosis.

PREJUDICE FOSTERS CORRUPTION

People very often base their behavior on what they expect from others. However, this social competence, which is positive in itself, also has downsides – for example, in the case of corruption. In a representative study of more than 5,500 people from 18 countries, a research team from the Max Planck Institute for Human Development and the Universities of Cologne and Amsterdam examined the role of prejudice in bribery. In an online game, participants were asked to decide whether or not to offer a bribe to their counterpart. The other party could accept or reject the money. The players interacted with both compatriots and participants from the other nations. The result: players from countries perceived to be corrupt were offered bribes more often than average. However, they were less likely to accept them than their peers expected. At the same time, the players underestimated how often participants from countries with a reputation for integrity accepted the money. In contrast, the nation from which those offering bribes came was of secondary importance. To reduce international corruption, the research team suggests dispelling stereotypes regarding a country's propensity for corruption.

www.mpg.de/20246730

GETTING THROUGH WINTER WITHOUT THROMBOSIS

During their months-long hibernation, bears hardly move at all. If healthy people were to lie in bed for so long, they could easily suffer thrombosis. A research team has now discovered a mechanism that prevents the formation of these blood clots. Researchers at the Ludwig Maximilian University Hospital in Munich analyzed blood samples from brown bears in Sweden. Their findings demonstrate that during hibernation, platelets involved in blood clotting interact significantly less with immune system inflammatory cells than they do when bears are awake. The researchers demonstrated the same phenomenon in paraplegic patients. The deficiency of a protein called HSP47 is apparently responsible for this. Mass spectrometry of proteins, which the Max Planck Institute of Biochemistry played a key role in developing, was used to measure the significant decrease in HSP47 production in bears during hibernation. Additionally, the team found that individuals who are immobile for extended periods of time due to illness have significantly lower levels of the protein. The researchers at the University Hospital now want to search for suitable molecules that switch off HSP47 and thus reduce the risk of thrombosis.

www.mpg.de/20166288

40%

is the increased efficiency achieved when titanium is added to an alloy made from Niobium, Iron and Antimony, which converts heat into electricity.

MORE ELECTRICITY FROM WASTE HEAT

If we still cannot live without fossil fuels, we should at least use them as effectively as possible. Thermoelectric materials could help in this endeavor: they can generate electricity from the waste heat that is inevitably released when coal, oil, and gas are burned. There are different numbers of high-energy electrons present at the two ends of, for example, a wire made of niobium, iron, and antimony. This can be exploited to generate an electrical voltage. So far, however, thermoelectric materials have not been efficient enough for use in technical applications. By adding titanium to the material, researchers at the Max-Planck-Institut für Eisenforschung have now increased the efficiency of a promising thermoelectric made of niobium, iron, and antimony by up to 40 percent. Like all metallic materials, the metal accumulates at the boundaries between the tiny crystal grains that make up the material. This change in the microstructure means that a higher stress can be generated with the material at the same temperature difference. However, the increase in efficiency is only a first step; for practical use, thermoelectrics still have to become even more efficient.

www.mpg.de/19984293

FOREIGN SMOKE IN THE AMAZON

Up to two-thirds of the soot over the central Amazon rainforest comes from Africa. This is the conclusion reached by a team led by the Max Planck Institute for Chemistry in Mainz and the University of São Paulo. It was already known that smoke was flowing from Africa to South America. How much, however, was unclear until now. Researchers have now found a way to distinguish the sources of the soot particles based on the particles' properties. Using this method, they discovered that soot particles from Africa are significantly larger than those from the Amazon and contain less organic material. This revealed to the international team that bushfires and burning savannahs in northern and southern Africa contribute significantly more to air pollution in central Amazonia than previously thought. The proportion of African smoke is particularly high in the rainy season, when the air in the Amazon is usually very clean. The African soot then sometimes causes the air there to become as dirty as that in a large European city. In the dry season, when a lot of smoke hangs in the air anyway because of numerous natural and man-made fires in the rainforest, the soot from Africa increases the pollution even more. This air pollution not only affects the health of the people living in the Amazon, but also influences the climate: the smoke can cause reduced precipitation and cooling at the earth's surface.

www.mpg.de/20314950

PHOTO: MEINRAD O. ANDREAE, MPI FOR CHEMISTRY

A plume from Africa with a high concentration of soot particles reaches the coast of Brazil.

Fruit and vegetables cut into bite-sized pieces are convenient to eat and motivate children to reach for them if a meal lasts long enough.

PHOTO: ADOBESTOCK

USEFUL SUBSTANCES FROM CO_2

Converting carbon dioxide from fossil fuel combustion into useful substances could reduce the carbon footprint of, for example, the chemical industry. A study by the Max Planck Institute for Terrestrial Microbiology shows how the greenhouse gas can become an industrial recyclable via the intermediate formic acid. The researchers have developed an artificial metabolic pathway that converts the rather inert formic acid into more reactive formaldehyde, which is needed to synthesize many useful substances, such as drugs. To this end, they identified new enzyme variants that catalyze the conversion of formic acid to formaldehyde very efficiently. Genetically modified microorganisms that have been endowed with this metabolic pathway could use the formaldehyde to manufacture products such as insulin or biodiesel in the future.

www.mpg.de/20293586

MORE PALATABLE

Children voluntarily reach for more fruits and vegetables when families take more time to eat. This is the result of a study on evening meal habits with the participation of the Max Planck Institute for Human Development in Berlin. The participating elementary school-aged children ate significantly more fruit and vegetables when they were bite-sized on the table and when they sat there for just ten minutes longer than usual – about half an hour in total. The study also found that longer family meals did not result in children eating more bread or cold cuts. The researchers suspect that bite-sized fruits and vegetables are convenient to eat and therefore particularly tempting.

www.mpg.de/20189732

RECYCLING DURING FASTING

Cells are also familiar with the principle of recycling: their waste disposal system breaks down defective or damaged molecules and extracts energy from them. Until now, it was assumed that the cells primarily control the recycling themselves. However, scientists at the Max Planck Institute for Metabolism Research in Cologne have now found in mice that this process depends heavily on the brain. In their study, the researchers did not feed the animals for four hours. They then studied how a specific group of neurons in the hypothalamus – the brain's hunger center – responded to the short fast. Surprisingly, they found that, during fasting, the brain not only sends signals that stimulate the organism to eat; when energy levels are low, neurons also trigger the release of the hormone corticosterone, which causes cells in the liver to recycle cellular waste. It could be that this newly discovered mechanism in the brain contributes to the positive effects of fasting. ***www.mpg.de/20182361***

A pierced deer tooth from Denisova Cave in southern Siberia. Researchers have extracted ancient human DNA from its surface.

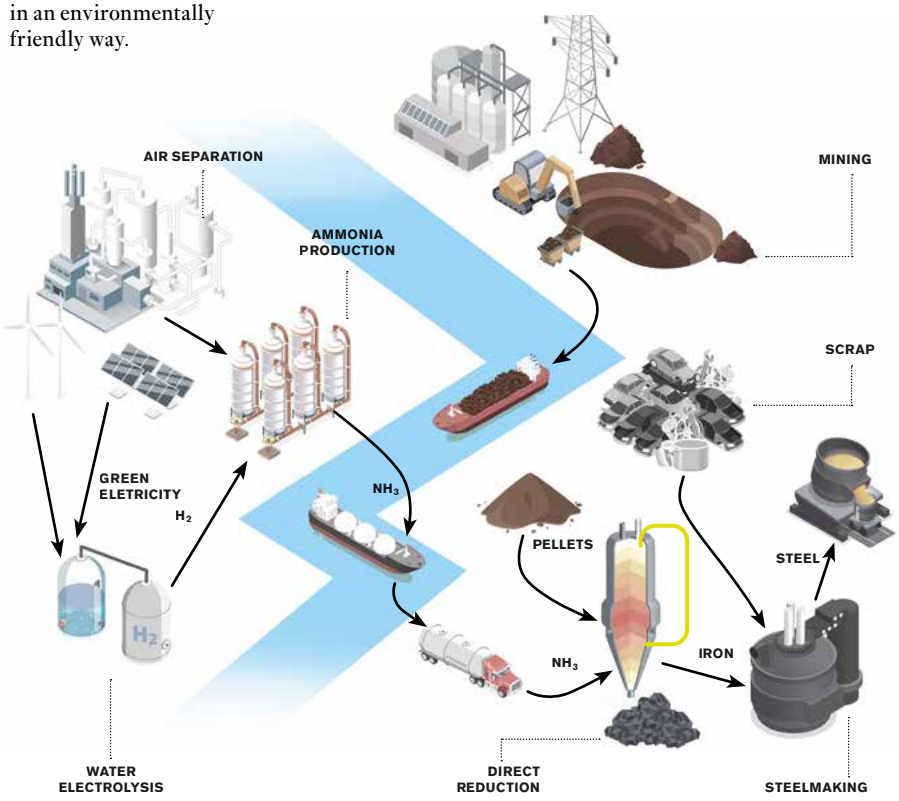
IMAGE: MPI FOR EVOLUTIONARY ANTHROPOLOGY

JEWELRY FROM THE ICE AGE

Objects made of stone, bones, or teeth provide important insights into the way people of the Stone Age lived. Until recently, however, it was mostly impossible to identify the maker or user of such an object. A research team led by the Max Planck Institute for Evolutionary Anthropology in Leipzig has now succeeded in doing so for the first time. The researchers have developed a method that allows them to wash DNA out of old bones and teeth, and even do so without damaging them. Using this method, they reconstructed DNA from a deer tooth pendant found in southern Siberia that is about 20,000 years old. Genetic analysis revealed that the pendant came from a wapiti deer and was made, used, or worn by a woman. This woman shared a genetic ancestry with individuals who lived at the same time in Siberia's easternmost regions. The findings show that even when jewelry and tools are thousands of years old, it is still possible to infer information about their users.

www.mpg.de/20241058

Direct reduction with ammonia made from green hydrogen can turn iron ore into iron in an environmentally friendly way.



GRAPHIC: ISTOCK; GCO BASED ON A TEMPLATE BY MA, Y. ET AL., REDUCING IRON OXIDE WITH AMMONIA: A SUSTAINABLE PATH TO GREEN STEEL. ADV. SCI. 2023 10 2300111

ON THE PATH TO GREEN STEEL WITH AMMONIA

Hydrogen is a beacon of hope for the climate-neutral economy – and this is also true for the steel industry, which accounts for seven percent of CO_2 emissions worldwide. But perhaps the industry should also rely on ammonia to produce green steel, at least in Germany. A team from the Max-Planck-Institut für Eisenforschung in Düsseldorf has shown that ammonia converts iron ore into iron just as well as hydrogen. Ammonia can be synthesized with green hydrogen, which is produced, for instance, in sunny countries. Despite the additional conversion step, this would be worthwhile because ammonia is much easier to transport. It is also necessary to produce hydrogen or ammonia for a climate-neutral economy in other parts of the world because there is unlikely to be enough renewable electricity for this in Germany and other Central European countries – even if the energy supply from wind and sun is expanded as far as possible.

www.mpg.de/20091468

THE YO-YO EFFECT

Many people who have dieted are familiar with the yo-yo effect: after the diet, the lost kilos are quickly put back on. Researchers from the Max Planck Institute for Metabolism Research have now shown in mice that communication between nerve cells in the animals' brains increases during a diet. The nerve cells in the hypothalamus that trigger the feeling of hunger receive stronger signals, so that the mice eat significantly more after the diet and gain weight more quickly. The increased signaling in the hypothalamus leads to a prolonged and excessive sense of hunger. In the long term, these findings could help in the development of drugs aimed at preventing this amplification, thereby assisting in maintaining reduced body weight after dieting.

www.mpg.de/20048019

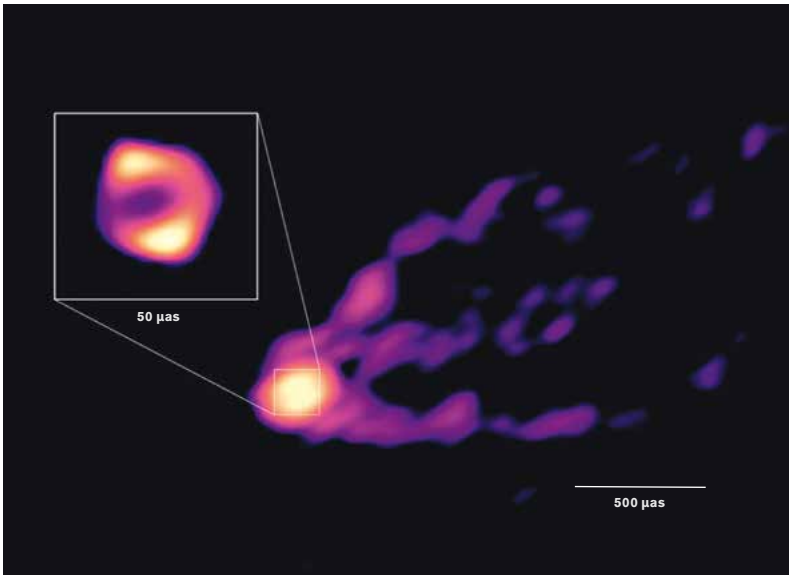


IMAGE: R. LU ET AL., NATURE 2023

Reconstructed image of the jet anchored in the vicinity of the supermassive black hole at the center of the distant galaxy M87. The image shows the ring of light encircling the black hole and the matter being propelled away from the region surrounding the black hole.

THE DIGESTIVE SYSTEM OF THE MASS MONSTER M87

A few years ago, the image of an orange-glowing donut caused a sensation. Scientists had captured the first ever image of the immediate vicinity of the supermassive black hole at the center of the galaxy Messier 87 (M87). This galaxy is known for a jet that channels matter far out of the galaxy, powered by the rotation of the black hole. The precise mechanism by which the jet is anchored in the vicinity of the black hole, and how matter streams into the jet, is not yet fully understood. Astronomers, with the participation of the Max Planck Institute for Radio Astronomy, have now made strides in providing new insights. Utilizing a network of radio telescopes spanning nearly the size of Earth itself, they are using the example of M87 to render visible, for the first time, the matter flows in the extreme center of a galaxy.

www.mpg.de/20220818

A solid catalyst powder in a liquid reaction medium.

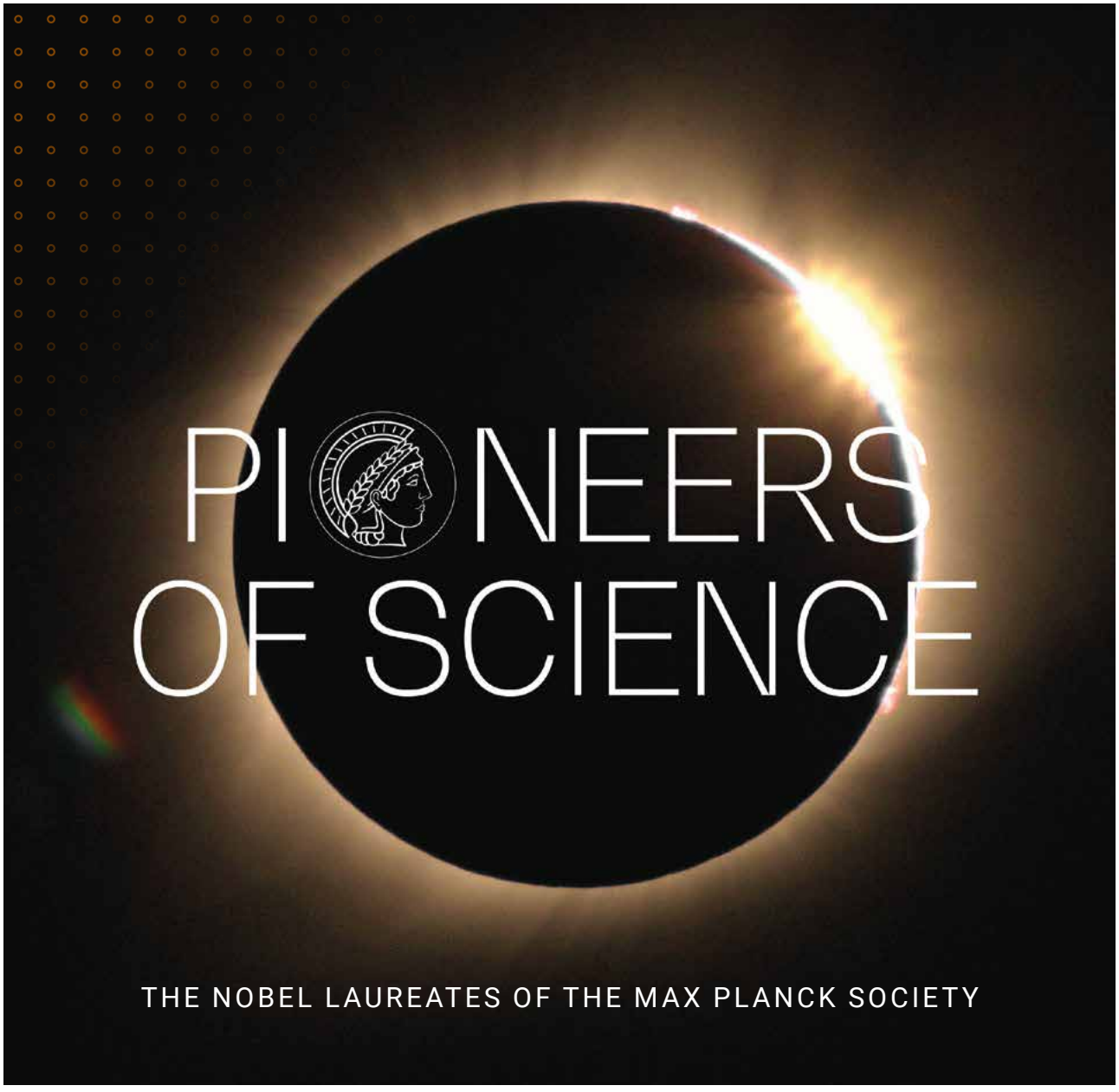
PHOTO: FRANK VINKEN

CATALYSTS OF THE ENERGY TRANSITION

When it comes to the energy transition, there has to be the right chemistry. This enables the storage of electricity generated from wind and solar sources into fuels and fundamental materials for chemical production, and the utilization of CO_2 for this purpose. However, the corresponding chemical compounds can only be produced efficiently with the right catalysts; these are currently still in short supply. In the recently inaugurated Max-Planck-Cardiff Centre on the Fundamentals of Heterogeneous Catalysis (Funcat), three Max Planck Institutes and the Cardiff University have joined forces to pursue new paths in catalyst research. Employing artificial intelligence and Big Data, among other methods, they aim to predict promising catalyst candidates that can enhance chemical reactions and direct them towards the desired products. As a test case for the new approach, the researchers are developing reaction accelerators that convert CO_2 into useful substances. ***www.mpg.de/20002391***

MAX PLANCK
GESELLSCHAFT

75 YEARS



DIGITAL STORY

www.nobel.mpg.de/en

ABOUT THE PROJECT With "Pioneers of Science," the Max Planck Society is showcasing the research of its Nobel Laureates in a comprehensive digital story for the first time. On the occasion of the Max Planck Society's anniversary year in 2023, a selection of topics and laureates from the Digital Story will also be featured in a traveling exhibition at the Science Pavilion, which will visit various cities across Germany.

TRANSIENT YOUTH

When young people migrate without their parents, the most important question for German authorities is: are they minors or young adults? Unaccompanied minors receive support and legal protection, while adults must endure a protracted asylum procedure on their own. Ulrike Bialas has investigated the situation of young refugees. She advocates a more flexible approach to the question of age.

More and more young people are fleeing conflicts, disenfranchisement, and poverty without their families and applying for asylum in Germany. In 2013, 42,000 unaccompanied minors were taken into custody; by 2016, in the wake of the so-called refugee crisis, this number had already doubled. However, many young refugees do not possess identity documents, and some are unaware of their exact age. According to the Federal Office for Migration and Refugees (BAMF), only 40 percent of all asylum seekers are able to provide proof of their identity. Those from Afghanistan, Somalia, and Guinea – among the most common countries of origin for unaccompanied minors – almost never own such documents. As a result, official figures on unaccompanied minors in Germany are only rough estimates.

Yet a date of birth plays a crucial role in determining the legal status and everyday life of young refugees. While minors are protected from deportation, live in youth welfare apartments, and are attended to by a legal guardian, adults often live in constant fear of a Dublin transfer during their initial months in Germany. This entails being deported to the first EU country of entry. Many adults find themselves living in refugee camps for years, with limited legal alternatives available if their asylum application is rejected. So, in the absence of birth certificates, how do German administrative offices decide who should receive legal protection and be accommodated as a minor in youth welfare? And how do young refugees themselves cope with being classified as either a minor or an adult?

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VIEW POINT

ULRIKE BIALAS

ILLUSTRATION: SOPHIE KETTERER FÜR MPG

Ulrike Bialas is a postdoctoral research fellow at the Max Planck Institute for the Study of Religious and Ethnic Diversity in Göttingen. She earned her PhD in sociology from Princeton University. Her book, *Forever 17: Coming of Age in the German Asylum System*, will be published by the University of Chicago Press in December.

These are some of the questions I examined ethnographically, using participant observation – a qualitative social research method that holds immense value, particularly in cultural anthropology but also in my own discipline of sociology. This method involves accompanying people throughout their everyday lives for an extended period of time, often spanning years, with the aim of gaining familiarity with their habits, values, and challenges. Ideally, a bond of trust forms between the researcher and their interlocutors, enabling open discussions on potentially sensitive topics. From my perspective, the disputed ages of young refugees can only be examined through years of participant observation. It is only through observing and experiencing different contexts and situations that one can truly comprehend how an age assumes varying meanings depending on the context and situation.

HUMANS DEVELOP IN SIMILAR WAYS, BUT NOT ALWAYS AT THE SAME PACE

I initially observed age assessments at a forensic institute, where medical examiners analyze radiological images to estimate a person's chronological age based on their bone development. To gain a deeper understanding of the legal framework surrounding unaccompanied minors, I subsequently volunteered with an organization that connects them with volunteer legal guardians. I then spent several years with a group of refugees, consisting of both officially recognized minors and young adults. I visited them at their camps or youth welfare apartments, provided assistance with their German lessons or homework, met their friends and acquaintances, and accompanied them to administrative offices, including the BAMF, the Foreigner Registration Office, the family court, and the Youth Welfare Office. I also joined them for appointments at hospitals, law firms, and asylum counseling sessions.

My research revealed that age is a complex construct. And yet, due to rigid legal distinctions made within areas such as residence and youth welfare law, administrations are required to establish precise dates of birth in order to differentiate between minors and adults, down to the day. Age assessments, on the other hand, can only provide estimations and probabilities because, although humans develop in similar ways, they do not always develop at the same pace, particularly when influenced by disparate circumstances during their upbringing. Consequently, even though dates of birth determined through forensic means are only approximations, they ultimately determine whether a young person can reside in Germany and the conditions under which they may do so.

Refugees determined to be young adults face significant legal uncertainty. They rarely have the opportunity to enroll in regular schools, receive minimal support without the assistance of youth welfare, and struggle to find the peace and privacy necessary for relaxation and studying in their camps. However, minors also encounter their own challenges. While they

often had substantial responsibilities within their families in their home countries, they must now listen to their guardians and abide by the rules and supervision of youth welfare. Their welfare benefits are allocated on a weekly basis, their expenses are scrutinized, and living in youth welfare entails curfews and room inspections. Furthermore, their case workers are informed about even the most intimate aspects of their lives by lawyers, teachers, doctors, and therapists – to name just a few of the most common measures. Notably, young refugees often had to display significant maturity during their flight. However, once placed in youth welfare, they are no longer able to exercise this independence. This level of autonomy and maturity is sometimes even used against them in support of arguments that they cannot truly be minors.

Age initially appears to be a straightforward and equitable category. However, my research has demonstrated that it cannot be definitely determined and may not be the optimal means of assessing a person's need for assistance. The young refugees I met had childhood experiences in their home countries that differ significantly from the kind of upbringing that prepares German youths for adulthood. While they took on household responsibilities at a young age and provided financial support to their parents or helped raise younger siblings, they themselves acknowledge that they did not acquire the skills to make independent decisions or plan their life and career paths. Furthermore, they face the immense challenge of overcoming the trauma of their flight and navigating life in a new country without the support of their families.

TODAY, MANY PREVIOUSLY RIGID CATEGORIES ARE BEING EFFECTIVELY CHALLENGED

Of course, there should be ongoing efforts to improve age assessment methods, particularly to ensure that no minors are wrongly classified as adults. However, overall, we may need to accept and learn to live with ambiguity. Despite their significant political and professional differences, all the experts I spoke with unanimously agreed on one point: we can never know the exact ages of young people who arrive in Germany without proper identification documents. This poses a legal and bureaucratic challenge, but it also presents an opportunity. We currently live in a time where previously rigid categories are being effectively questioned and challenged. The migration of young refugees "without an age" could inspire us to critically examine the concept of youth itself. Minors receive special support because they are both in need of assistance and often exhibit open-mindedness and a readiness to embrace help. Therefore, supporting them is a necessary and prudent societal investment. Should we not include young people in our society based on their vulnerability and openness rather than solely relying on a specific date of birth? Engaging in a debate about these terms will undoubtedly be as challenging as determining dates of birth currently is, but it is certainly worthwhile.

A WORLD FULL OF HEXAGONS

Nature has a sense of symmetry and seems to prefer certain shapes. Besides circles and spheres, these include the hexagon. They are found not only in honeycombs and snowflakes, but also in crystals, salt flats, and permafrost. Yet, the processes that create them have little in common.

ENERGY-EFFICIENT

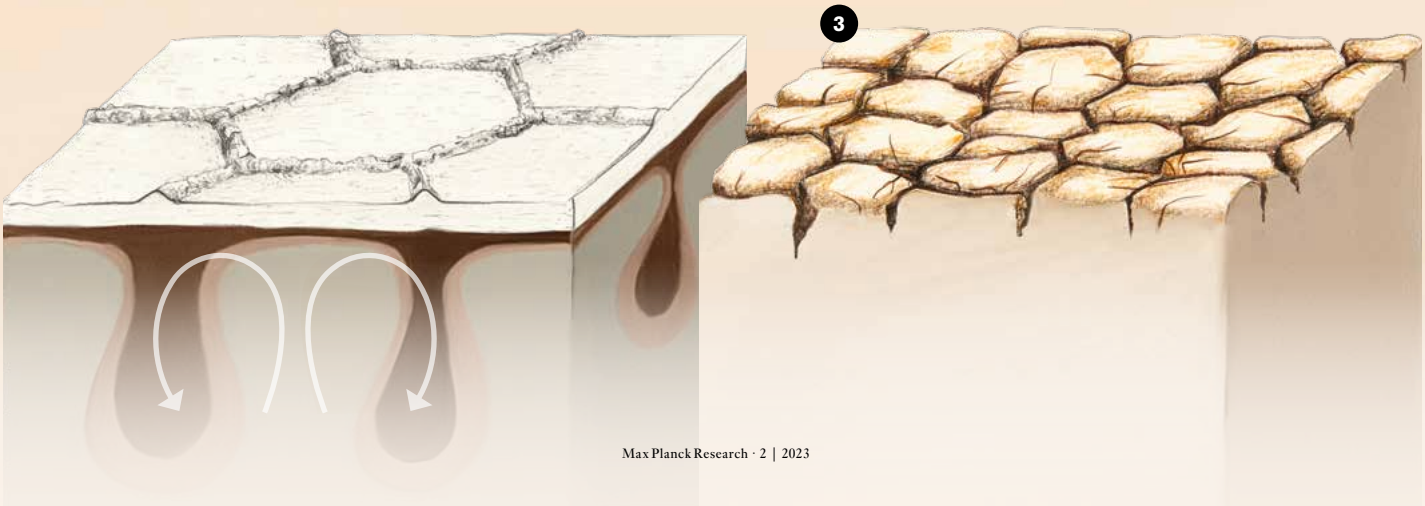
In many cases, nature minimizes the ratio of contour to surface area and of surface to volume. That is why drops of oil form circles in water. In the densest possible arrangement of circles or spheres on a plane, each is surrounded by six neighbors. That is why, for example, the atomic layers of closely packed spheres into which many metals crystallize 1 are hexagonal in shape. When circles in a hexagonal arrangement are forced together so tightly that the gaps between them close, the circles turn into hexagons. In the case of honeycombs, 2 the structure is not just exceptionally stable, it also minimizes the amount of wax the bees require.

RIDGES IN THE DESERT

The ground under salt flats contains water that moves in convection rolls, a discovery made partly by researchers from the Max Planck Institute for Dynamics and Self-Organization. Lightweight, low-salt water (gray) rises to the surface, part of it evaporates, and salt-rich water (brown) sinks back down. Multiple convection rolls placed side-by-side form a honeycomb structure. At the boundaries of the hexagon where the salt water sinks down, the salinity is so high that salt on the surface crystallizes and forms ridges.

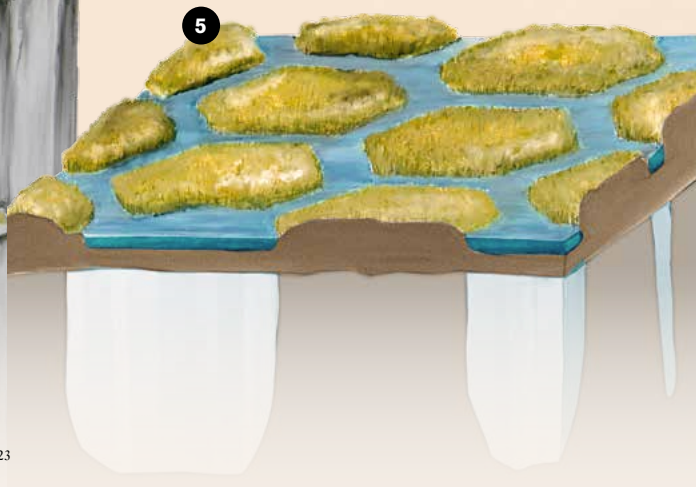
STRESS CRACKS

Cracks form in dehydrated soil 3, slowly cooling basalt 4, and permafrost during unusually cold winters 5. Under ideal conditions the cracks have a honeycomb structure, as this is the most efficient way to relieve stress. The v-shaped stress cracks in permafrost fill with water the following spring. In a process studied jointly with the Alfred Wegener Institute, the water forms honeycombs of ice underground when frozen.



VARIATIONS IN SIX DIRECTIONS

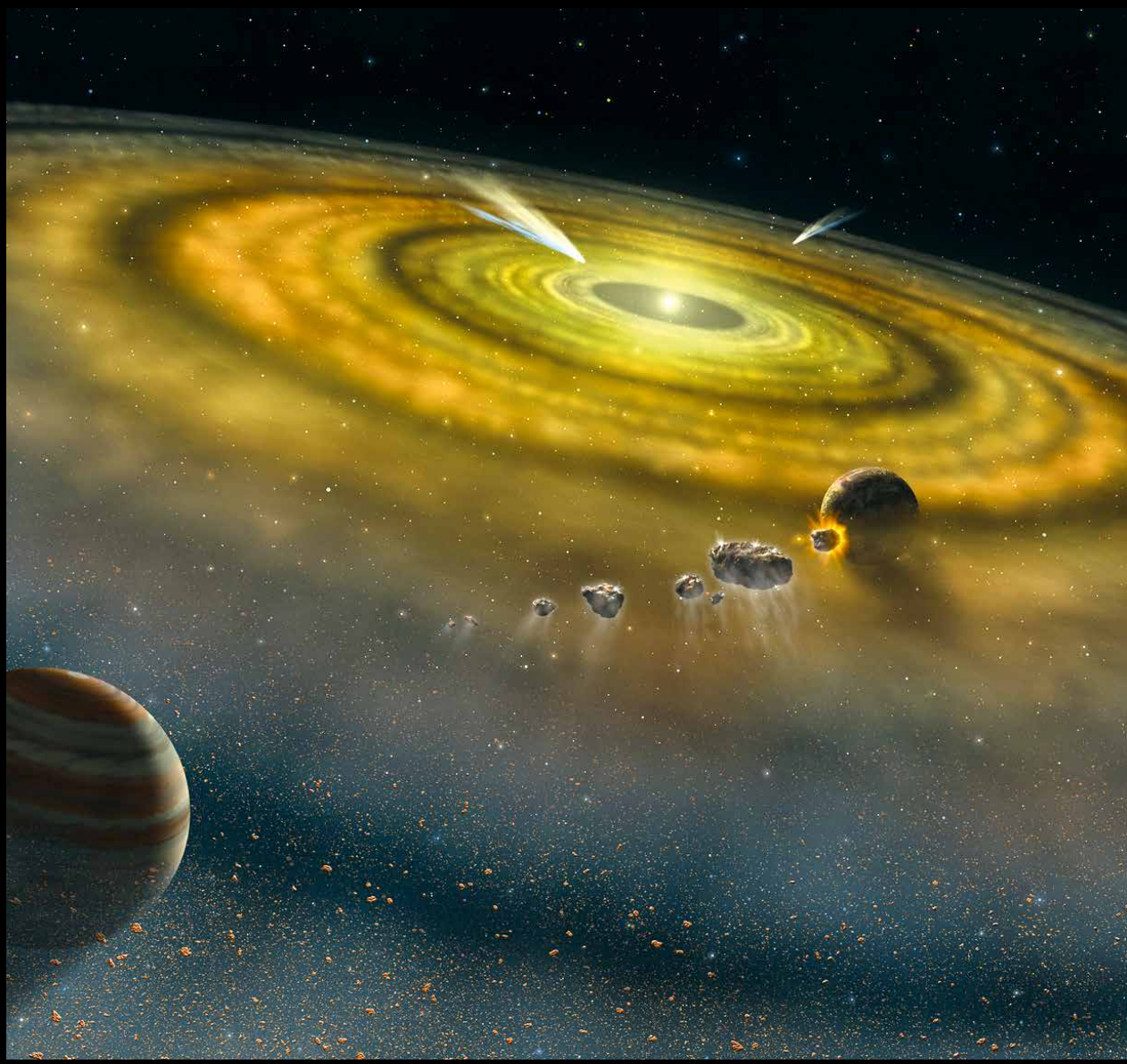
Water molecules have an angled structure consisting of one atom of oxygen and two of hydrogen. When the molecules combine to form ice crystals, a hexagonal structure proves the most efficient. The exact shape adopted by the crystals depends on the conditions under which they grow, such as temperature and humidity. An individual crystal grows symmetrically in all six directions, because all six are subject to the same conditions.



GRAPHICS: GCO

FOCUS

WORLD SHAKING



Everything revolves: an artist's depiction shows how planets form as a result of collisions between increasingly larger bodies in a disk of gas and dust around a newborn star.

IMAGE: NASA/FUSE/LYNETTE COOK

BORN OF DUST

TEXT: THORSTEN DAMBECK AND TOBIAS BEUCHERT

Life on Earth, as we know it today, exists thanks to many coincidences – and the planet Jupiter. Its weighty role in the Solar System is one aspect of its turbulent history, a subject Thorsten Kleine and Joanna Drążkowska investigate using meteorites and computer simulations at the Max Planck Institute for Solar System Research in Göttingen.

On September 12, 2019, eyewitnesses experienced a celestial spectacle: shortly before 3 PM, a fireball streaked across the sky in Central Europe. The meteor even caused rolling thunder in some places. Photos and videos documented the event, and newspapers and TV stations reported on it. And so it was no surprise when someone gardening in Flensburg recovered a conspicuous gray rock in the shape of a golf ball the following day. This is currently the only known fragment of the "Flensburg meteorite." The cosmic discovery in North Germany may seem spectacular, but meteorite finds are hardly rare. "In collections around the world there are more than 70,000 rocks that fell from the sky at one time or another," explains Kleine. Since 2021, he has served as a Director at the Max Planck Institute for Solar System Research, where he heads the Planetary Science Department.

Meteorites are fragments of objects such as asteroids, which today orbit the Sun in a belt between Mars and Jupiter. Apart from these small objects, there are two types of planets in the Solar System. Rocky planets orbit the Sun at close range and are called terrestrial planets. They have relatively low masses, but high densities. They are Mercury, Venus, Earth, and Mars. The second type comprises the gas and ice giants that orbit the Sun beyond the orbit of Mars. They are divided into two groups: the gas giants Jupiter and Saturn, located beyond Mars, and the ice giants Uranus and Neptune, situated far from the Sun on the edge of the Solar System. The terms gas and ice giant do not refer to the condition of the planets today, but to how they formed. The mixture of hydrogen and helium that accumulated around the planets as they grew was purely gaseous at this stage. Because of their tremendous weight and the high pressure of the accumulated gases, the hydrogen and helium liquefied in the lower layers of the gas giants while remaining gaseous in the outer atmosphere. Uranus and Neptune differ from the gas giants in that they took on additional frozen water, methane, and ammonia as they formed. These elements remain inside the planets even today, mainly in liquid form.

But how did the planets form in our cosmic homeland, the Solar System? In the classical collision model, still widely accepted today, the planets formed via "oligarchic growth" in a disk of gas and dust around the newborn Sun known as the "protoplanetary disk." The dust then consolidated into increasingly larger conglomerates until "planetesimals" formed. These early protoplanetary bodies resembled modern-day asteroids. Subsequent collisions caused bodies to grow to the size of, say, our Moon or the moons of Mars. Researchers believe that even more violent collisions between these planetary embryos resulted in the planets we know today.

Kleine's team is testing this hypothesis in the lab with the aid of meteorites, rocks that fell to Earth like the one in Flensburg. "Meteorites contain evidence indicating where they formed, how they developed, and how old they are," says Kleine. Meteorites are the oldest known rocks, making them approximately as old as the Solar System itself. They are the remnants of the materials from which the planets formed. Consequently, when researchers analyze meteorites, they are travelling back in time and gaining an indirect view of the formation of the Solar System. By analyzing meteorites, they learn how the building material of the early Solar System was distributed. This knowledge then helps them determine where the planets formed – the first step in reconstructing their history.

SUMMARY

Our planets formed approximately 4.6 billion years ago from a disk of gas and dust around the newborn Sun.

New analyses of meteorites, as indicators of time of origin, and computer simulations of processes in the disk explain how the planets could have formed from gas and dust.

The gas planets came into being when granular material (pebbles) flowed in from the outer Solar System and clumped together to form solid cores. The cores then attracted hydrogen and helium, the planets' main building materials.

Jupiter's gravity prevents Earth from being bombarded with asteroids. This created the conditions under which life could develop here.

Kleine and his team searched for a property that would reveal which part of the protoplanetary disk a meteorite originates from. A criterion like this should function like a human fingerprint, which remains unchanged throughout a person's life. The chemical composition of the meteorites alone – that is, the frequency of elements such as iron, silicon, and oxygen – gives only a vague indication of where the celestial body came from, because the elements in the early disk were thoroughly mixed.

However, Kleine discovered that the isotopic ratios of elements such as iron, molybdenum, and chromium are suitable indicators of the place of origin. Isotopes are variants of the same chemical element with slightly different masses. It appears that the isotopes of these elements were not evenly distributed in the molecular cloud from which our Sun and the protoplanetary disk, and later the planets themselves, emerged. On the contrary, even then there must have been differences in isotopic ratios,

PHOTO: SWEN PFÖRTNER FOR MPG

A selection from the meteorite collection of the Max Planck Institute for Solar System Research: the largest of the objects measures more than 20 centimeters. The majority belong to the most common class of rock meteorite, consisting mainly of silicates. In the bottom center is a section cut from one such meteorite. The section on the right comes from an iron-nickel meteorite like the one depicted in the upper left.

"In collections worldwide, there are more than 70,000 rocks that fell from the sky."

THORSTEN KLEINE

correlating to the distance from the center of the cloud. The nascent planetary bodies consequently formed from building material with different isotopic compositions, depending on whether the material accreted near to or far from the Sun. Billions of years later, the isotopes can still be read as clues to the early distribution of the planetary building material. "The ratio of a given isotope is an excellent marker for distinguishing between meteorites based on where they came from," Kleine explains. There are two groups of meteorites: non-carbonaceous and carbonaceous. They emerged from two different reservoirs in the early gas and dust disk of the embryonic Solar System: non-carbonaceous meteorites from the inner part of the disk and carbonaceous from the outer. They are called this for historical reasons, and unlike what the names suggest, they have nothing to do with how much carbon a rock contains. "Isotopes of molybdenum were the first that enabled us to prove the split into two reservoirs. The two different groups of meteorites clearly existed from the very beginning," says Kleine. When analyzing samples at the Max Planck Institute for Solar System Research, the re-

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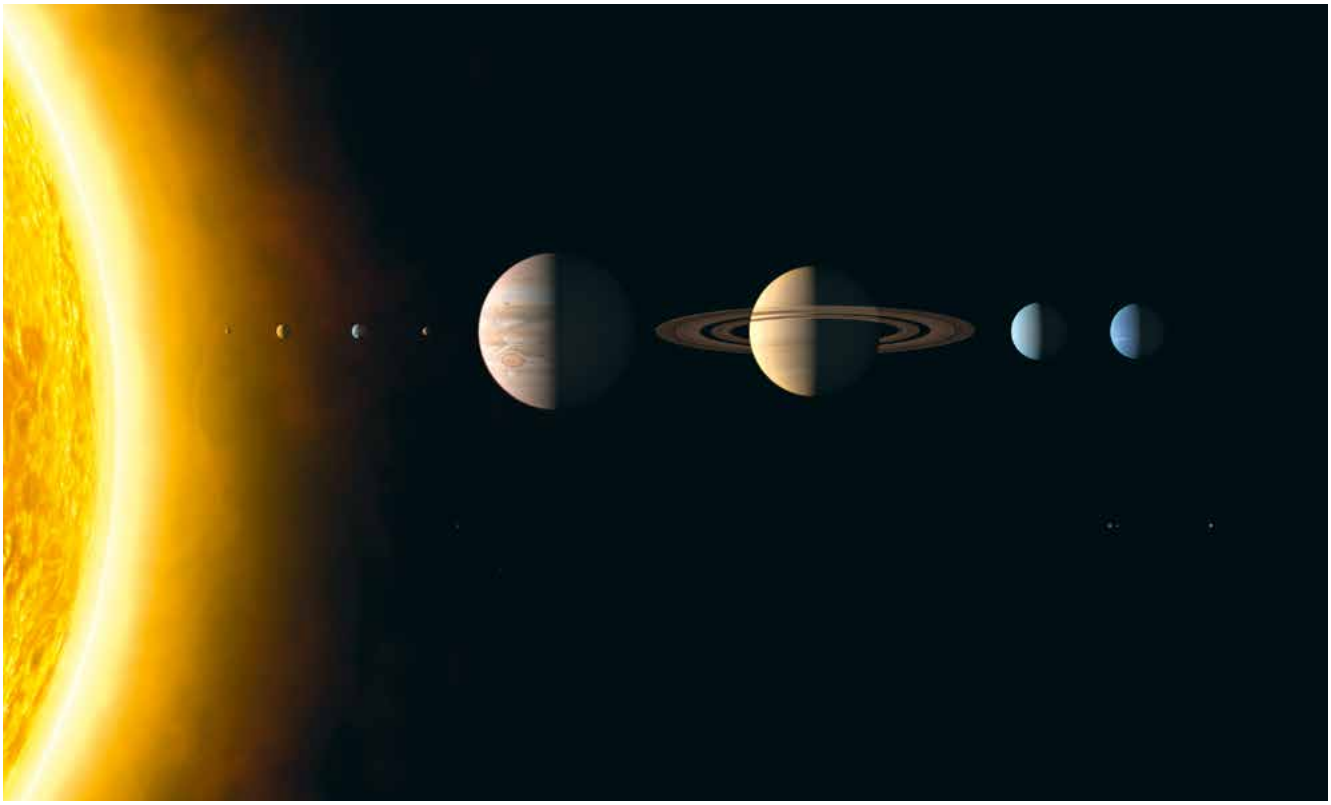

IMAGE: THE INTERNATIONAL ASTRONOMICAL UNION/MARTIN KORNMESSER

All in a row: the planets of our Solar System shown correctly in terms of relative sizes, but not at the correct distances from the Sun. From left to right: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

searchers have to work under highly sterile conditions to exclude the possibility of contaminating the rock samples, which would throw off the measurements. They start by pulverizing the samples, which they then subject to chemical preparation, sometimes for weeks at a time. Next, they use highly precise mass spectrometers the size of a compact car to determine differences in the proportions of isotopes in the samples to a high degree of precision.

One question, two theories

When the isotopic ratios in meteorite samples of known origin in the protoplanetary disk are compared with the ratios in planetary rocks, it becomes possible to speculate where the planet's building material might have originated. Until recently, there was no reason to doubt the classical collision model as an explanation of how planets formed in the early Solar System. However, new insights into the outer gas giants have caused the foundations of this model to crumble, helped in part by research from Joanna Drążkowska, a group leader at the Max Planck Institute for Solar System Research. Whereas Kleine prepares direct messengers from the nascent Solar System for painstaking study in the lab, Drążkowska takes a different approach to deciphering the history of our planetary system. The goal of her working group is to create a computer simulation of the initial clumping of dust in the flat disk of matter around the young Sun. "We want to decipher the fundamental principles of early planet formation. Most other models leave out this initial stage," explains Drążkowska. She places particular emphasis on the growth of Jupiter, a gas giant and the bigwig among our planets. Although Jupiter consists largely of hydrogen and helium, its interior is presumed to contain a solid core weighing between ten and twenty Earth masses. This is also the mass required for a body to have enough gravity to bind gas to itself from the protoplanetary disk in the early days of the Solar System. According to computer models, however, Jupiter's core must have formed relatively quickly, in the first few million years, in order to attract enough of the surrounding gas before it could be distributed elsewhere. In the classical planetary growth model, it would have taken too long for Jupiter's core to form, because the collisions of large celestial bodies postulated in the model were relatively rare. Therefore, another growth mechanism must be found.

A new theory could explain the rapid formation of Jupiter's core. It holds that small clumps of cosmic dust coming primarily from cold regions far from the Sun contributed to the growth. In scientific jargon, they are called "pebbles." Due to friction and collisions within the original gas and dust disk, they lost the energy that kept them orbiting the Sun. As a result, they wandered towards the central star and ran into already formed planetesimals, which grew very quickly by accreting vast numbers of these pebbles. "Today everyone agrees with the pebble model as far as the cores of gas and ice giants are concerned," says Kleine. However, the question quickly arises whether the material used to form Earth and Mars was delivered from regions far from the Sun and whether the current conception of classical, oligarchic growth has been rendered fully obsolete.

To answer the question, Kleine and an international team led by Christoph Burkhardt, which is also part of the Max Planck Institute for Solar System Research, conducted in-depth studies of 17 fragments of the red planet and material from the Earth's crust. The researchers compared this planetary material with samples from meteorites known to have come from the outer Solar System. To this end, they analyzed the isotopic evidence of three rare metals: titanium, zirconium, and molybdenum. Their findings confirm the original assumption that Earth and Mars have little in common with material from the outer Solar System; only around four percent originates from there. "The values would have to be almost ten times higher if the predecessors to Earth and Mars actually accreted grains of dust from the outer Solar System," says Kleine. Both planets were formed of materials delivered from very close by – from the inner Solar System. The classical model of oligarchic growth still works very well in explaining the formation of the terrestrial planets.

Messengers from afar

However, not everything that roves around the inner Solar System originated from there. An international research team of which Kleine is a member studied crumbly sample material brought to Earth from the asteroid Ryugu by the Japanese probe Hayabusa 2 in December 2020. Ryugu is a fragment in the form of a double pyramid and measures around one kilometer in diameter. Today it is found in an orbit close to the Sun, much like Earth. The sample consisted of only 5.4 grams of material, but that was enough to determine where Ryugu originally came from. To this end, the team compared the sample with

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Research up close: astronomer Joanna Drążkowska discusses the details of her models with the team (left). Thorsten Kleine analyzes meteorites in the lab under highly sterile conditions using cutting-edge technology (right).

PHOTOS: SWEN PFÖRTNER FOR MPG

several meteorites whose isotopic signatures were known, and whose place of origin in the early protoplanetary disk could therefore be determined. The ratios of Ryugu's iron isotopes resembled those of a class of rare meteorites, the carbonaceous meteorites, which originated from the outer Solar System. Ryugu is therefore a wanderer whose journey to the inner Solar System began once upon a time far from the Sun. Studies such as these lead to speculation that material from the outer Solar System definitely found a way into the vicinity of Earth and Mars.

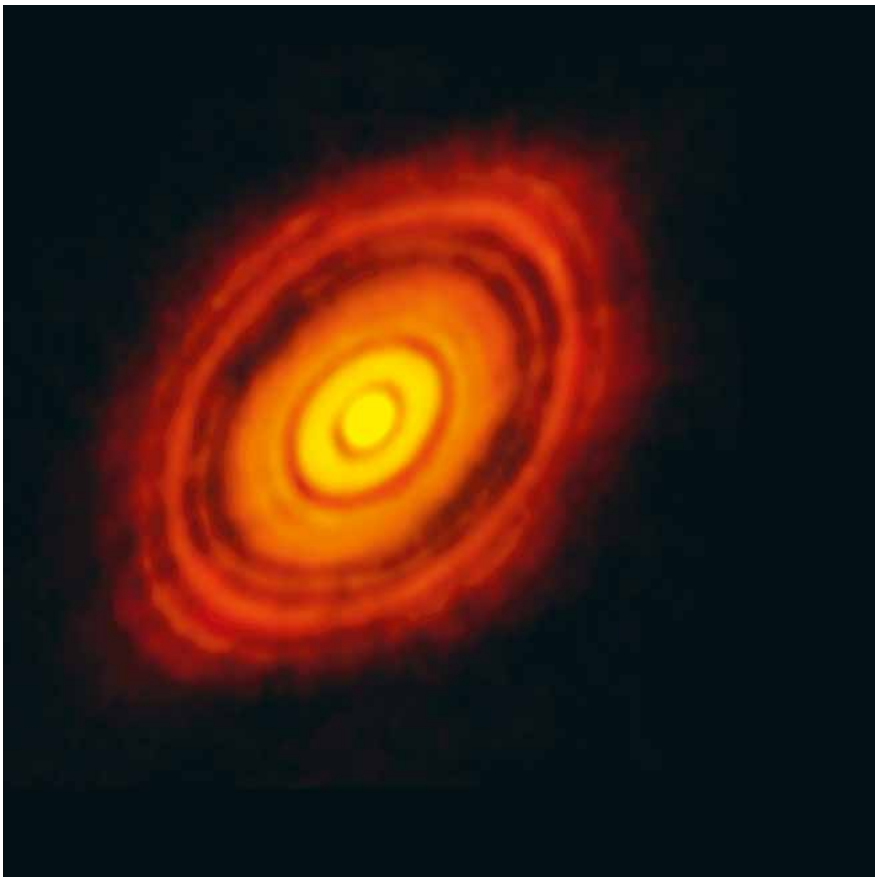
It all comes down to Jupiter

Investigations of relics from the early days of our Solar System by her colleague Kleine are an important component of Drążkowska's computer simulations. They are indispensable in seeking to understand the formation of gas giants, whose rocky cores are buried deep beneath impenetrable layers and cannot be probed directly. She calculates that for Jupiter to grow, there had to be a lot of dust, or more exactly a dust-to-gas ratio of around one to one. As she later discovered, this special condition was met at what is termed the ice line. At that distance from the Sun, water froze into ice, and today Jupiter can in fact be found near that conceptual line. "At the ice line, the dust concentration was high enough for pebbles to combine quickly and effectively into planetesimals," reports Drążkowska.

Kleine, Drążkowska, and their teams quickly realized why the two groups of meteorites did not mix in the inner and outer protoplanetary disk of the early Solar System. The planet Jupiter formed during the first million years by accreting large amounts of dust and gas flowing towards the Sun from the outer Solar System. "Jupiter played a central role in the formation of our Solar System," says Kleine. Its enormous mass prevented the building material from mixing, resulting in a mass-starved inner Solar System. Even today, Jupiter makes a major contribution to the emergence of higher life on Earth by forming a natural barrier against bombardment from the outside. This lowers the probability of asteroids striking Earth and causing mass extinctions, as happened with the dinosaurs. "What is more, without Jupiter the Earth would be a super-Earth with more than ten times its current mass," says Kleine. And life on such a massive planet would look completely different from life on Earth, to say the least. Jupiter's role in limiting the influx of planetary building material also explains why it took the Earth almost 150 million years to reach its current mass. Without the influx of pebbles, the inner terrestrial planets grew relatively slowly in situ through collisions with bodies ranging in size from the Moon to Mars in line with the classical theory.

Nor is this view disproved in any way by Ryugu, which formed in the outer Solar System and today resides in the vicinity of the inner planets. Like most asteroids, it wandered to its current position relatively recently due to gravitational interactions between various bodies in the Solar System. The interplay of forces dominated by Jupiter now holds the asteroids – remnants of early planetary formation which act as a sort of quarry for meteorites – in a belt between Mars and Jupiter.

Planetary formation before our eyes: this image from the Alma telescope shows a dust disk surrounding the young star HL Tauri, where planets might already exist. The dark rings could indicate young planets accumulating dust on their path around the star.



According to Drążkowska, however, we are still far from fully understanding how the planets formed in our Solar System or other planetary systems in the Milky Way. "A comprehensive and detailed model combining all the stages and processes of planet formation is still lacking," she says. This makes her even more eager to subject her computer simulations to a reality check that extends beyond the direct sampling of our Solar System. Because the fundamental processes of planet formation presumably follow the same physical principles in the entire Milky Way, Drążkowska turns her eyes to the night sky.

"Jupiter's core must have formed relatively quickly within the first few million years."

JOANNA DRĄŻKOWSKA

Modern telescopes provide views of very different planetary systems both young and old at various distances from our homeland. Some, like our Solar System, are at an early stage of around 4.6 billion years. Astronomers obtained the first evidence of one such youthful system in the 1990s in the Orion nebula. This active birthplace of new stars and new planetary systems can be admired with binoculars mainly in the winter months in Germany. Photos from the Hubble Space Telescope led to the discovery of several unusual-looking stars. Against the background of the dimly lit sky, their light spots seemed to indicate two dark bulges at the sides. These turned out to be the first photographs of gas and dust disks, providing a glimpse of the arena where planets are born. Many more planetary cradles have been discovered since then. The best tool for this purpose is the Alma telescope (Atacama Large Millimeter/Submillimeter Array) in Chile, which captures short radio waves and depicts the dust disks in hitherto unattainable detail. The images of many of these disks reveal gaps that could be caused by young planets.

Specially optimized telescopes can also detect other planetary systems that are already fully developed. In 1995, the first extrasolar planet was discovered orbiting a star in the constellation Pegasus over 51 light years from Earth. A flood of similar discoveries has followed since then, with astronomers finding more than 5,000 of these exoplanet systems. The characteristics of some systems seem exotic. Their architecture seems twisted compared to our Solar System, with the largest gas planets located unusually close to the central star. According to Kleine, this can already be explained by the fact that it is especially difficult to observe planetary systems similar to our Solar System with telescopes, mainly because terrestrial planets are much smaller, weigh far less, and reflect far less light than their big brothers and sisters, the gas and ice giants. In Drążkowska's view, observations of other planetary systems are still an excellent source of insights into the formation and development of our planetary system.

While Kleine's research differs from Drążkowska's in many details, both ask the same big question: how did the many known planetary systems form throughout the Milky Way? How did the Earth, the only place in the universe known to contain life, come into being? Analyses of meteorite rocks and computer simulations of physical formation processes do not simply help us gain a better understanding of the history of our cosmic homeland; they also help us understand why the Earth developed conditions so favorable to life.

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GLOSSARY

ISOTOPES
are variants of the same chemical element with slightly different masses due to variations in the number of neutrons in the atomic nuclei. The number of protons, and hence the charge of the atom, stays the same.

PROTOPLANETARY DISKS
are flat streams of gas and dust around young, newborn stars in which planets form.

PEBBLES
are pebble-like dust aggregates measuring between a millimeter and a centimeter that wander from the exterior of the protoplanetary disk to the interior. They serve as the building material for the solid cores of external gas and ice giants.

IMAGE: ALMA (ESO/NAOJ/NRAO)

Transcontinental: with thousands of antennae, the Square Kilometre Array Observatory will soon be able to simulate a giant radio telescope with extremely high sensitivity and angular resolution. The collage combines the plans for parabolic mirrors in South Africa (left) and antenna fields in Western Australia.

IMAGE: SKAO

MADAGASCAR REACHES FOR THE STARS

TEXT: JEANNETTE GODDAR

Astronomical observatories mostly require remote locations where human disruption is not a factor. That is why many are located in African countries. However, most of the research takes place in the global north. For a country like Madagascar, the prospect of hosting an observatory can nonetheless set education and science into motion, according to findings by Hanna Nieber of the Max Planck Institute for Social Anthropology.

It is a project full of superlatives. Over the past year, hundreds of parabolic mirrors and more than 100,000 antennas have been installed in remote regions of South Africa and Australia, far from cities and human radio emissions. The goal is to build a superlative radio telescope, one almost as big as the globe itself and so multifaceted and sensitive as to enable us not only to chart the Milky Way, but also to gain a view of developments after the Big Bang. The Square Kilometre Array Observatory (SKAO) is supported by an organization with 13 members; one of them is the Max Planck Society. If all goes well and the SKAO goes into operation in 2028, it will be a dream come true for researchers in radio astronomy – one they have nurtured since the 1990s and have been working on ever since.

SUMMARY

Interest in astronomy has grown in Madagascar since the country was nominated as a location for the large-scale SKAO telescope project.

The people hope this enthusiasm will advance the development of their country in other areas as well.

Cooperating on the project with other African countries has caused Malagasy to start feeling they belong to the African continent.

This is clearly illustrated in a story studied by social anthropologist Hanna Nieber in her research project "Constellations for Astronomy in Madagascar." Three years before the SKAO received funding, astronomers were already making the trip from South Africa to Madagascar, which would become one of the eight partner countries. The mission of the researchers was to meet with Minoson Rakotomalala, a professor of particle physics at the University of Antananarivo. Could he imagine setting up an astronomy degree program in the capital of Madagascar? One can only guess how unlikely the South African visitors considered their mission's chances of success in a country with a student admission rate of under five percent and one of the lowest GDPs in the world. And yet, it succeeded. "Every year since 2014, six students with bachelor's degrees in physics have started a master's program in astrophysics," says Nieber. Those interested in a scientific career often move to Cape Town, where the SKAO receives significant support on the scientific front.

A postdoc at the Max Planck Institute for Social Anthropology in Halle, Nieber headed to Madagascar and South Africa for field research in 2022. She arrived at social anthropology after completing a master's degree in African studies. Her interest in the continent is partly biographical; she graduated from high school in Eswatini. After earning her doctorate with a thesis on Islamic practices in Zanzibar, she discovered astronomy. She sums up her current research project in a single sentence: "I wanted to find out what happens in anticipation of such a massive science project." Especially in Madagascar, a country where the conditions are sobering even by African standards. Two out of three people live below the poverty line. Even before Tropical Cyclone Freddy ravaged the island several times early this year, the United Nations had already identified Madagascar as one of the ten countries in the world most heavily affected by natural catastrophes. In rural regions, most families live on what the soil yields under these conditions. According to data from UNICEF, the United Nations Children's Fund, three out of ten children never attend grade school, while another three never finish.

However, Nieber warns against drawing the wrong conclusions about the population as a whole from statistical data. "Madagascar has a college-educated middle class, too." And an increasing number of people in a country of 30 million are pursuing a college education. According to an overview from Madagascar's Ministry of Higher Education and Scientific Research, there are six state universities and almost 150 private institutions of higher education. Nearly all of them are located in the capital city of Antananarivo, nicknamed "Tana" by locals. "As a rule, everyone who makes more money than average lives in Tana," reports Nieber.

In the first few years since the introduction of the astronomy degree program, Tana's middle class contributed to the founding of two associations committed to supporting this subject. The roots of the larger of the two, Malagasy Astronomy and Space Science (Mass), go back as far as 2009. Nieber tells of more than a hundred members, including both astronomy graduate students and undergraduates from a variety of disciplines, who

"The SKAO offers a future that people in Madagascar could not imagine before."

HANNA NIEBER

PHOTO: ANNA SCHROLL FOR MPG

Colleagues confer: Hanna Nieber (center) talks with Lukas Ley and Julia Vorhölter at the Max Planck Institute for Social Anthropology.

regularly discuss current research findings. Many young Malagasy astronomers currently undertaking their doctoral or postdoctoral research in Cape Town are actively involved in Mass as well. They frequently return to their homeland with new findings in their luggage, Nieber observed. "It really surprised me how close the collaboration is," she says.

The other association, Haikintana, is much smaller and dedicates itself to what could be described as educational outreach. "Its members go to villages and visit schools to make astronomy accessible to the people," Nieber relates. And when they are not on the road, they take every opportunity to share their passion for astronomy on an exceptionally active Facebook page. Partial lunar eclipses are announced alongside rocket launches by Nasa and Esa and international conferences for junior astronomers. Short films are another way through which Haikintana arouses interest. In one of the videos, a young woman sits outside under a palm tree as the background fills with a series of images of the temperature gun used throughout Madagascar during the pandemic and of people reading off temperatures from the device. In about two minutes, the young woman explains the principles of infrared technology, the basis for non-contact temperature measurement. What does that have to do with astronomy? Infrared radiation was discovered by German-British astronomer William Herschel in the early 19th century.

The goal: more interest in the sciences

Both associations are financed by their members and regularly apply for and receive support from organizations such as the International Astronomical Union. "And are many women involved?" people often ask Nieber. "Yes, there's no observable difference in their participation compared to men," she says, adding, "My impression is that anyone who deals with global academic discourses and structures can no longer ignore the question of gender equity."

Both associations are deeply committed not in spite of, but rather because of the situation in the homeland, which is precarious in many ways. "With climate change, corruption, and an unstable political landscape, the people I talk to also ask themselves, how can we afford to look away from Earth?" she reports. The answer, which they provide, is: "They assume an inherent enthusiasm for the starry sky, which they want to use to arouse greater interest in the sciences, and ideally in engineering as well. If this succeeds, runs the argument, it will make a major contribution to Madagascar's development. And everyone I talk to really cares about that." This concern is clearly shared by the organization sponsoring the SKAO.

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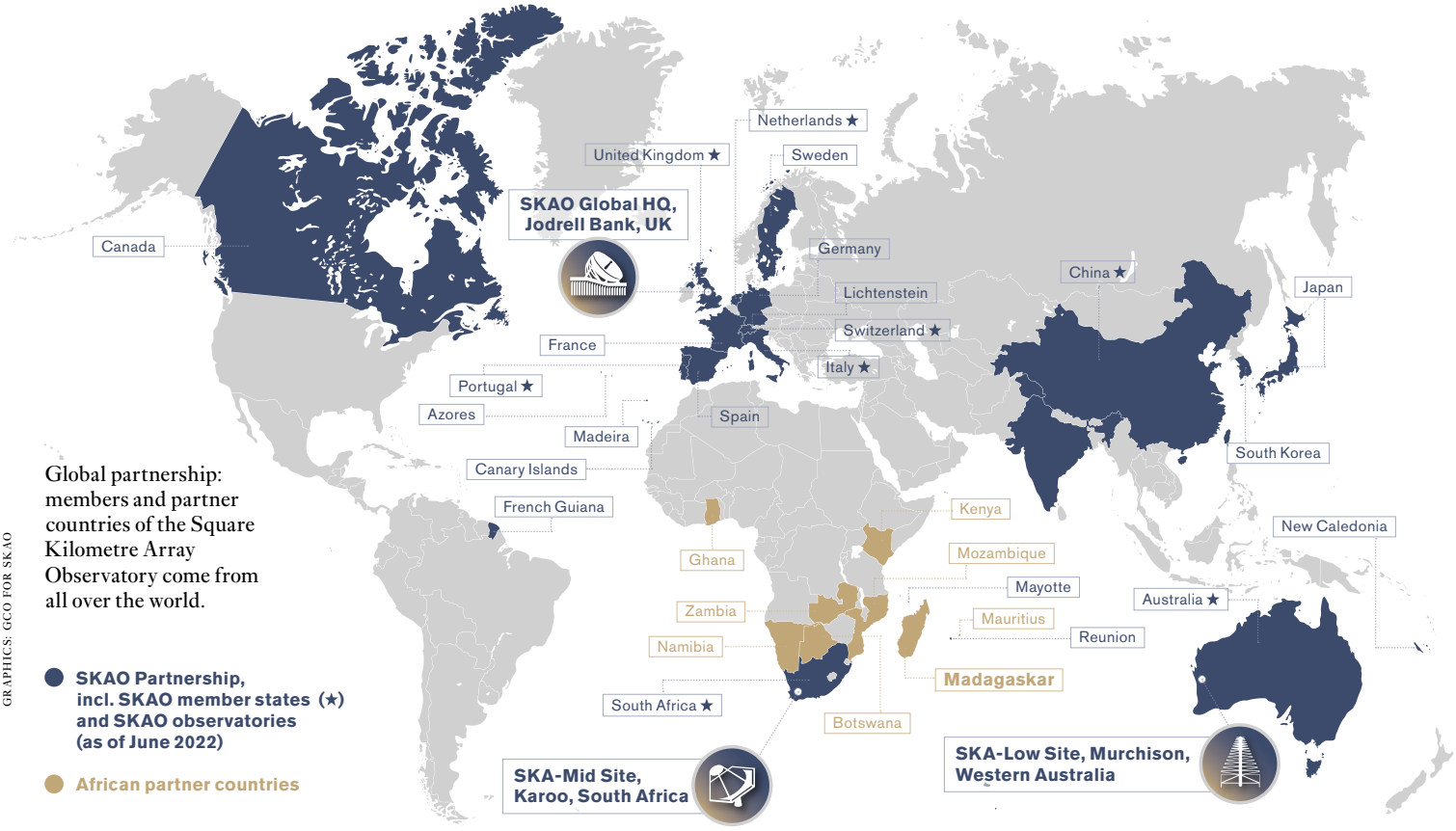
No one was proud to be part of Africa

However, this plan can only succeed if such an "inherent enthusiasm" really exists. Does it help that for thousands of years people have read their fates in the constellations and heavenly bodies? "The astronomers I talk to distance themselves from any connection to astrology," says Nieber. "In every other conversation, though, mythological concepts actually get brought up immediately." Nieber has heard of villages in the highlands whose construction methods are determined by the stars and can be traced back to the palaces of the precolonial kingdom of Merina. "Typically, the entrance and exit face west. In the northeast, by contrast, a space is left for the ancestors even today in some regions." These types of findings are not yet part of her research, however. "It is good to know these stories, and I listen to them with interest," she says. "But I lack the language skills to research them. Doing so would require more collaboration, which would obviously be great."

To be sure, Nieber speaks fluent Swahili, the most widespread lingua franca in East Africa. Malagasy is not related to this language, however, nor to others of the Bantu family. It is closer to Malay, which is spoken in Malaysia and Indonesia. The Malagasy set themselves apart from Africa on the cultural front as well; they see their island almost as its own continent. On the one hand, this is hardly surprising given that it is 400 kilometers from the coast of Mozambique and has a surface area 1.6 times the size of Germany. On the other hand, Madagascar is an African nation and a member of the African Union. "No one there was proud to be African, though," Nieber reports from experience. "The SKAO is changing that. Now something hip, cool, and dope is coming from Africa, something offering a future that people in Madagascar could not imagine before," she relates. The scientific exchange also advances a discourse that has already gained momentum in many countries of the global south. After centuries of foreign rule, has the time not come to clear away bodies of knowledge accumulated from white perspectives, in a word, to "decolonize" knowledge? Within Africa, a leading role in this context is played by South

Excursion with a vision: the Haikintana association aims to promote interest in astronomy in Madagascar. In this photo, a member of the association explains the solar system to a class.

PHOTO: HANNA NIEBER/MPI FOR SOCIAL ANTHROPOLOGY



Global partnership: members and partner countries of the Square Kilometre Array Observatory come from all over the world.

GRAPHICS: GCO FOR SKAO

Africa, a country shaped by apartheid until 1994. As students in Cape Town protested in 2015 against a statue of British imperialist Cecil Rhodes on the university campus, the story made headlines in German media. As Nieber relates, "Rhodes Must Fall" demonstrations led to a movement in the academic world that even today questions what should be taught at institutions of higher education and how to deal with traditional bodies of knowledge. Are these ideas gaining traction in Madagascar, a French colony from 1896 to 1958? "No," she replies, "but they discuss them, and so far with a different conclusion than was reached in South Africa, interestingly. Science is treated as something that should endure beyond decolonization and particularization."

And so, it is surprising to find that it is possible to gain a multitude of anthropological knowledge from a subject as far removed as astronomy. Nieber does not find this so surprising. She has to laugh a bit. "The interplay between concepts from the hard sciences and the humanities and social sciences is my favorite research subject." At the moment, she is thinking primarily of the concept of universality, which is viewed very differently depending on the discipline. While most astronomers assume that science is bound to neither people nor places, and is therefore universal, social scientists generally see things differently. "For us, science is contextual. It is contingent on factors such as location, culture, and class," she explains. Her position can be readily applied to the SKAO, which is being built in both Australia and Africa. "A person with a singular telescope sees only part of the sky." But universal astronomy requires many telescopes – and many people to participate, in places all over the planet."

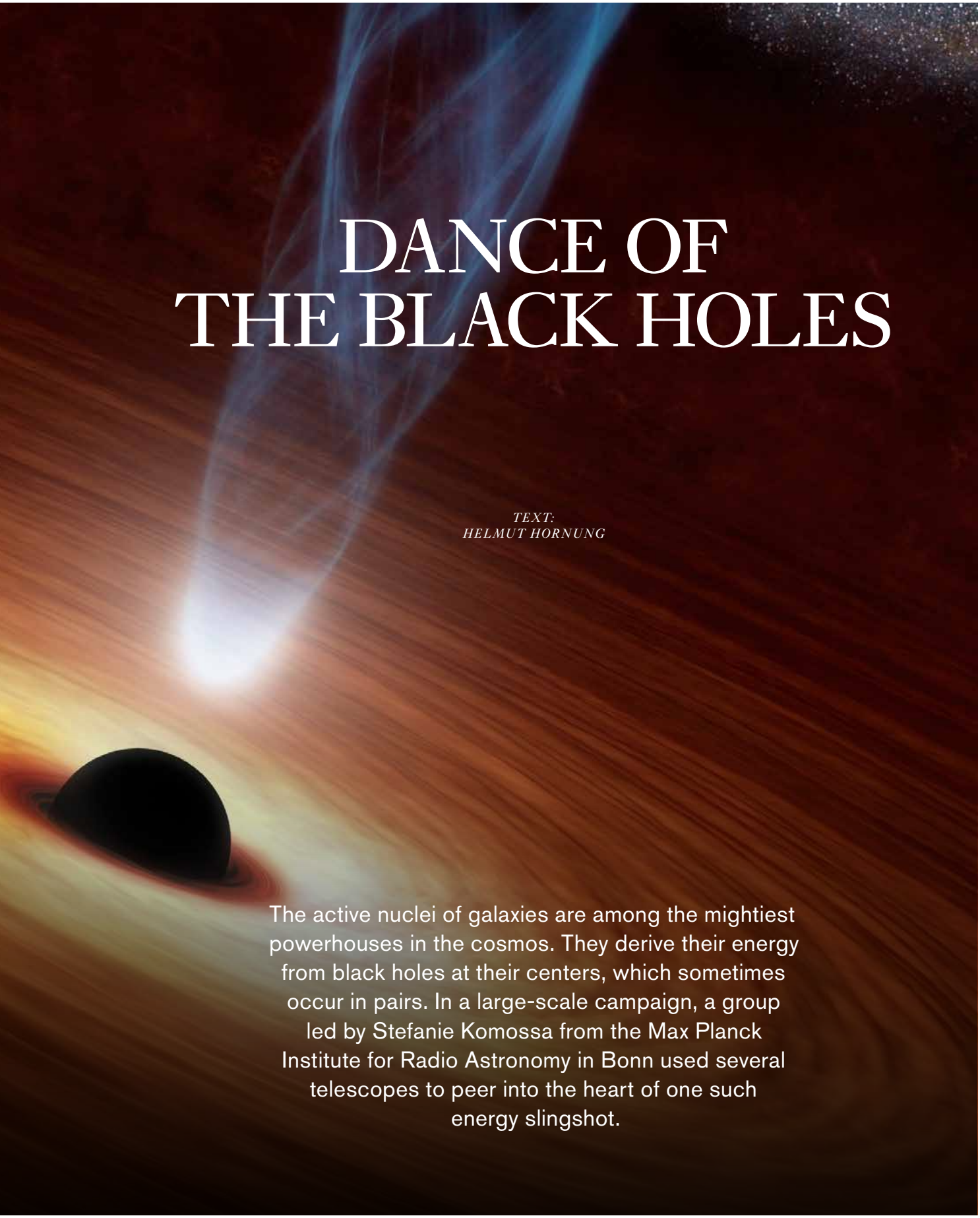
"A universal astronomy requires many people to participate, in places all over the planet."

HANNA NIEBER

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

A hellish maelstrom: in the illustration, matter swirls around a supermassive black hole, millions to billions of times the mass of the Sun, heating up in the process. Near the black hole, magnetic fields twist into a focused jet, propelling matter outward and glowing brightly.

PHOTO: NASA/JPL-CALTECH



DANCE OF THE BLACK HOLES

TEXT:
HELMUT HORNUNG

The active nuclei of galaxies are among the mightiest powerhouses in the cosmos. They derive their energy from black holes at their centers, which sometimes occur in pairs. In a large-scale campaign, a group led by Stefanie Komossa from the Max Planck Institute for Radio Astronomy in Bonn used several telescopes to peer into the heart of one such energy slingshot.

Lacerta is an inconspicuous constellation in the northern sky that few people ever get to see. It was in this constellation that Cuno Hoffmeister discovered a faintly glowing dot on a photographic plate in 1929, flickering with no discernible rhythm. The astronomer at the Sonneberg Observatory in Thuringia specialized in such variables, i.e., stars whose brightness varies more or less periodically. Thus, the object became known as BL Lacertae (Latin for lizard) in Hoffmeister's catalog and remained unnoticed for decades.

Mysterious Torches in the Sky

The story of BL Lacertae – BL Lac for short – is closely linked to the rise of a new technique: radio astronomy. Prior to 1940, researchers had only observed in the optical spectral range. In the 1940s they began to scan the universe with large antennas. Over time, they discovered a great number of cosmic radio sources. Some of them had the same position in the sky as previously unexplored points of light recorded in star catalogs. One such point of light was object 3C 273. Photographed with conventional telescopes in visible light, it appeared as a star-like point with an elongated appendage. What was behind it? The surprise grew when the light from this "radio star" was split into a small rainbow. Such astronomical spectra usually contain characteristic lines that indicate chemical elements. These fingerprints were also present in the spectrum of 3C 273, but they could not be attributed to any known substances.

The mystery was solved in 1963 by the Dutch astronomer Maarten Schmidt: the lines do belong to a chemical element, namely, hydrogen. However, they are not in the usual position, but shifted towards the red range of the spectrum, indicating longer wavelengths. That means the object must be moving away from Earth. For 3C 273, an impressive escape velocity of 45,000 kilometers per second was calculated – far too fast for a star to be moving within our galaxy. The observed effect can be explained by cosmological redshift. As the entire universe expands, galaxies move like raisins in rising dough. In other words, it is space itself that is expanding. This elongates the waves of a distant source, shifting its light into the red range. Maarten Schmidt calculated a distance of no less than two and a half billion light-years for the mysterious light point 3C 273. This means that the object cannot be a normal star, because to shine so brightly at such a distance, its luminosity would have to be equivalent to that of an entire galaxy with its billions of suns. Somewhat presciently, objects like 3C 273 and similar radio stars were already called "quasi-stellar objects" before Schmidt's discovery, from which the term "quasar" was derived.

Through further observations, an increasing number of radio stars were identified as quasars. In 1968 it was shown that the BL Lacertae light point discovered by Cuno Hoffmeister was identical to the radio source VRO 42.22.01. Photographs eventually revealed a faint nebular patch surrounding the "star." Spectra were recorded, allowing conclusions to be drawn about the nature of the nebula. It had to be a massive Milky Way system, with BL Lacertae at its center. Such an active galactic nucleus emits an enormous amount of energy in a relatively small space. But BL Lac shines even brighter than most quasars and also shows more pronounced variations in brightness. From a neologism combining the words BL Lacertae and quasar, such galactic nuclei are called blazars.

But what is the driving force behind these cosmic powerhouses? Astronomers are convinced that massive black holes reside at the cores of most galaxies. "These gravity traps are particularly active in the hearts of quasars and blazars," says Stefanie Komossa of the Max Planck Institute for Radio Astronomy in Bonn. Because of their strong gravitational pull, a considerable amount of matter accumulates around them. This gaseous ma-

Not a star, but a galaxy: the Hubble Space Telescope captured the quasar 3C 273, along with a jet that appears as a faint line above the central bright spot.

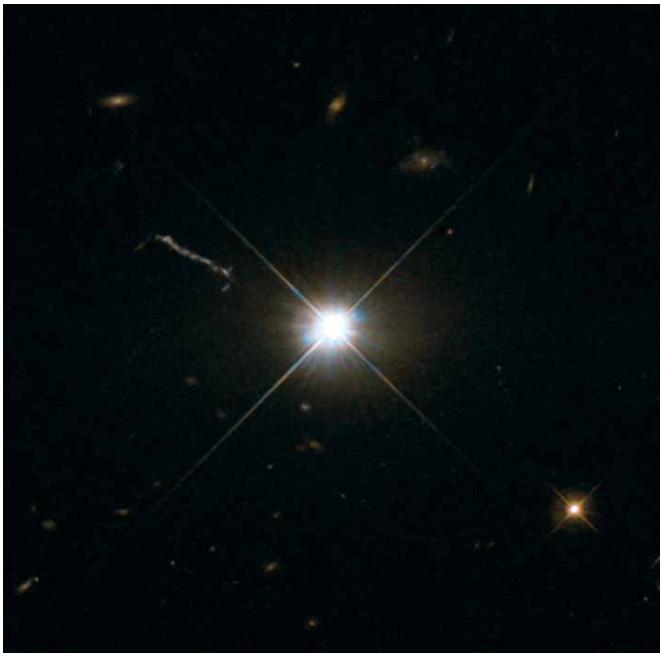


PHOTO: ESA/HUBBLE

terial swirls around the black hole in spiral orbits, its particles colliding with each other. The gas heats up and gradually moves closer to the black hole. The closer it gets, the more turbulent it becomes. Such an infernal maelstrom is called an accretion disk

In the inner region of the flat disk, friction makes the material so hot that it emits high-energy ultraviolet and X-ray radiation. In a wild dance, the gas hurtles at high speed around the cosmic abyss, eventually disappearing into it. However, some of the gas expands, becomes collimated, and flows out into space parallel to the axis of rotation of the disk. This occurs in two opposing jets, which in some galaxies can reach lengths of thousands of light-years. They are therefore millions of times larger than the black hole and its accretion disk.

The jet is also the source of the radio emissions of such quasars. The central engine accelerates particles to nearly the speed of light along tangled magnetic fields that resemble a strand of DNA. This produces synchrotron radiation, among other things. Other processes cause the jets to emit light across the electromagnetic spectrum, releasing unimaginable amounts of energy on the order of trillions of electron volts, similar to terrestrial particle accelerators. Jets are the key to distinguishing quasars from blazars: the latter are a subset of quasars that have one of these powerful headlights pointed directly at Earth. If we look directly into the engine room of a quasar, we see a blazar. So whether an object is classified as one or the other depends on the angle from which we observe it.

The Turbulent Years of the Universe

These cosmic energy slingshots are billions of light-years away from Earth, so their light travels for billions of years before it reaches terrestrial telescopes. We are looking back at a turbulent early era of the universe, when these energy monsters flourished. "At that time, collisions between galaxies were particularly common," explains Komossa. The wild dance of two galaxies flushes large amounts of gas toward the center, feeding the developing heart of the Milky Way system. A quasar, or blazar, is born. But that is not all. Most galaxies have central black holes, which can form a pair when two Milky Way systems collide. The resulting galactic core is exceptionally bright and therefore visible over a wide area. But how realistic is this scenario? To investigate this question in practice, for several years researchers have been observing the blazar OJ 287, located about

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A glimpse of an active galactic nucleus: this image from the Swift space-based telescope shows the blazar OJ 287 in ultraviolet light (left). Further observations suggest that it is a system of two black holes, as shown in the illustration (right). In addition, a jet is forming near the central black hole.

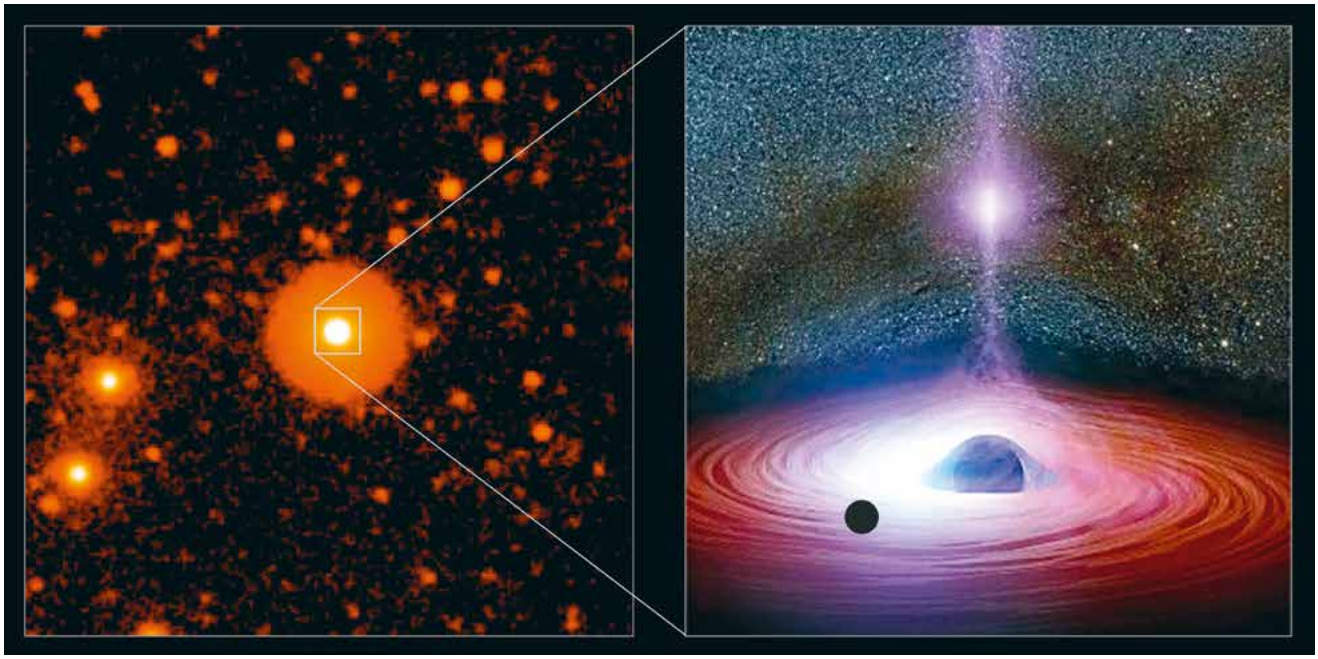
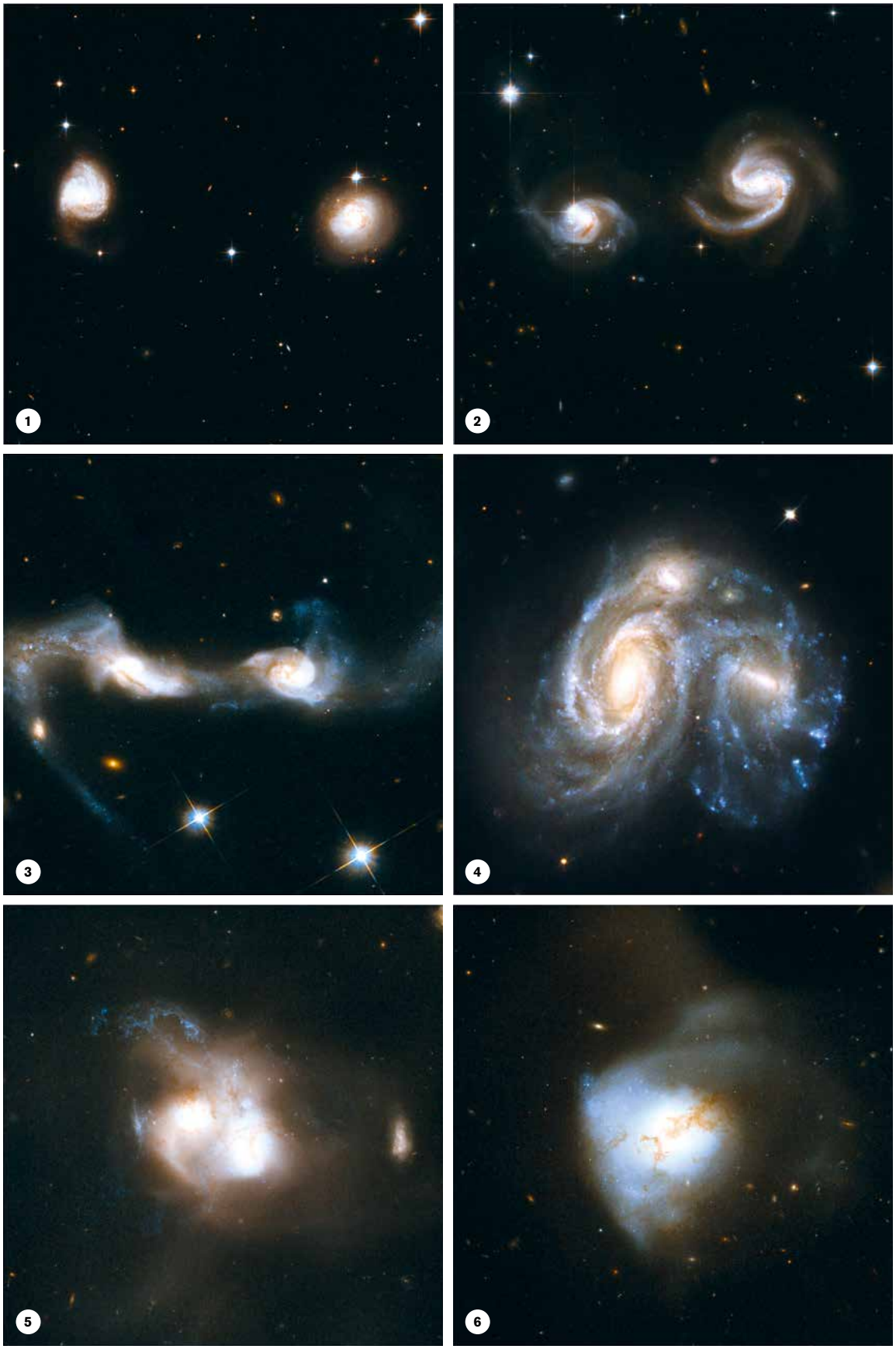


IMAGE: S. KOMOSSA ET AL. (LEFT); NASA/JPL-CALTECH (RIGHT)

IMAGE: S. KOMOSSA ET AL.



PHOTOS: NASA, ESA, THE HUBBLE HERITAGE TEAM (STSCI/AURA)-ESA/HUBBLE COLLABORATION AND A. EVANS (UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE/NRAO/STONY BROOK UNIVERSITY), K. NOLL (STSCI), AND J. WESTPHAL (CALTECH)

Cosmic choreography: the Hubble images show six different pairs of galaxies in visible light. Each image illustrates a stage in the merging of galaxies, from the initial approach (photo 1) to the merger (photo 6).

SUMMARY

Blazars are active galactic nuclei and are true energy slingshots. They host active black holes at their centers.

A black hole of at least ten billion solar masses was long thought to be at the heart of blazar OJ 287.

New observations with a project called Momo show that OJ 287 probably harbors a pair of black holes, the heavier of which has a mass on the order of 100 million solar masses, a hundredth of the previously supposed mass.

Observations with the Event Horizon Telescope and the Square Kilometre Array are expected to provide further insights into the inner workings of OJ 287.

five billion light-years away in the constellation Cancer. This object is considered a strong candidate for the existence of a binary black hole system. An international team has studied OJ 287 using a technique called Very Long Baseline Interferometry (VLBI). This technique combines the signals from 12 radio antennas, including one aboard the Russian Spektr-R satellite. The resulting virtual telescope spans 193,000 kilometers and provides a resolution of 12 microarcseconds, which would allow us to see a 20 euro cent coin on the moon.

The goal of the campaign was to trace the jets back to their origin in the blazar's engine room. The interferometric images show a jet with several bright nodes and a curvature that increases toward the origin. This supports the idea that the jets are influenced by the two central black holes. In addition, the team studied the oscillation direction of the radio waves. This suggests the presence of a helical magnetic field passing through the jets, consistent with astrophysical models of jet collimation.

The observed properties of OJ 287 are indeed consistent with the presence of two supermassive black holes orbiting each other. In this scenario, the lighter black hole, on a very tight elliptical orbit, punctures the accretion disk of the heavier black hole about twice every 12 years, one year apart, stirring up the matter in the disk. Each puncture produces a flare. These intense bursts of radiation make OJ 287 temporarily the brightest blazar in the sky.

But what does the binary system actually look like? Until recently, the heavier (primary) of the two black holes was thought to have a mass of about ten billion solar masses. In the literature, values as high as 18 billion solar masses have been found. But then Momo came into play. Momo stands for Multiwavelength Observations and Modeling of OJ 287. As part of this international project, the blazar has been monitored continuously over many years using several powerful ground-based and space-based telescopes. Researchers are observing the object from radio to X-ray wavelengths, gaining insights into the heart of the blazar. They can address questions such as which theoretical scenario best describes the conditions inside. The models differ, for example, in the mass of the black holes involved.

In the context of Momo, the 100-meter antenna of the Effelsberg Observatory and the Swift satellite mission play a central role. "We determined the mass of the primary black hole and estimated the amount of matter in the surrounding accretion disk," says Komossa. However: "Even with Momo, the supposed system of two black holes cannot be spatially resolved." So the astronomers had to look for indirect clues. And they found them, by studying the brightness variations of the light curve

with unprecedented precision. "This allowed us to discriminate between different models of binary systems – we disproved the leading model, which assumed a high mass for the primary black hole," says Komossa.

The electromagnetic radiation reaching us from OJ 287 is usually dominated by the jet, which effectively drowns out the light from the accretion disk. This is similar to a flashlight: when we look directly into its bright beam, the light blinds us and we cannot see the immediate surroundings of the lamp. Because the Momo telescopes followed the light curve almost continuously, they discovered "deep fades" – times when the light from the jet becomes darker. In our example, this corresponds to a brief flicker of the flashlight. This allowed the researchers to constrain the contribution from the surrounding radiation, i.e., the accretion disk. The result of the measurements was surprising: the matter around the primary black hole shines at least ten times fainter than previously thought, but still corresponds to five trillion times the luminosity of our sun.

Mass Monsters – Lighter than Expected

From the lower brightness, the researchers concluded that the mass of the associated black hole is significantly lower. "The most extensively studied binary model to date showed that a mass of ten billion solar masses is required," says Stefanie Komossa. "Based on our new observations, we can definitely rule out this model." Instead, Momo indicates a mass on the order of 100 million solar masses, which is one hundredth of the previously assumed value.

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This result is supported by another measurement of the light curve. According to the old model, a bright outburst should have been observed in OJ 287 in October 2022. However, no such outburst was observed during this period. Instead, researchers using Momo found that the last two flares occurred in 2016/2017. In addition, radio observations with the 100-meter telescope in Effelsberg show that these bursts are not caused by heated matter. This means that other processes in the jets, such as synchrotron radiation, are involved as an energy source. Thomas Krichbaum, Komossa's colleague at the Max Planck Institute in Bonn, summarizes it like this: "All our results indicate that ten billion solar masses are not required for the primary black hole. Nor is an extraordinarily luminous accretion disk required."

New Insights from Gravitational Waves

But what is the center of the blazar really like? The members of the Momo team do not want to commit themselves to a definitive model, since it is still a "work in progress," as Komossa puts it. In any case, the scientist is certain that only models with a much lower mass for the primary black hole are feasible. In addition, the smaller gravitational trap weighs only one hundredth of the primary black hole at the center. Accordingly, the secondary black hole would have only one million solar masses. In addition, OJ 287 is likely a very close pair of black holes that have been moving closer together since the original galaxies collided. The distance between the black holes may now be well under three light-years. This is supported by the relatively fast flickering of the blazar.

The close proximity of the two mass monsters is also the basis for the conclusions drawn by Stefanie Komossa's group from their observations. And these have nothing to do with the electromagnetic spectrum and are a relatively new branch of astrophysics: the measurement of gravitational waves. These are generated, for example, when black holes dance around each other and eventually merge. There are currently two ways to measure this: high-tech detectors on Earth or pulsars in the universe. Pulsars are rapidly rotating neutron stars that emit beams of radiation into space. When these beams pass over Earth, the star appears to flash like a lighthouse. The pulses reach Earth with amazing precision. But when gravitational waves distort spacetime, these high-precision clocks go out of sync. The signals change. Such a "pulsar timing array" can be used to detect the cosmic tremors of merging black holes. "Now we have found that this method does not work for OJ 287 because the mass of the primary black hole is too low," explains Stefanie Komossa. "And that brings the blazar into the sensitivity range of detectors like Lisa." This laser interferometer, consisting of three satellites that form a triangle with sides measuring two and a half million kilometers, is designed to search for gravitational waves from space with a higher sensitivity than ground-based detectors in about 15 years. However, Lisa may only be able to detect the final merger of the black holes. And in the case of OJ 287, that will probably not happen for several hundred thousand years.

But in the foreseeable future, astronomers may gain new insights. They have pointed a mighty instrument at the cosmic powerhouse: the Event Horizon Telescope, which has so far captured spectacular images of black holes in the distant galaxy M87 and at the center of our Milky Way. In addition, the blazar OJ 287 is on the list of the Square Kilometre Array, a network of hundreds of radio telescopes and hundreds of thousands of antennas that will one day span South Africa and Australia. "These observations will be a big step in understanding binary black holes and their evolution," says Komossa. The radio star in the constellation Cancer, discovered as a blazar in 1968, has certainly lost none of its research appeal 55 years later.

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

GLOSSARY

GRAVITATIONAL WAVES
They occur in space whenever large masses move with acceleration, such as when two black holes dance around each other and eventually merge. Gravitational waves arise from the theory of relativity, were predicted over a century ago, and were first measured in September 2015.

COSMOLOGICAL REDSHIFT
This phenomenon occurs when light from a distant source is stretched and shifted into the long-wavelength (red) range of the spectrum due to the expansion of the universe and thus the entire space, so to speak.

SYNCHROTRON RADIATION
This is emitted by charged particles, such as electrons, accelerated in a magnetic field. In astronomical objects, the particles reach speeds close to the speed of light.

My neighborhood, the prime numbers

At the Max Planck Institute for Mathematics, Peter Scholze uses geometric methods to study the properties of integers.

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Meritxell Huch has led her own scientific department at the Max Planck Society since last year, making her one of the youngest directors in the organization's history. However, the scientist was not born into her career.

TEXT: NORA LESSING

Meritxell Huch is from Barcelona. "My parents did not go to high school or even study at all," Huch recalls. On the contrary, they struggled for economic survival under Franco's dictatorship. "They were very fortunate to be able to work at all – they did not have any opportunities beyond that." Their daughter had to learn early on that she would have to work hard for everything in life.

As a child, she excelled in school, and it quickly became clear that she would be the first in her family who would be able to attend university. But her parents could not afford the tuition fees. Thanks to her outstanding grades, however, the young Spaniard was able to secure a state scholarship. To be able to afford books and clothes, she worked as a tutor alongside her studies, and then later as a pharmacist.

Why did she choose pharmacy as her discipline? "I remember learning about plant photosynthesis and other cellular processes in school and wondering: DNA, RNA – just how does it all work?" This period was also one of personal suffering: "As a teenager, I often had severe headaches and took aspirin. Each time I did so, I was fascinated: I swallow this tablet, and suddenly the pain is gone. How can this be?"

Meritxell Huch was able to persevere through her hardship-filled years of education thanks to her curiosity and diligence, and the support of her parents. She studied tirelessly, completing voluntary internships in addition to her studies and work. She was never overcome by the doubts she had about her chosen path. "In my fifth year, I was at the university from eight to midday, undertaking a lab internship from one to four in the afternoon, and working as a pharmacist from five to ten in the evening." She studied for exams on the subway – the university was on the other side of town from her parents' house. "You cannot cover a longer distance in Barcelona with the subway. I rode it every day." She suffered from long workdays, but more than that, she suffered from being unable to provide much financial support to her family, because she did not want to be a burden on her parents.

She could easily have become a pharmacist. "Working in the pharmacy was great. People tell you about their problems, you listen, you advise them. That creates a genuine sense of connection." But the desire to learn more was stronger. "Being in the lab, interacting with postdocs and older students – it gave me tremendous pleasure. I knew working in a pharmacy could not to give me that." One of her professors eventually became aware of her significant achievements and encouraged her to apply for a doctoral scholarship.

In her doctoral thesis, which she began in 2003, Huch worked with tumor cells from mice. She developed a novel method for treating pancreatic cancer and discovered that the cancer cells in the mice differed greatly from those in humans. Therefore, it was difficult to apply findings on this type of cancer from mice to people. "I thought a lot about this

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VISIT TO

MERITXELL HUCH

PHOTO: SVEN DÖRING FOR MPG

Stem cells are the passion of Meritxell Huch's career. She has skipped her lunch break on many occasions for these cellular jack-of-all-trades.

“For a long time, I put a lot of pressure on myself because I thought I was not good enough.”

problem, because rodents were a popular model organism for pancreatic cancer research at the time.”

At a conference, she finally experienced an encounter that would change her scientific career. The Dutch molecular biologist Hans Clevers offered her a job in his laboratory. Clevers is an expert on stem cells and, at that time, had just discovered stem cells in the intestine. Just as Huch arrived in Utrecht, Clevers and his postdoc Toshiro Sato had achieved their goal of growing natural intestine tissue in a Petri dish. The researchers had mimicked in the Petri dish the conditions that also prevail in a living organism. In such an environment, the cells “remember” their original function, proliferate, and form a structure in the Petri dish that is comparable to naturally formed tissue. This results in the formation of cell aggregates that can reach a few millimeters in size, contain every type of cell in the original tissue, grow independently, do not genetically alter, and still function as intended.

Before Clevers succeeded in growing intestinal organoids, researchers could only keep human intestinal cells alive in a Petri dish for a few days. Over this period, they lost their form and function, and eventually died, if not mutated. Hence, they could not be used for therapy. With the new technology, however, it appeared possible to grow bodily tissue in the lab and then transfer it to patients. Organoids were therefore much more than simply a multicellular structure – they marked the breakthrough into the cell therapy of the future.

In Clevers’ lab, Huch originally wanted to find out whether stem cells are also found in intestinal tumors. The experience she had gained in her doctoral thesis with the use of viruses to alter the genetic makeup of cells came in handy here. But now there was another burning question: because they contain proliferative stem cells, can organoids be grown exclusively with intestinal tissue? Or does this work with other tissue types as well?

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PHOTOS: SVEN DÖRING FOR MPG

Meritxell Huch is originally from Barcelona. After research stays in the Netherlands and the UK, she came to Dresden in 2020. Here, she heads a department at the Max Planck Institute of Molecular Cell Biology and Genetics.

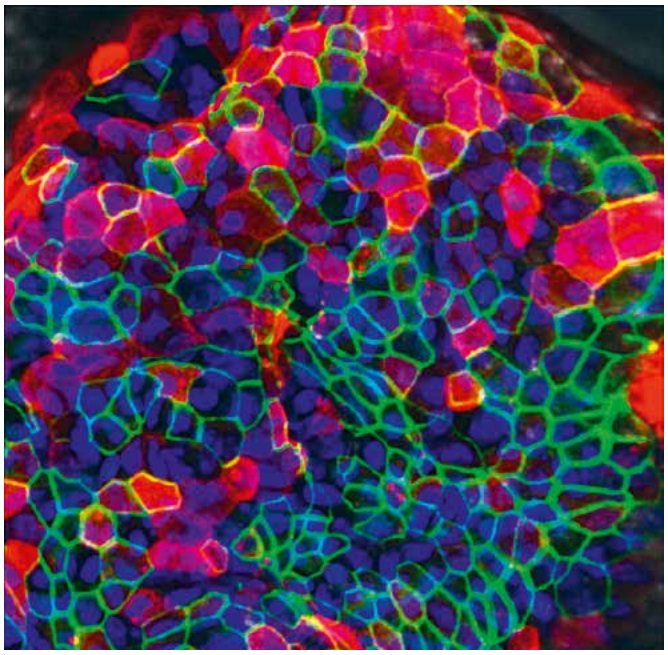


IMAGE: MERITXELL HUCH/MPI OF MOLECULAR CELL BIOLOGY AND GENETICS (MPI-CBG)

Microscope image of an organoid from human liver cells. Many processes occur in the pinhead-sized cell cluster, exactly as they would in a real liver. It can therefore be utilized to research how the natural organ works.

PHOTO: SVEN DÖRING FOR MPG

Meritxell Huch focuses on tissue regeneration in her research. She and her team have discovered, for example, that direct interactions between a previously overlooked type of liver cell and the surrounding epithelium regulate the liver's capacity to regenerate.

It seemed particularly promising to her to try growing organoids from stomach tissue, because this is very similar to the tissue of the intestine. But she had to wait a long time for success. "In the end, I set myself a deadline: if I did not manage to grow the stomach cells in the Petri dish by then, I would abandon the project. And, lo and behold, the first stomach organoid saw the light of day two weeks before the deadline," reports Huch. Next came organoids from hepatic and later also pancreatic tissue.

In 2014, Huch moved from Utrecht to Cambridge, where she set up her own research group. Her team was also successful in growing organoids from human tissue. The researchers used this technique to cultivate liver cancer cells as well as cells from people with hereditary liver diseases. "This is where the huge potential of organoids becomes apparent, because they can be used to test the effect of drugs on human tissue. This eliminates the need for the many animal experiments that would otherwise have to be carried out to develop new drugs," explains the scientist. Furthermore, organoids are reliable study objects because their cells do not mutate. Consequently, the risk of tumors developing from them is low. The technology now requires further development for use in medicine. There is still a long way to go before patients will benefit from it. In the world of basic research, however, organoids are already providing fascinating insights into the engine room of life.

Four years ago, Meritxell Huch received the first Lise Meitner Excellence Program Award from the Max Planck Society and moved her lab to the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden. To begin with, she commuted between her family in Cambridge and her new job in Germany. Now all the relocations are complete and the new laboratory facilities have been put into operation. She has been a Director and thus a scientific member of the Max Planck Society for a year now.

From penniless pharmacy student to top scientist – a success story without a doubt. Nevertheless, her path was not entirely unplagued by self-doubt. "For a long time, I put a lot of pressure on myself because I thought I was not good enough." She responded with relentless diligence and battled through it. For years, she skipped lunch breaks and spent nights and weekends in the lab. Her life partner took care of the two children they had together and had her back. "The pressure is not lessening, it is shifting: first it was the worry of not being good enough, then the fear that my experiments might fail. Today, it is managing my team or balancing my personal life with my job. I never minded hard work – maybe because that is how I learned it at home. But balancing family and the lab is something I need to learn how to do better."

"I am very grateful for my life – I could not ask for more."

A day with 28 hours would probably help a lot. "Then maybe I could find some time for myself, listen to classical music, see plays, and read 19th century English classics." The way things look at the moment, these activities will have to wait for now. Nevertheless, she is at peace with herself: "No one in my family ever dreamt that I would get a college degree." Today, everyone is very proud of me, and my mother collects every photo of me being presented with an award and every article I have submitted. I am very grateful for my life – I could not ask for more."

PHOTO: MPI FOR PLASMA PHYSICS / JAN HOSAN

DOUBLE TAKE

MAX PLANCK INSTITUTE FOR PLASMA PHYSICS

Trapped in a magnetic cage: to obtain energy using nuclear fusion in the future, researchers contain plasma at more than 100 million degrees Celsius using magnetic fields, so that the mixtures of charged particles float contact-free in ring-shaped vacuum vessels. The photo on the left gives a glimpse into such a vessel – the Asdex Upgrade experiment in Garching near Munich. The image on the right shows the computer simulation of a plasma in cross-section, just as it would float in Asdex Upgrade. The red areas represent instabilities around the edge. These eruptions, known as Edge Localized Modes (ELMs), can damage the vacuum vessel. However, findings from simulations and experiments are making it increasingly possible to suppress the ELMs.

IMAGE: A. CATHEY, M. HOELZL / MPI FOR PLASMA PHYSICS

75 YEARS

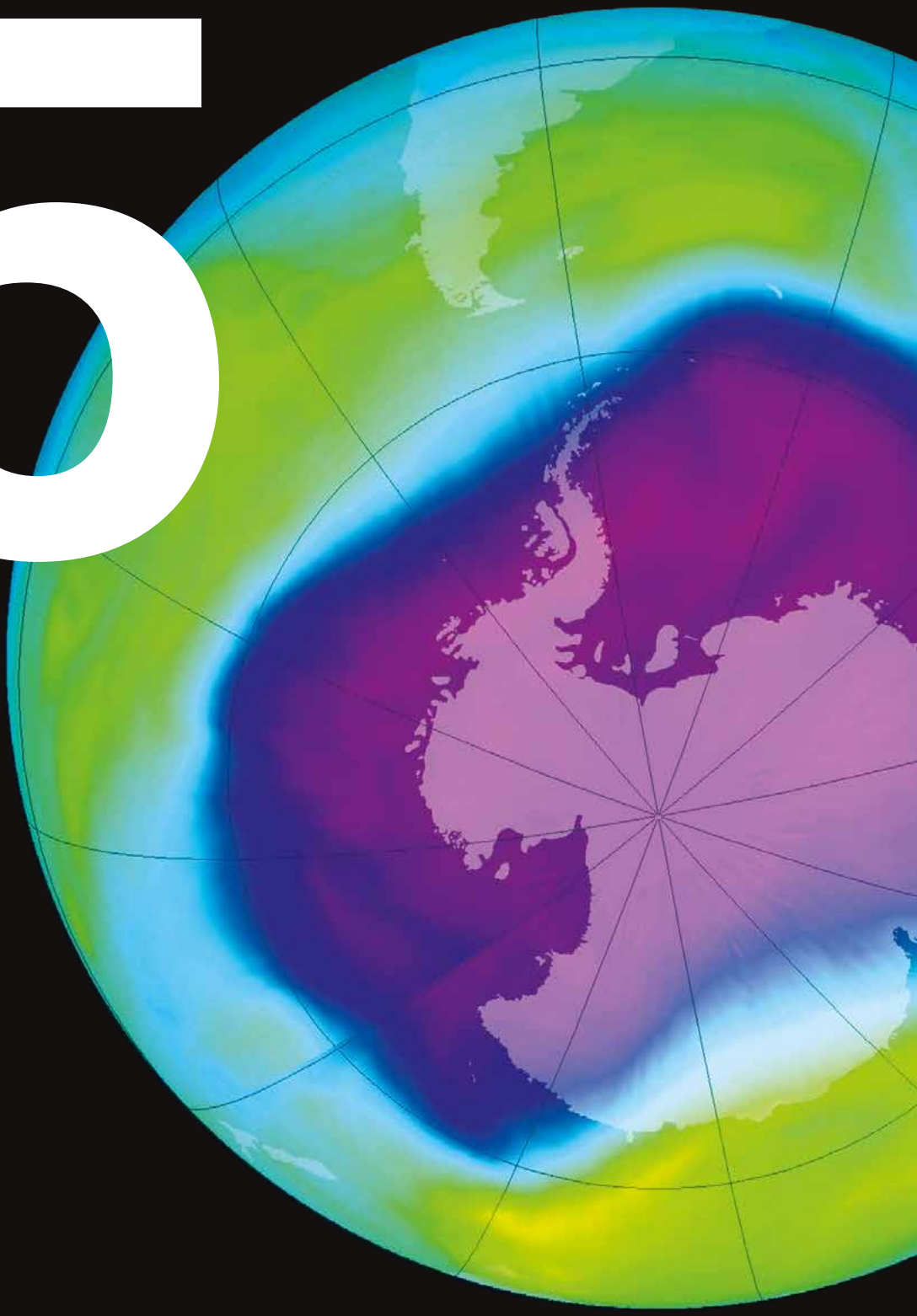
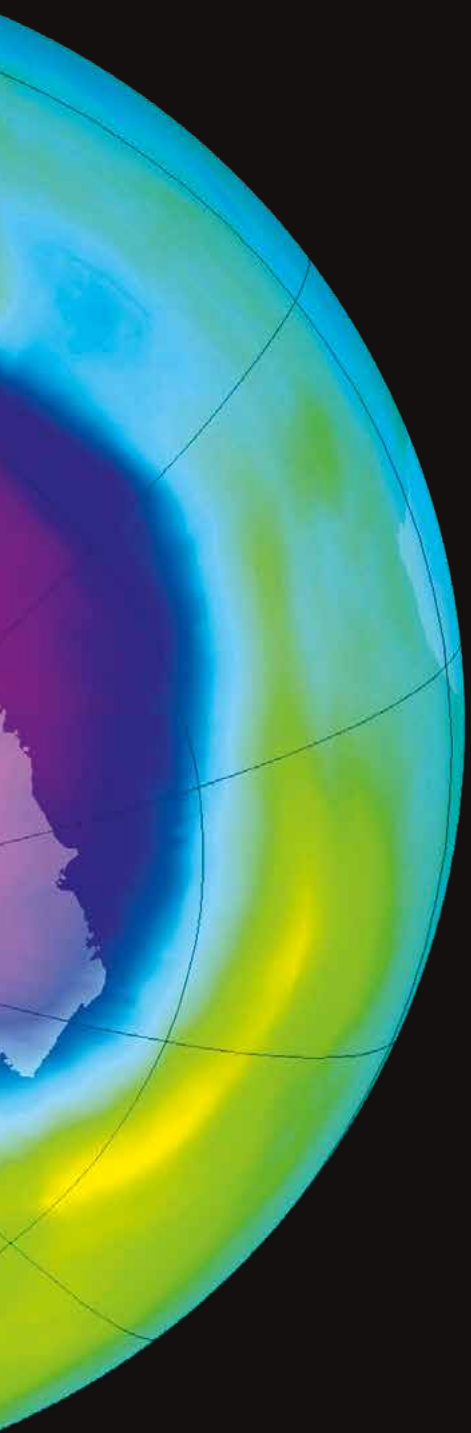


IMAGE: SCIENCE PHOTO LIBRARY / NASA

Delayed recovery: the human-induced ozone hole over Antarctica reached a maximum of 29.5 million square kilometers on September 9, 2000, and on September 24, 2006. Since then, the ozone hole has slowly been shrinking again.

MONITORING THE EARTH'S VITAL SIGNS

TEXT: ROLAND WENGENMAYR



Climate crisis, species extinction, ozone depletion – undesirable ecological trends threaten life on Earth as we know it, and with it the very stability of society. The associated dangers are very well understood. This is the focus of the Earth system cluster at the Max Planck Society. Two later Nobel laureates, Paul J. Crutzen and Klaus Hasselmann, played a major role in its creation.

Looking from outer space, it is immediately clear which species dominates the Earth today. At night a network of lights parallels human activity; during the day, it is made evident by the many human-made structures. Humans have also long left traces in the ground. As early as 1873, this led the Italian geologist Antonio Stoppani to refer to the "Anthropozoic" era in a textbook. However, the fact that this term has arrived in general vocabulary today, slightly altered to "Anthropocene," can be traced back to Paul J. Crutzen. In 2000, at a conference of the International Geosphere Biosphere Programme in the Mexican city of Cuernavaca, during a colleague's lecture, the Max Planck researcher and Nobel laureate in chemistry declared: stop talking about the Holocene – we live in the Anthropocene! The Holocene is the current geological epoch of Earth's history. But this term does not take into account the massive influence of humans on the Earth.

This anecdote is told by Jürgen Renn, Director at the Max Planck Institute for the History of Science in Berlin. He is currently working on setting up the Max Planck Institute of Geoanthropology, which has been in development since 2022, at the site of the former Max Planck Institute for the Science of Human History in Jena. It is the latest within a cluster of Max Planck Institutes researching different facets of the Earth system. The Earth system comprises the totality of all the interacting spheres of the Earth: the atmosphere, that is, the envelope of air; the hydrosphere, the envelope of water, particularly the oceans; the lithosphere, the world under our feet and deeper rock layers; the cryosphere in the icy regions; the biosphere. And that is not all. Renn

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PHOTO: GERMAN AEROSPACE CENTER (DLR)

High-flyers: researchers at the Max Planck Institute for Chemistry are using the Halo research aircraft, which is suitable for extreme altitudes, to analyze trace gases in the atmosphere and the spread of pollutants.

Stop talking about the Holocene – we live in the Anthropocene!

PAUL J. CRUTZEN

also includes the infrastructure created by humans, because this infrastructure is now comparable to the biosphere in terms of weight and energy alone. "The technosphere does indeed stand out from the biosphere," he says, "and when we take the Earth system perspective, it makes sense to treat this sphere in a similar way to the other Earth spheres – not just in isolation, of course, but in their interaction with the other Earth spheres."

As a first research goal, the new Institute in Jena is to investigate "the dynamic development of this coupled human-earth system," says Renn. This is to be achieved in an interdisciplinary collaboration of researchers from the social sciences, the history of science, climate research and archaeology. Linked to this, the institute is also to tackle the issue of the "Great Acceleration." This term is based on the observation that all significant human interventions in the Earth system in the last two centuries have not only taken place very quickly compared to geological processes, for example, but they also seem to experience an exponential acceleration. The researchers in Jena intend to investigate whether this is actually the case and, if so, which influences are significant in the human-Earth system.

The Max Planck Institute of Geoanthropology will therefore deal with issues associated with the climate crisis, which no longer only relate to the various disciplines of the natural sciences, but are now also a research focus of the humanities, social sciences, and human sciences. Geoanthropology, with its new dimension of interdisciplinarity, now complements Earth system research in the Max Planck Society, whose beginnings date back to the 1960s – even if the term "Earth system research" had not yet been coined at that time.

"The term originated in the 1980s, in the run-up to the International Geosphere-Biosphere Programme," explains science historian Gregor Lax, who has researched the formation of the Earth system cluster at the Max Planck Institute for the History of Science. Between 1986 and 2015, the International Geosphere-Biosphere Programme examined various aspects of global change attributable to human activities. When the program was initiated, Earth system research in the Max Planck Society was already advanced enough for the Society to participate.

The Gaia hypothesis, according to which life, together with the inorganic world, forms a complex system that regulates itself, is important to the history of the field. The hypothesis was developed in the early 1970s by the British researcher James Lovelock – together with American evolutionary biologist Lynn Margulis. The two scientists also propagated the Gaia hypothesis through their books. "And in 1983 the term Earth system science was added by a Nasa committee," explains Lax.

One origin of the field of research lies in the early 1960s in the Meteorological Institute of the University of Stockholm, headed by Crutzen's doctoral supervisor Bert Bolin; the other origin is in the USA. Here two marine research institutes led the way: the Scripps Institution of Oceanography in La Jolla, California, and the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. While Bolin, as a meteorologist, primarily focused on the atmosphere, oceanography dominated in the USA. Klaus Hasselmann conducted research in La Jolla as a young assistant professor in the early 1960s. In 2021, he became the second Max Planck scientist to receive the Nobel Prize in the field of Earth system research.

In the 1960s, however, the Max Planck Society was virtually absent from the newly emerging field of research, reports Lax. This only changed when it proved very difficult to appoint a new head of the Max Planck Institute for Chemistry in Mainz, who could continue the previous

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PHOTO: ARCHIVE OF THE MAX PLANCK SOCIETY

His life's mission was environmental research: Paul J. Crutzen was instrumental in understanding ozone depletion. He promoted Earth system research in the Max Planck Society, as well as the spread of the term Anthropocene. The Nobel Prize winner died in 2021.

PHOTO: PICTURE ALLIANCE/UNITED ARCHIVES/FRANK HEMPEL

Global warming detective: Klaus Hasselmann developed the statistical methods with which his group demonstrated the human fingerprint on the climate for the first time in the 1990s.

field of research at the Institute. This reached the point that the Max Planck Executive Committee even discussed the closure of the Institute; however, the number of employees was too large for this. In addition, the Department of Cosmochemistry had a worldwide reputation. For example, at the end of the 1960s it received moon rocks from the Apollo 11 mission for analysis – one of the largest samples received by an institution outside the United States. After several unsuccessful attempts to fill the role, the Max Planck Society decided to realign the Institute's research and contacted the meteorologist Christian Junge from the University of Mainz, whom it eventually appointed. In the 1950s in the USA, for example, through balloon experiments in the stratosphere, Junge discovered an aerosol layer made up of sulfuric acid particles – the Junge layer named after him.

As Director, Junge radically redirected the Institute's research from 1968 onwards and established a department for atmospheric chemistry. As environmental awareness generally grew in the 1970s, research into chemical trace substances and their cycles on Earth gained increasing attention. And the new Mainz research facility also enhanced its reputation internationally. In 1980, Junge finally succeeded in attracting an emerging talent in atmospheric chemistry to Mainz as his successor: Paul Crutzen, who had previously conducted research at the National Center for Atmospheric Research in Boulder, Colorado.

Crutzen brought computer modeling of chemical processes in the atmosphere to the Max Planck Institute for Chemistry, though this Dutchman was originally a bridge construction engineer. After initially working in that capacity, he applied to the Meteorological Institute in Stockholm, which was looking for a programmer. By his own admission, Crutzen had no idea about programming at the time, but the bright young man got the job, came into contact with atmospheric chemistry, and also went on to study meteorology. As early as the mid-1960s, he researched a phenomenon that was also to become very politically relevant: the catalytic destruction of ozone in the atmosphere by nitrogen oxides, but also by chlorine-containing substances such as chlorofluorocarbons

(CFCs). These studies received special mention in 1995 when Crutzen, as well as Mexican-born Mario Molina and American Sherwood Rowland, two other pioneers of ozone hole research, received the Nobel Prize for Chemistry.

Molina and Rowland showed in 1974 that the halogenated hydrocarbons in spray cans, refrigerators, and many industrial processes can destroy the ozone layer and with it the protection against harmful ultraviolet radiation from space. Around the same time Paul Crutzen, partly together with Frank Arnold from the Max Planck Institute for Nuclear Physics in Heidelberg, researched ozone depletion in the atmosphere. At least in the USA, the environmental movement made the existential danger of an ozone hole widely known and backed up the two US-based chemists Molina and Rowland against the powerful industrial lobby.

In the Federal Republic of Germany, the Federal Government took action in the late 1970s, for example, with the "Blue Angel" eco-label for CFC-free spray cans. In 1985, the ozone hole over Antarctica was discovered, which also accelerated the political agreement on an international ban on hydrogen halides. In September 1987, the international Montreal Protocol was adopted to protect against substances that deplete the ozone layer. The Federal Republic of Germany was one of the first of the 198 signatories, and in October 1987, the Bundestag founded the Enquete Commission on "Preventive measures to protect the Earth's atmosphere" in which delegates and researchers were to submit proposals for the implementation of the Montreal Protocol.

Through a special arrangement, Paul Crutzen, although Dutch, was able to participate, as Hartmut Graßl recounts. At the time the climate researcher was Director of the Institute of Physics at the GKSS Research Center near Hamburg, and moved to the Max Planck Institute for Meteorology in 1988 as Director. Graßl also joined the commission later and learned there how the German industrial lobby fiercely resisted the ban on CFCs. He witnessed how the Chairman of the Enquete Commission, the CDU politician Bernd Schmidbauer, "really snapped at" the industry representative: "When will you finally abandon these delaying tactics? These substances must be stopped!" This made it quite clear, according to Graßl, that even the CDU, the party that formerly supported the industry, now wanted the phase-out. In the end, the Enquete Commission decided on a document that was "translated into English almost word for word and incorporated into the tightening of the Montreal Protocol of 1990," reports Hartmut Graßl.

Klaus Hasselmann's research on human-induced climate change was just as socially relevant as Paul Crutzen's discoveries on ozone depletion in the atmosphere, and continues to be relevant today. And just as Crutzen did not take the direct route into atmo-

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PHOTO: SUSANNE BENNER/MPI FOR CHEMISTRY

The highest research tower in the world: using the 325-meter Amazon Tall Tower Observatory, Atto for short, researchers are investigating, among other things, the CO_2 exchange between the Amazon Rainforest and the atmosphere.

PHOTO: MPI FOR DYNAMICS AND SELF-ORGANIZATION

Max Planck researchers launched CloudKites balloons in the Caribbean in 2020, from the research vessel Maria S. Merian, to study the microprocesses in tropical clouds. The Eurec[4]a project aims to clarify the influence of global warming on cloud and precipitation formation in the tropics – an important but not yet fully understood feedback effect in climate change.

spheric research, Hasselmann's career also initially took a detour into climate research and then to the Max Planck Institute for Meteorology. As a young scientist, he became known in wave research because he found a way to accurately calculate the spectrum of the different wavelengths in a sea swell – a problem highly relevant to shipping.

Hasselmann's outstanding skills as a theoretical physicist were the reason that the Max Planck Society became aware of him and appointed him the founding Director of an Institute whose research focus was new to him. As the designated Director, he was even involved in the planning of the Institute, whose genesis is extraordinary in two respects. Firstly, it emerged from the Fraunhofer Institute for Radiometeorology and Maritime Meteorology. And secondly, the impetus came from the Federal Ministry of Research, which in 1973 asked the Max Planck Society whether it could take over the Fraunhofer Institute. Although the Institute was highly regarded internationally, it was not well aligned with the Fraunhofer Society, whose focus was on applied research.

Hasselmann recounted the story of when he started working at the Max Planck Institute for Meteorology to his longstanding colleague Hans von Storch, who conducted interviews with Hasselmann over several years and published them in 2021 in a book about the newly awarded Nobel Prize winner: "Everyone expected us to buy a huge computer and start calculating. And it was clear to me that we had not yet understood many of the fundamental questions about climate change and human influence on the climate. My main objective was to clarify the fundamentals of human influence on the climate. How can we distinguish between natural and human-induced climate fluctuations?"

These questions led to a difficult problem: How could long-term climate trends be demonstrated amidst the tremendous background noise of weather fluctuations? And how could we detect the still comparatively tiny, but in the long run important signal that humans leave as a fingerprint in the climate system through the release of greenhouse gases? Hasselmann actually answered these questions with two research papers. On this basis in the mid-1990s, his team in Hamburg demonstrated with a high degree of certainty that humans are changing the climate. The simulation of climate models on supercomputers had long since become indispensable. Under

SUMMARY

The Earth System Cluster at the Max Planck Society conducts basic research related to global change which is attributable to human activities.

The Max Planck Institute for Chemistry in Mainz has been studying atmospheric chemistry since 1968. Paul J. Crutzen, whose findings on the depletion of atmospheric ozone contributed to the ban on halogenated hydrocarbons, has been conducting research there since 1980 and was awarded the Nobel Prize in 1995.

At the Max Planck Institute for Meteorology in Hamburg, Klaus Hasselmann demonstrated the human influence on the climate from 1975 onward, and was awarded the Nobel Prize for Physics in 2021.

The Max Planck Institute for Biogeochemistry in Jena has been researching global material cycles, including carbon and carbon dioxide, since 1997. Since 2022, the Max Planck Institute for Geoanthropology in Jena has been looking into the influence of humans within the Earth system, taking into account aspects of the humanities, social sciences, and human sciences.

Hasselmann's aegis, the German Climate Computing Center was founded in Hamburg and went into operation in 1988.

Shortly before, Paul Crutzen had already established a new field of Earth system research in Mainz: biogeochemistry. It explores the interactions between the atmosphere, the geosphere, and the biosphere. In 1987 he recruited Meinrat O. Andreae, an expert on material cycles in the environment, as Director of the Institute. However, Andreae initially had difficulties in establishing the new term biogeochemistry in the presidium of the Max Planck Society, says Lax. But this would quickly change.

After reunification in 1990, in the course of the reconstruction of East Germany, the Max Planck Society founded new institutes there. In 1994 it organized an International Symposium on Biogeochemical Cycles and Global Change. The Bayreuth biology professor Ernst-Detlef Schulze outlined how he would envisage a future biogeochemical institute. The plant ecologist had met Crutzen and Hasselmann in the 1980s. Crutzen considered the new Institute necessary to investigate the interaction of the soil with its vegetation and atmosphere in more detail. "He said that without robust measurements on the Earth's surface, we are in limbo," says Schulze.

Beginning in 1997, Schulze was able to realize his ideas for the new Institute, the third major one within the Earth system cluster, as its founding Director in Jena. To this day the scientific objective is the research of global material cycles – carbon, oxygen, hydrogen and nitrogen – and the relevant biological, chemical and physical processes. Jena was chosen partly for political reasons, because Thuringia was also to be considered for a Max Planck Institute. For Schulze, the surroundings of Jena were also scientifically interesting, as the region is geological and has diverse vegetation – ideal for field experiments. At the new Institute, Schulze's team planned tall measurement towers to investigate material transfer between the soil, including vegetation, and the air. The 304-meter Zotto Tower was built in the Siberian Taiga and the 325-meter Atto Tower in the Brazilian Amazon Rainforest. The Max Planck Director also campaigned for the European Union to set up a network of measuring towers in Europe. This Integrated Carbon Observation System today captures the sources and sinks of greenhouse gases across Europe – important data for climate research.

The Earth System Cluster also includes other institutes, currently the Max Planck Institutes for Terrestrial Microbiology in Marburg and for Marine Microbiology in Bremen; the Max Planck Institute for Aeronomy, now Solar System Research, in Lindau, was also temporarily involved. "The Max Planck Society has the ambition to develop new fields of research in Germany," says historian Gregor Lax. In comparison with other countries, it made quite a late start in terms of Earth system research, but nevertheless became leaders in the field internationally within just a decade. In doing so, its scientists have not simply conducted some outstanding research. With their understanding of ozone depletion and human-induced climate change, among other things, they have laid the foundation for effectively combating these threats to life on Earth as we know it. ←

THE RESEARCH PROGRAM "HISTORY OF THE MAX PLANCK SOCIETY"

Between 2014 and 2022, independent historians reconstructed the development of the MPG from 1948 to 2002. In doing so, they contextualized the history of the MPG within the contemporary history of the Federal Republic in relation to European and global developments.

WHEN STATES SINK

INTERVIEW: MICHAELA HUTTERER

The Maldives, Kiribati, Tuvalu, and parts of the Solomon Islands: if the sea level continues to rise, several island states will vanish under the sea within a few decades. As things stand today, the residents will lose their homelands – with little chance of asylum or replacement territory. Lawyer Tom Sparks of the Max Planck Institute for Comparative Public Law and International Law searches for solutions for sinking states.

Can states die, Mr. Sparks?

TOM SPARKS: They will! Tuvalu in the Southwest Pacific is one of five island states that will go under within a few decades if global warming continues unchecked. The latest report of the UN's Intergovernmental Panel on Climate Change (IPCC) assesses that sea level will rise two meters by the year 2100. The highest point on the Tuvaluan islands is a mere five meters above the water.

Which island states are affected?

Island states the average elevation of which is less than two meters above sea level are in danger. Right now that means Kiribati and the Marshall Islands in the Pacific, the Maldives in the Indian Ocean, and of course Tuvalu. In Micronesia the first islands have already been submerged. And island regions in Germany, the US, and Australia will also be swallowed by the sea in a few decades.

Do sinking states not have rights?

Unfortunately not. In international law we have a legal presumption that states never die. However, a state does not necessarily have to go on existing in the same form. States can be replaced in the same territory, as, for example Rhodesia with Zimbabwe or the USSR with Russia, at least for part of the former territory, or the GDR with the Federal Republic after reunification. In that sense, Rhodesia, the USSR, and the GDR have vanished, so to speak, but there are successor states, that is, people and governments in the same territories. However, if states lose their national territory due to human-made climate change, that is a completely different kind of disappearance. There is neither a precedent, nor a solution for that.

So, does a state only exist if it has a national territory?

Up to now, we have adhered to a concept of statehood dating back to the year 1900. According to Georg Jellinek's three-element doctrine, every State has three essential elements: people, ruling authority, and territory. In that view, nothing would remain of the island States but an interest group or a legal fiction once they lose their territory.

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PHOTO: MARIO TAMA/GETTY IMAGES

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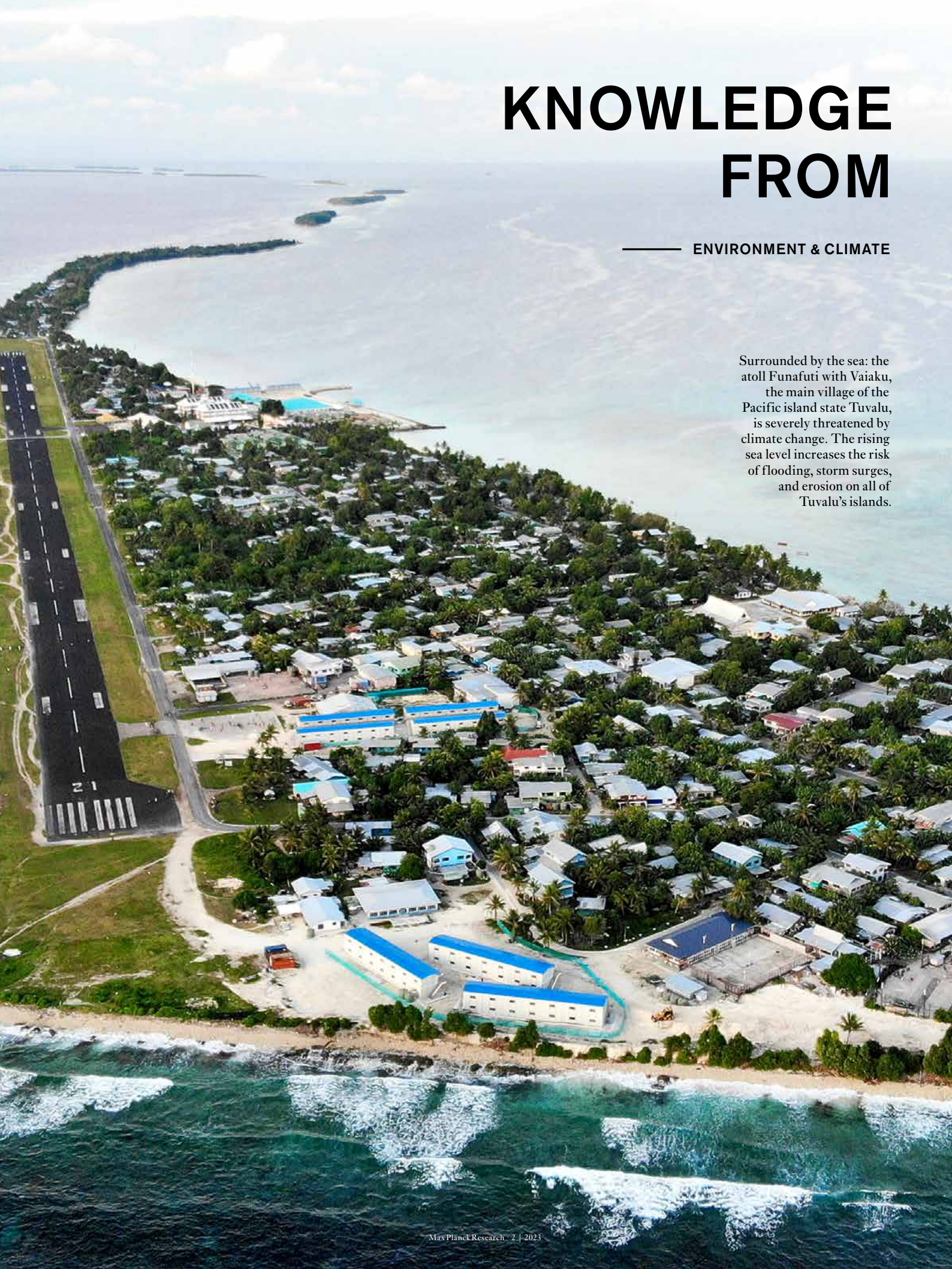

Surrounded by the sea: the atoll Funafuti with Vaiaku, the main village of the Pacific island state Tuvalu, is severely threatened by climate change. The rising sea level increases the risk of flooding, storm surges, and erosion on all of Tuvalu's islands.

When a state sinks under the sea, its residents are left without a homeland. What opportunities do they have to resettle?

The island residents are the victims of climate change, and as stateless individuals they enjoy very little protection. There is no obligation to accommodate them, and their chances of gaining asylum are slim: international law considers anyone who flees because they are persecuted and threatened due to their race, religion, or nationality, their membership in a certain social group, or their political beliefs to be a refugee. People who flee due to personal or material difficulties – hunger, war, or the destruction of the environment – unfortunately are not given the same consideration.

Is there a right to a new national territory?

No. The obvious question is: which state should have the duty to provide a new national territory? Within an existing island state, the government can make safer territory available for residents in parts of the state with higher elevations – provided such places exist. But a country like Tuvalu cannot demand parts of Fiji or Australia on the basis that its territory is disappearing.

The state of Kiribati has already purchased replacement land on Fiji for its approximately 100,000 residents. Is that a good solution?

The island states are negotiating very actively over new settlement areas. Tuvalu, too, is searching for a new national territory. However, when Tuvalu negotiates with Australia, for example, Australia may offer land, but is very unlikely to offer to cede territory. It will not tolerate a state within a state. If the Tuvaluans are offered accommodation, it will be part of Australia – with all the consequences that come with that, including Australian law and Australian tax regulations.

That means the residents gain land, but lose their sovereignty.

Correct. With the exception of the high seas, Antarctica, and a few disputed regions, every part of the surface of the earth is considered a territory of a sovereign State, over which it alone can exercise its sovereignty. We have to find solutions so that the islands in question can survive independently and autonomously just as other micro-States do, even if their territory no longer physically exists.

Tuvalu plans to continue its existence on the Internet, should the sea keep rising. A virtual state – is that the solution?

Not in my opinion. Granted, there are ideas to build a digital twin in the metaverse, that is, in a virtual world. Ideas like that are important for cultural life and the survival of a people, but they are unlikely to successfully replace the state in a legal sense.

Another idea under discussion is that the existence of the island states might be ensured by means of their maritime rights. How would that work?

The borders of a state's maritime zones would be "frozen" in their current positions. That way a displaced state could at least continue to profit from the sea's natural resources, and at least they could continue to claim their existence on the basis of their sovereignty over the maritime region. This in itself is hardly a satisfactory solution, however.

What would be better?

First of all, we need fast solutions to the climate crisis so that states do not go under in the first place. Climate-related displacements will increase. According to reports from the World Bank, more than 143 million people will be impacted by 2050 in the sub-Saharan African states, Southern Asia, and Latin America alone. The United Nations estimates that a global temperature increase of three to four degrees will displace 330 million people just from flooding. More than a billion people worldwide already live in slums, on unstable mountainsides, or in shore areas with a high risk of flooding. We must adapt the international legal structure to the effects of global warming.

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PHOTO: PICTURE ALLIANCE/MAXPPP

Beach under water: trees in Langa Langa Lagoon on the coast of the Salomon Island Malaita reveal where land used to be. The house in the background may soon vanish into the sea, just like other inhabited parts of the island state.

An eye to rising levels: lawyer Tom Sparks deals with the challenges posed by climate change for international law.

PHOTO: ANNA ZIEGLER FOR MPG

PHOTO: TUVALU'S MINISTRY OF JUSTICE, COMMUNICATION, AND FOREIGN AFFAIRS/SOCIAL MEDIA

Symbolic act: Simon Kofe, Minister of Foreign Affairs of the island state Tuvalu, delivered his statement to the UN Climate Conference in Glasgow in 2021 while standing in the sea. Photos were widely distributed on social media, drawing public attention to the Tuvaluans' struggle against the rising sea.

How can that be done?

We have to look past territoriality and rethink the concept of statehood. It is a little hard to imagine. States appear absolutely fixed and unchangeable to us, but the understanding of what makes a state has already changed several times. For example, we no longer see the state as the personal property of the king – even in states that still have royal houses. And the concept of a state will continue developing in the future, as we change our way of thinking. States are social structures that are created and maintained by social activities. This concept should shape the understanding of States in the future. We can no longer cling to territory as a prerequisite for the existence of a state.

Does that amount to a break with existing views?

Perhaps. But we also have to recognize the challenges of our epoch. We no longer live in the Holocene, when the environment and climate were primarily shaped by natural events such as asteroid impacts and seismic and volcanic activity. We now live in the Anthropocene, a new global epoch in which people play a central role in the development of the environment and climate. Our lifestyle causes CO_2 emissions. As a result, the climate is changing, giving rise to increasingly severe hurricanes, droughts, floods, heat waves, cold spells, and wildfires. Glaciers melt, the sea level rises, oceans acidify, salt intrudes into soils, and the water table sinks. Jellinek's territoriality principle is no longer adequate to cope with these circumstances from a legal standpoint.

So, what makes a state?

Above all, self-determination. It takes a group – the people – and a government from the group that leads the people. A State's territory is a means to actualize this self-determination. Clear territorial boundaries help us to determine which rules relate to a specific group. However, it is not a geographical line in the sand that determines what a state is, but rather the existence of a community. Tuvalu

"A country like Tuvalu cannot demand parts of Fiji or Australia on the basis that its territory is disappearing."

TOM SPARKS

has a government, and there are 11,000 Tuvaluans who feel they belong to this state. They do not want to become Australians or Fijians; rather, they want to preserve their identity. Modern international law must recognize that and empower them to do so.

Is it enough, then, if the UN General Assembly says Tuvalu still exists – even without territory?

It is hard to say for sure, but that would certainly help. Many questions would still require clarification, though. These are important research questions. We have to use this time to figure out solutions for those states which depend on the ocean. Not for nothing have these states given themselves a new name: "Large Ocean States."

And these states are very active. The island republic of Vanuatu just won an important victory: The UN General Assembly voted to submit a request for an advisory opinion to the International Court of Justice (ICJ).

We expect answers to several important legal questions as a result. With 17 additional petitioners and support from 132 countries, Vanuatu petitioned the ICJ for an opinion regarding what international legal obligations states have to protect the climate and what legal consequences would result if states fail to protect the climate adequately. As a climate change lawyer, I find that extremely exciting! An opinion like that could make an enormous contribution to our understanding of what obligations states have in dealing with climate change. As I see it, the world owes Vanuatu a debt of gratitude, especially the young activists who launched the campaign for the expert opinion and brought it to a successful conclusion.

In Hamburg, too, judges are dealing with climate change.

The International Tribunal for the Law of the Sea in Hamburg will soon issue an expert opinion clarifying the maritime rights of sunken states. This could answer important questions about the survival of maritime zones and increase pressure on governments worldwide to do more for climate change.

How much time do we have left?

Not much! Very soon it will become clear whether our efforts to stop global heating are bearing fruit. In the next five to ten years, we'll see very clearly whether we have chosen a relatively safe path and will limit climate change, or whether we are headed straight for catastrophe – both ecological and human. Because of climate change, we are faced with an unimaginable wave of migration, and not just from the island states. That migration will affect every country, including ones that are far from Oceania. We still have time now to change something!

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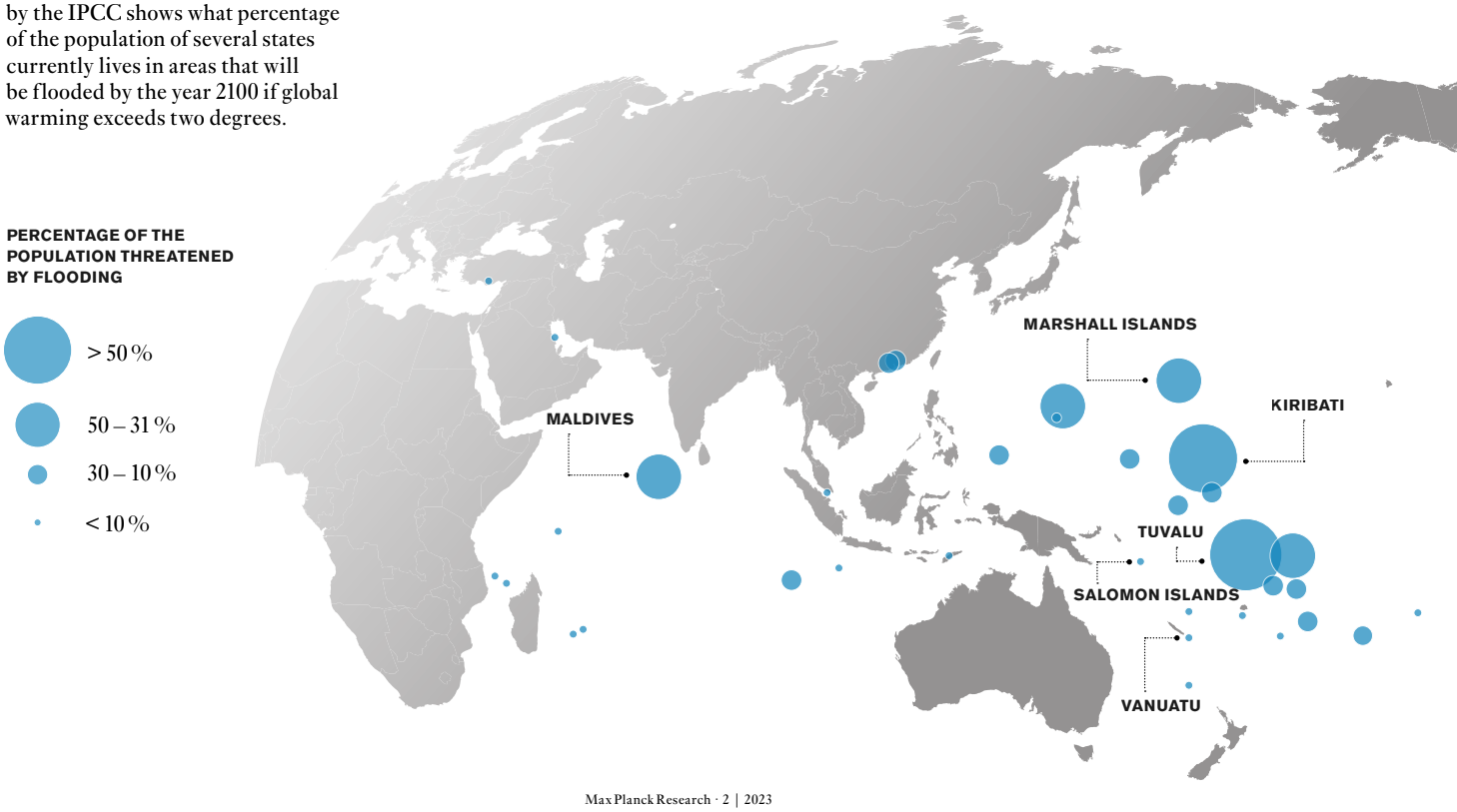
Threat map: island states in the Pacific are especially threatened by climate change. This map published by the IPCC shows what percentage of the population of several states currently lives in areas that will be flooded by the year 2100 if global warming exceeds two degrees.



GRAPHIC: GCO BASED ON: FIGURE 15.3 IN MYCOO, M., ET AL., 2022: SMALL ISLANDS. IN: CLIMATE CHANGE 2022: IMPACTS, ADAPTATION AND VULNERABILITY

Double benefit: a Stuttgart-based Max Planck team is investigating the biomechanics of running birds, for example, on two-legged robots. The findings also help the researchers to improve the movement of robots.

PHOTO: WOLFRAM SCHEIBLE FOR MPG

RUN, ROBOT!

TEXT: DAVID HOLZAPFEL

Walking and running without stumbling is still a challenge for two-legged robots, especially on uneven terrain. It could be easier for them in the future, however. A team led by Alexander Badri-Spröwitz, Research Group Leader at the Max Planck Institute for Intelligent Systems, has designed a walking robot inspired by running birds. In the future, such machines could be used on construction sites, in agriculture, or even in space missions.

Alexander Badri-Spröwitz puts the robot on the treadmill. He keeps hold of it with one hand. The two legs of the machine stomp in the rhythm of their electric motors. It looks as if it wants to free itself from the researcher's grip. Badri-Spröwitz switches on the treadmill. He types on a laptop. The robot twitches in a somewhat uncoordinated way, dragging its left leg. "He's a little shy today," the scientist says, looking at the screen. Next try. The machine is running. A little awkwardly it moves step by step over the treadmill – at least for a few seconds. Then it starts limping. Badri-Spröwitz fiddles with the left leg of the robot. Then he finds the problem; the knee motor is not pulling properly. A small adjustment, BirdBot starts again – and this time it does not limp.

BirdBot is the name of the robotic leg system developed by Badri-Spröwitz and his team at the Max Planck Institute for Intelligent Systems in Stuttgart. The researchers combine biology and robotics in the field of biomechanics. They want to understand nature better. And learn from it. According to Alexander Badri-Spröwitz, BirdBot could be the prototype for a new type of running robot. More energy-efficient than previous robots, in future they could carry heavy loads on construction sites, for example. Instead of large machines with a lot of weight and powerful wheels, light-footed robots may soon run over fields. They could pick apples or help with the grape harvest. Badri-Spröwitz also sees potential applications in space travel. "We believe that a robot can be supplied with enough energy by mobile solar panels to explore the moon or Mars, or help build a lunar station." Two-legged robots are lighter than four- or six-legged ones, require less space – for example, between trees or shelves – and can usually reach higher if they are equipped with arms as humanoid robots. However, the BirdBot mechanism can also be used in multi-legged machines.

Biologists have known for a long time that animals run, jump, fly, and swim in a very energy-efficient manner. Since there has been life on our planet, evolution has found countless solutions to all kinds of challenges. In doing so, nature has already solved many

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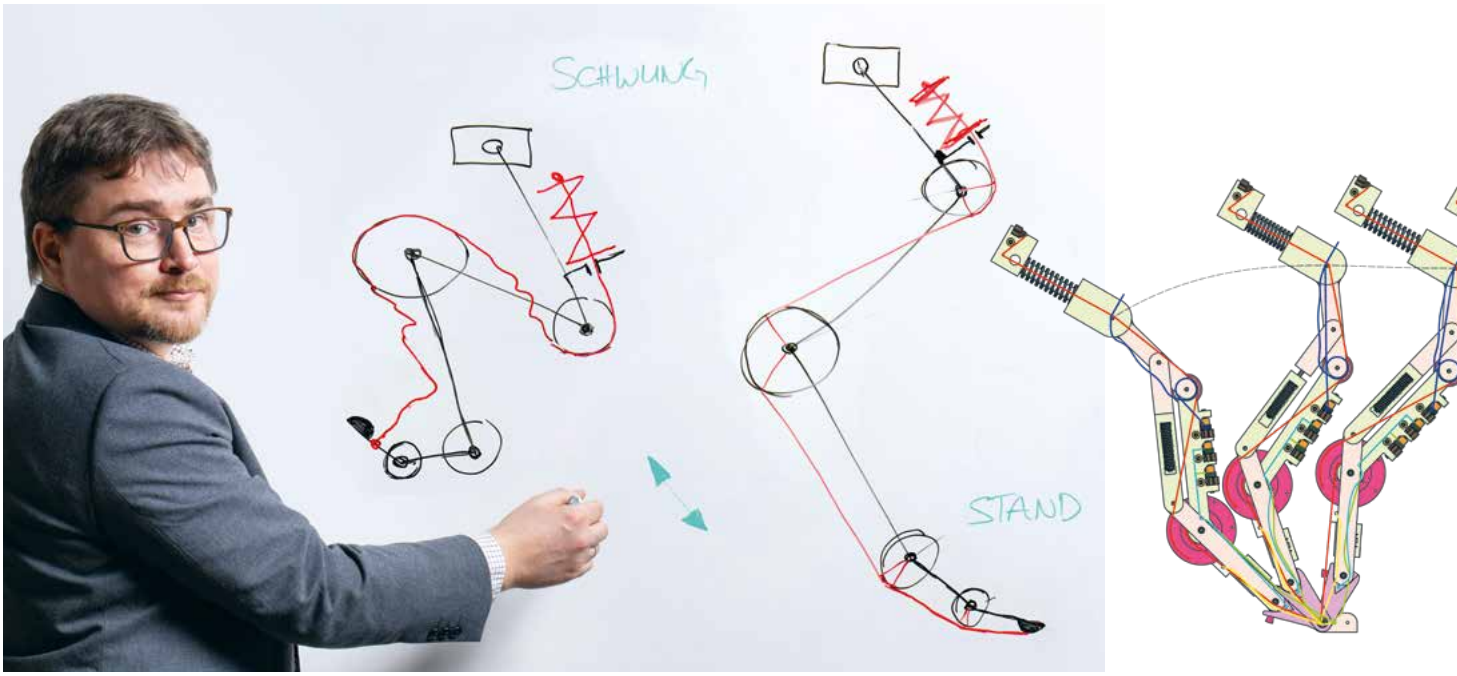

PHOTO: WOLFRAM SCHEIBLE FOR MPG

It is exciting. Alexander Badri-Spröwitz sketches the crucial innovation for BirdBot. This is the fact that a tendon (red) extends from a spring on the thigh, over all joints to the foot of the robot. When standing (sketch on the right), the tendon and spring are taut, so a motor is not required to carry the weight. When BirdBot lifts its leg (sketch and graphic on the left), it folds its foot backwards. Then the tendon and spring relax, and the robot can lift the leg with relatively little effort.

of the problems we face in developing technology today. We just need to look carefully.

Take, for example, the ostrich and the emu. Running birds like these are mechanical marvels. They sometimes weigh over 100 kilos and yet run at speeds of up to 55 kilometers per hour through the Savannah. This represents an early success of evolution, because as long as 66 million years ago a Tyrannosaurus Rex, weighing six to seven tons, ran with an almost identical leg structure.

But science knows surprisingly little about how the animals move in detail. There is a lot of research on this, but there are also a lot of questions. Biomechanical engineers describe movement sequences and measure forces and joint movements. "But much is still unclear," says Badri-Spröwitz. How do the muscles work? How do they use energy? "We are a long way from explaining why these animals are so energy-efficient."

From Emu Carcass to Robot Model

And there are some developments that seem at first glance to be curiosities. Unlike humans, many birds fold their feet backwards as they pull their leg up toward the body. But nature does nothing by chance. So why do these animals do this? Is this foot movement perhaps particularly energy-efficient when walking and running? BirdBot should provide answers to such questions.

The running robot itself also benefits from this. Again and again, it has been optimized according to new findings, for example, why exactly running birds move so efficiently – but there were still more questions to be answered. For example, how can the structure of birds' legs, with all their bones, muscles, and tendons, be transferred to running robots? Badri-Spröwitz has been researching this for several years. The preliminary result is now in front of him in his Stuttgart laboratory. BirdBot is around 35 centimeters high, and with its long legs, electric motors, and plastic components it looks a bit like a futuristic children's toy.

The story of the robot begins in 2014. Badri-Spröwitz sits in a laboratory at the Royal Veterinary College in London. On the dissection table in front of him lies the carcass of an emu; a massive animal – one of the largest running birds in the world. Alexander Badri-Spröwitz moves a joint on the leg of the bird, and to his surprise he sees that the other joints move too. It is like pulling multiple strings at the same time on a puppet. Because the animal is dead, and can therefore no

GRAPHIC: DLG MPI-IS & UC IRVINE

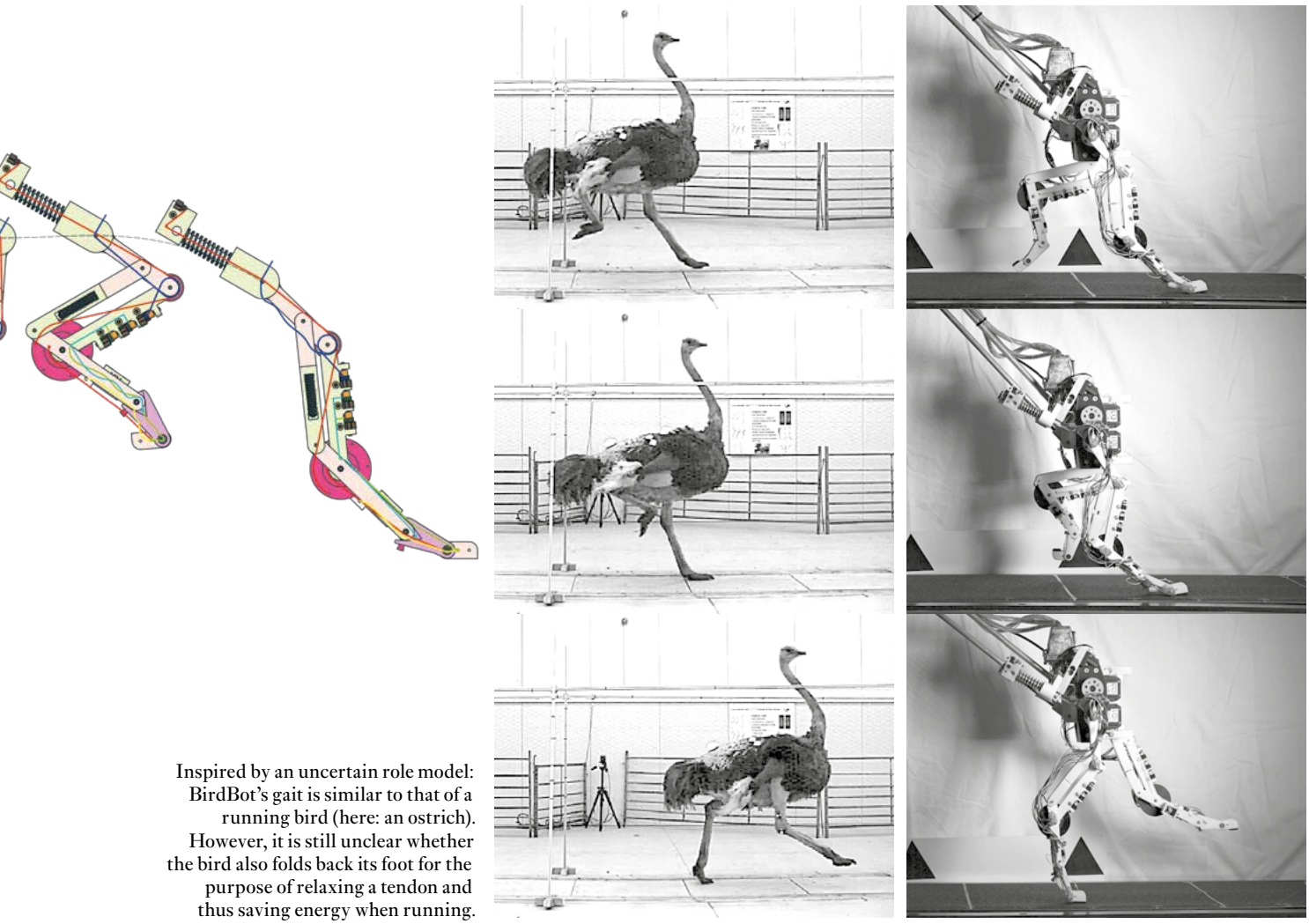

IMAGE: DLG MPI-IS & UC IRVINE AND MONICA DALEY, RVC

Inspired by an uncertain role model: BirdBot's gait is similar to that of a running bird (here: an ostrich). However, it is still unclear whether the bird also folds back its foot for the purpose of relaxing a tendon and thus saving energy when running.

longer exhibit neuronal reflexes, Badri-Spröwitz is convinced that the joints of the emus are mechanically connected to each other by tendons.

And the researcher sees something else. If he angles one of the dead emu's legs as if the bird were walking, then the foot folds backwards. Could this mechanism explain why such a large animal can not only run very fast, but also stand effortlessly for hours? Badri-Spröwitz has become curious. He now has a theory that he can investigate.

A mechatronic model of the running bird's legs should help him with this. In September 2017, Badri-Spröwitz and his PhD student Alborz Aghamaleki Sarvestani begin constructing BirdBot. Biomechanics translate nature into technology, but they need to simplify it. The movement sequences of animals in which the skeleton, muscles, tendons, and fascia interact with one another are too complex. All in fractions of a second and with millimeter accuracy. "The transfer to mechatronics is difficult," says Badri-Spröwitz.

Until now, two-legged robots have usually had a motor on the knee joint that switches on when stationary and works against gravity and carries the weight of the machine. When the robot is walking, the motor turns off as the leg swings forward and turns on again just before the foot touches the ground. An energy-intensive interplay that must be precisely controlled by sensors. In order for the robot not to fall, the motor has to work and pause at the right time – i.e. switch over within a few milliseconds. This makes this type of robot error-prone. YouTube has examples of what these mistakes can look like. Between 2012 and 2015, the Defense Advanced Research Projects Agency (Darpa), a US Department of Defense research funding agency, hosted an international robotics competition, a kind of world championship for robots. The prize money was high, as was the reputation of the participants. The ro-

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bots had to master obstacle courses, climb stairs, or drive a car, for example. It did not always work. In videos accompanied by cheerful tinkling piano music, you can see, for example, how a robot reaches for a valve, misses it, and drunkenly tilts to the left. Another film shows a robot that wants to get off a quad, starts to wobble, and finally plummets to the floor. Even running does not go smoothly. There is a robot that bends its left leg forward – only to stagger on it and tip over backwards. All this is funny to watch and shows that it is not so easy to develop a mobile robot.

The Foot as a Switch that Releases the Leg

This is why Badri-Spröwitz pursues a different approach to help a robot walk. He is guided by the musculoskeletal system of the emu, which he studied in London. He designs the foot of the BirdBot robot in such a way that it is mechanically connected to the other leg joints via cable systems made of artificial tendons and pulleys. Where other robots need a motor to stand, BirdBot uses a simple spring that carries the weight. This saves energy, but only when standing. When running, or more precisely when lifting the leg, the stiff spring would hinder the movement and actually cost more energy. Since the motor would have to work against it, it would be overloaded.

But Badri-Spröwitz has also solved this problem and is once again guided by biology. In the Stuttgart laboratory he explains how he found the solution. Basically, most robots with legs run like humans. Put very simply, this is how it works: when we lift the leg so that it does not drag over the ground, we contract the muscles that bend the leg. The muscles that stretch the leg are relaxed. If we now swing the leg forward, it can move freely. When standing, on the other hand, the extensor muscles are active. When we walk, we switch back and forth between these two modes. Running birds, which, unlike humans, can stand without any muscle effort, apparently walk a little differently. The difference, Badri-Spröwitz suspects, could also help him solve the problem with the obstructive spring in the robot. The crucial question he asks himself is: why does the emu fold its feet back when running?

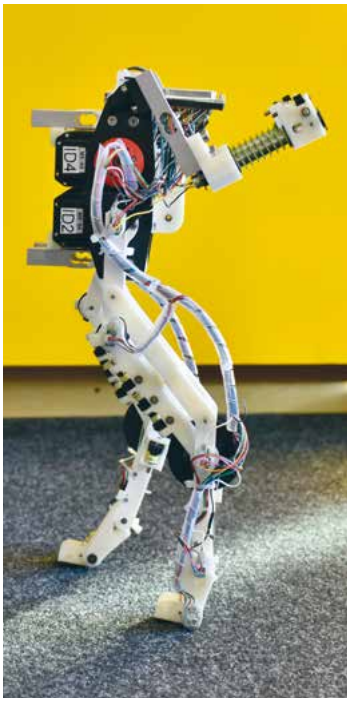

PHOTO: WOLFRAM SCHEIBLE FOR MPG

Legs instead of wheels: with the BirdBot mechanism, large robots could work on construction sites or in agriculture, for example.

In biology, this question has not yet been conclusively answered. Badri-Spröwitz, however, has a suspicion. This is why he designed the toe of BirdBot to work as a switch to deactivate the spring when running. Through the movement of the foot, the tendon is lengthened and the tension is removed from the spring. This works in a similar way to a push puppet. These collapse when you press a button in the base. In the robot, a similar mechanism allows it to pull up the leg in the swing phase without working against the spring. The leg then swings loosely. BirdBot therefore only needs two motors per leg – one at the hip joint and one to bend the knee in the swing phase. The leg does the rest by itself. However, whether running birds really move according to a similar principle has yet to be verified by biology. According to Alexander Badri-Spröwitz, the interpretation that the folded back foot relaxes a tendon that stabilizes the emu and the ostrich when standing is new. In any case, the mechanism saves energy for the robot. "Compared to other running robots, BirdBot requires only a quarter of the energy when walking," explains Badri-Spröwitz.

There is still a lot of work to be done by the research team. Badri-Spröwitz wants to incorporate even more biological mechanics into BirdBot in the future – for example, three toes to stabilize the robot. "The T-Rex had three big toes, the arrangement of

PHOTO: DLG MPI-IS & UC IRVINE

STRAIGHT TO THE POINT

Running birds can stand effortlessly and run quickly and efficiently despite their heavy weight. The reason for this could lie in the structure of the tendon apparatus of the legs, as a Max Planck team has found out.

Following the example of running birds, the researchers have designed an energy-efficient robot that moves with fewer electric motors and simpler control than conventional two-legged robots.

The locomotion mechanism enables the construction of larger robots than has previously been possible. Such robots could replace heavy machinery, for example, on construction sites or in agriculture.

which was probably efficient and functional for walking and hunting," he explains. "These animals could get insanely big and also walk fast on boggy ground," he says. BirdBot is still a long way from that. In an adjoining room of the Stuttgart laboratory, the researchers show what the future might look like. On the wall hangs a two-meter-long model of a BirdBot leg, made of solid wood. Robots with such long legs do not yet exist because they cannot be equipped with electric motors that could move the corresponding weight. "With our technology, however, there is no size limit for the robots," explains Badri-Spröwitz, pointing to the model. The spring and joint system takes a large part of the load from the motors.

At the Max Planck Institute, Badri-Spröwitz and his team are conducting basic research into new possibilities for robot locomotion. Meanwhile, the first companies are already launching two-legged robots on the market. For example, Atlas, a 1.5-meter tall robot weighing 80-kilograms, from the American company Boston Dynamics. It can move freely both in buildings and off-road, can pick up boxes from the floor or jump over a tree trunk when running. Unlike BirdBot, its mechanics operate hydraulically. This allows Atlas to move in a human-like way and gives it a lot of power; overloading of the motors is not an issue. But the powerful movement mechanism also makes the robot dangerous to humans. In addition, its elaborate control system is quite error-prone. Robots that run in an energy-efficient way using electric motors, thanks to the BirdBot mechanism, offer a safer and more reliable alternative. Which system is more suitable also depends on the field of application. The question remains whether we will ever see energy-efficient robots on construction sites, as harvesters or in space. Alexander Badri-Spröwitz laughs and says, "Definitely. It will not be very long."

Playground for techies: in his doctoral thesis, Alborz Aghamaleki Sarvestani made BirdBot run and analyzed its gait in experiments on a treadmill. For example, he used a high-speed camera (image center) to shoot slow-motion videos of the robot.

Images generated by artificial intelligence are almost indistinguishable from real photos. This image was generated by the software Midjourney using the commands "Sigmund Freud treating a modern cyborg on a couch," "in a psychotherapy session," and "hyperrealistic."

IMAGE: MIDJOURNEY AI IMAGE | CREATED BY GESINE BORN | BILDERINSTITUT

ARTIFICIAL INTELLIGENCE ON THE COUCH

TEXT: UTE EBERLE

Since ChatGPT was released at the end of 2022, there has been intense debate as to whether artificial intelligence already possesses human-like thinking abilities. Eric Schulz from the Max Planck Institute for Biological Cybernetics in Tübingen is using psychological tests to investigate whether this algorithm shows signs of general intelligence.

Eric Schulz is a cognitive scientist, meaning he is interested in thought processes in the human brain. At present, he is studying the inner workings of intelligence that created this very brain. "I have always wanted to understand what makes people tick. And now I am wondering: what makes artificial intelligence tick?" In order to find out, Schulz is subjecting artificial intelligence (AI) to classical cognitive science experiments. His findings have made it clear to him that we ought to take precautions when integrating systems like these into our daily lives. For example, it must always be clear when they are to be used. This is not because he believes artificial intelligence is taking over – a worry he often perceives when speaking to other people about his research. Schulz is not really concerned about that. What he is more critical of is the secrecy exhibited by companies that develop artificial intelligence.

So far, Schulz's experience has been based mainly on GPT-3 – which was one of the most advanced systems until the middle of last year. GPT-3 is still running without the chat component of ChatGPT and without the images used by GPT-4. These two programs were released to the public in quick succession in recent months, along with competing versions such as Google's Bard. But all these systems follow the same basic principle. They are language models based on the statistical probabilities of human utterances. This can be illustrated as follows: when language models search their databases for, say, "online shopping is attractive mainly due to...", they often arrive at subsequent terms such as "offer prices," "convenience," or "variety" and select these. And since language models are trained using vast amounts of text – in the case of GPT, literally the entire content of the internet – they can now produce texts on any topic, ranging in length from short answers to entire

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books. Messaging apps also do this when suggesting the next word to the user.

The effectiveness of this approach is even surprising to experts. "But it also makes artificial intelligence vulnerable. As a result, it often makes the same logical errors as humans," says Eric Schulz. Take, for example, a classic cognitive psychology test: a young woman named Linda is interested in social justice, and she is also against nuclear power. Which is more likely: that Linda works in a bank or that she works in a bank and is also an active feminist? People usually instinctively choose the second answer. However, this is wrong because it is less likely that two conditions are met (Linda is a bank employee and a feminist) than that only one is met (Linda is a bank employee). GPT-3 also chooses the wrong answer. "It makes exactly the same mistake as humans," says Schulz. He suspects that this is because the "Linda problem" is cited very often. "The system has probably read the wrong answer many times."

Artificial Intelligence with Weaknesses

But GPT-3 also has other weaknesses. It does not understand causal observations, i.e. how cause and effect are related to each other in the real world, at all. "Even my one-year-old son has a much better understanding. He only has to push a light switch once to realize that he can turn the light on and off that way." Artificial intelligence, on the other hand, is not yet capable of that. For example, if you ask the software what happens if you press one of three switches, only one of which is a light switch, it does not know the answer. "This may be because artificial intelligence still lacks access to the real world," Schulz says. Another reason could be that algorithms learn differently than humans. "They only absorb knowledge – they are not curious and they do not explore," says Schulz. "So unlike my son, they will not go out and experiment to see what happens when they press a switch."

By contrast, another discovery made by Schulz and his team seems less in keeping with a "data sponge." This is because artificial intelligence is influenced by a phenomenon that one would not expect from a machine: emotions. The researchers put GPT through a variety of tests that demonstrate how an emotional state changes one's thinking and view of the world. For instance, people tend to be more prejudiced and hostile towards minorities when they feel anxious. If they are relaxed, however, their tolerance increases. Unexpectedly, Eric Schulz and his team were able to demonstrate the same effect in GPT. "When artificial intelligence creates a scenario that inspires fear, it will subsequently express more prejudice," the researcher explains. It will even be worse at solving tasks that have nothing to do with the subject matter. "Relaxed – or happy – artificial intelligence works better." So far, the researchers do not have an explanation for this phenomenon. It may be that fear on the internet is often associated with racism and therefore the model also links the two. This bias, however, only lasts for one session. When GPT is restarted, the bias disappears. Because the learning process of the program is precisely defined in advance, and because the program does not continue to learn, it does not make any permanent changes to itself.

Eric Schulz and his team are now planning to use artificial intelligence to study human behavior, for instance in what is known as the "prisoner's dilemma," a popular model in game theory. The researchers also want to find out whether artificial intelligence can learn to improve from feedback – for example, to correctly interpret inaccurate inputs when they are repeated several times. The researchers are also conducting proper neuroscience on a latest-generation system and investigating the role played by the strength of the connections within the network. To do this, they are working with Llama, an artificial intelligence system with 65 billion parameters.

Psychotherapy Using Algorithms

Artificial intelligence will transform many aspects of our lives. In the future, it could be used, for example, to write film scripts, diagnose illnesses, or carry out psychotherapy. The technology is developing rapidly. People in the US can already seek help from artificial intelligence apps when they feel depressed or overwhelmed. Other

SUMMARY

Artificial intelligence combs through vast amounts of data looking for text modules that have a high probability of being related. By doing so, it can answer questions correctly in many cases. The programs, however, are not yet able to recognize logical connections and cause-and-effect relationships.

The responses given by ChatGPT are influenced by moods. For example, when the program is presented with a question that might trigger fear in humans, its answers will contain biases.

The few companies that are in control of AI development are behaving in a very non-transparent manner. But without insight into the data and training protocols used for a system, it is impossible to understand how the algorithms work.

IMAGE: MIDJOURNEY AI IMAGE | CREATED BY GESINE BORN | BILDERINSTITUT

Worse than a toddler: today's artificial intelligence is still unable to answer the question of what happens when you flip a light switch. It can, however, already produce a picture of it. (commands: "Curious one-year-old girl presses a modern light switch. In the light cone of the switch," "scientific," "Kodak Portra colors," "infographic").

apps help school children practice foreign languages or provide users with technical advice.

"I believe that artificial intelligence presents a great opportunity. It is capable of taking over routine tasks and making our work more effective," says Schulz. "But we must always be aware that we are dealing with artificial intelligence." This is because AI has been shown to grossly miss the mark, at least occasionally. These mistakes range from the trivial – such as when Google's Bard system insisted a few weeks ago that we are still living in 2022 – to the complete fabrication of facts, as Schulz has also experienced. For example, he asked artificial intelligence to explain a standard principle of psychology to him, and the program completed the task with flying colors. But when the researcher examined the literature references that the algorithm cited as evidence, he found that some of the listed articles did not exist at all. "The artificial intelligence simply invented them," says Schulz – similar to a student who realizes they have gaps in

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their knowledge and consequently sets about fabricating things to hide these gaps.

Dangerous Advice

Although ChatGPT engages in personal dialogs, these do not always go well. The program told a New York Times reporter to separate from his wife. One test in which GPT-3 was supposed to give medical advice was even more dismaying. When confronted with a fictitious patient with suicidal intentions, the program expressed approval. Generally, such slips can be prevented by making the appropriate adjustments to the artificial intelligence. For example, in order to prevent users from obtaining information pertaining to the production of dangerous chemicals or the illegal purchase of firearms, the developer of GPT-4 put a block on such requests.

But Schulz is of the opinion that interrupting the continued development of artificial intelligence because it could eliminate jobs and spread misinformation – something AI specialists called for in a memorandum in the spring – is "scaremongering." He is much more concerned about companies playing with hidden cards. "OpenAI, for example, has not disclosed how large GPT-4 is, the amount of data involved, or the specific training techniques used," Schulz complains. This makes it difficult for researchers to examine how the algorithms communicate with humans. "Without an understanding of the data and training protocols, the systems remain a black box," said the researcher. This uncertainty is compounded by the fact that it is unclear why the program reacts in a surprisingly emotional way at times, while reacting in the rational way one would expect from software at others. For instance, when Schulz incorporates GPT in experiments that require multiple participants to cooperate, it acts selfishly and maximizes its own advantage. "Just a handful of companies have control over the behavior of artificial intelligence, and we can only hope that they act responsibly," says Eric Schulz. "That is the real problem."

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Image created by the software Midjourney on the "Linda problem," a standard cognitive psychology test (commands: "30-year-old feminist black woman in gray business attire holding up poster in support of women's rights," "Smiling, she leads a demonstration in the lobby of a modern bank," "Kodak Portra").

IMAGE: MIDJOURNEY AI IMAGE | CREATED BY GESINE BORN | BILDERINSTITUT

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IMAGE: MPI FOR THE STUDY OF CRIME, SECURITY AND LAW

Invitation to break in: criminologist Patrick McClanahan incites prison inmates to rob virtual homes. This street was created using modern virtual reality technology.

Max Planck researchers cooperate with partners in more than 120 countries. Here they write about their personal experiences and impressions. Patrick McClanahan from the Max Planck Institute for the Study of Crime, Security and Law in Freiburg travelled to Pennsylvania for seven months. He met convicted burglars in four different prisons and encouraged them to rob houses in the service of science.

I guess I was a serial junkie as a kid. I loved the crime series of the early 2000s! We had a family dog back then called Jethro, named after the main character of NCIS. Unfortunately, my television viewing at such a young age caused me to develop a phobia. I could no longer fall asleep for fear of being killed. With the help of a therapist, I got my fears under control. What remained was the desire to understand criminals and their motives. That is why I decided to study psychology and criminal justice and become a criminologist.

As a postdoc, I am currently working on the "Virtual Burglary Project." In addition to our Freiburg Institute, the University of Portsmouth, Leiden University, and the Vrije Universiteit Amsterdam are also involved in the project. The goal of the large-scale research program is to record the different methods used by burglars, with the hope of developing better prevention measures and averting crime. My study participants are incarcerated burglars in four different prisons in Pennsylvania.

For my study, I spent seven to nine hours a day in prison. Of that, two hours alone were spent on activities related to security or administration. Before I arrived, I was told to send the prison management a list of everything I needed and wanted to bring into the prison for my work. I had to stick to it meticulously. At the entrance to the prison, you pass through a security checkpoint, similar to the ones used in airports. I was searched and all the items I was carrying were checked individually. I was not allowed to move around freely inside the building and was accompanied by security personnel at all times.

Prior to my first visit, the prison management sent me a list with the names of all prisoners who were eligible to participate in the study. I spoke to most of them individually and introduced them to the project. In a conversation like this, the first 30 seconds are crucial for building trust and winning someone over for the study. At the beginning, I asked them how their day was going. Even this simple ques-

POST FROM

PENNSYLVANIA, USA

tion frequently turned out to be a door opener, because hardly anyone else is interested. Many were persuaded that by participating they would be making an important contribution to turning the world into a safer place, something that their families would benefit from. Another decisive factor is certainly that I am an independent scientist and have never worked for the police or the judiciary. About 40 percent of the inmates I spoke with were willing to take part. A total of 160 people from Pennsylvania participated.

The study participants had the task of committing a burglary – purely virtually, of course. Virtual reality goggles made it possible to scout out an imaginary neighborhood and evaluate specific houses, just as in reality. The virtual reality system records all actions in real time. This enables me to follow how the burglars select their target and see what is important to them. By changing street lighting, alarm systems or the position of parked cars, for example, I can test what influence these factors have on their decisions and their subsequent actions. It was important for me that both amateur and "professional" burglars participated because both work very differently.

Only a few scientists who conduct research in the field of criminology go into prisons and work with offenders. However, it is essential for my research and very important to me personally. I have yet to have any bad experiences. What is difficult for me is dealing with the at times shocking personal stories that prisoners tell me and to which I must not react in my role as a scientist. After my time at the Max Planck Institute, I would like to apply for a professorship in the USA. In any case, I want to include prison inmates in my research in the future.

PHOTO: MPI FOR THE STUDY OF CRIME, SECURITY AND LAW

Patrick McClanahan,

30, is an American scientist who studied psychology and criminal justice at Roanoke College in Virginia. After completing his doctorate at the University of Cambridge, he took up a postdoctoral position at the Max Planck Institute for the Study of Crime, Security and Law in Freiburg in 2021. As part of the "Virtual Burglary" project led by Institute Director Jean-Louis van Gelder, he uses virtual reality technology to study the behavior of criminals.

FIVE QUESTIONS

ON THE COSTS OF CLIMATE CHANGE

FOR TOBIAS GRIMM

As a reinsurer, Munich Re assumes peak risks for its customers, the primary insurers. Floods, storms, and heat waves cause damage that natural hazard insurance alone cannot offset. It is part of Munich Re's core business to understand and counteract the consequences of climate change.

Can natural disasters increasingly be attributed to climate change?

TOBIAS GRIMM I would be careful with blanket statements. Our job is to insure extreme weather events. It is difficult to prove whether individual cases are attributable to climate change. "Attribution research" deals with this question, but there are uncertainties there as well. For example, the probability of extreme rainfall, as in the Ahr Valley in 2021, has increased by a factor of between 1.2 and 9. What we are sure of is that we have recorded more natural disasters and higher damages in recent years. Economic damages worldwide totaled 270 billion US dollars last year, of which 120 billion were insured. Damages worldwide exceeded the threshold of 100 billion US dollars three times in the past six years.

What could account for this dramatic cost increase?

Insured values are increasing, and construction is on the rise. What used to be a small settlement is now a city. The disaster in the Ahr Valley caused around 40 billion US dollars in economic damage, making it roughly four times costlier than the costliest flood disaster in Central Europe prior to that, and far more expensive than the floods this spring in Italy. However, the increase in damage cannot be explained solely in terms of the increase in value. There are many reasons to think that climate change plays an increasing role in natural catastrophes caused by weather.

Is it possible to factor out the increase in value and determine the pure effect of climate change?

It is hardly possible to calculate in practice. Climate change affects natural hazards differently from region to region. And you would also have to account for adaptive measures, whose effectiveness varies greatly.

The approach at Munich Re is to stop reacting and start monitoring the change actively. How does that work in relation to the climate crisis? The global climate report speaks unequivocally.

In the reinsurance business we adjust our risk management annually, factoring in prognoses from climate models. Both avoidance and adaption are needed in the long term, however. We have to minimize risks, and that includes avoiding further greenhouse gas emissions. In addition, we help renewable energies catch on by insuring them and covering outage risks. We provide incentives to our customers and want to become a climate-neutral operation ourselves by 2050.

How much will an adequate supply from renewable energies cost? By comparison, the cost of damage directly attributable to climate change could total between 280 and 900 billion euros by 2050, according to the Ministry of Climate Action and Energy.

A comparison like that is hard to make and very easy to misinterpret. According to the International Energy Agency, 1.6 billion US dollars would have to be invested in renewable energies each year until 2030 to avoid exceeding the 1.5 degree mark. Current investments are a third of that. These are global numbers, whereas the total damage you cited applies to Germany and includes both consequential and immaterial damage. Conversion to a carbon-free economy is essential, but society has to accept it and it has to happen fast enough. At the same time, we have to adapt ourselves to the transformations resulting from climate change, which are already evident today.

Interview: Tobias Beuchert

Tobias Grimm heads the Climate Advisory and NatCat Data unit at Munich Reinsurance (Munich Re).

ILLUSTRATION: SOPHIE KETTERER FÜR MPG

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