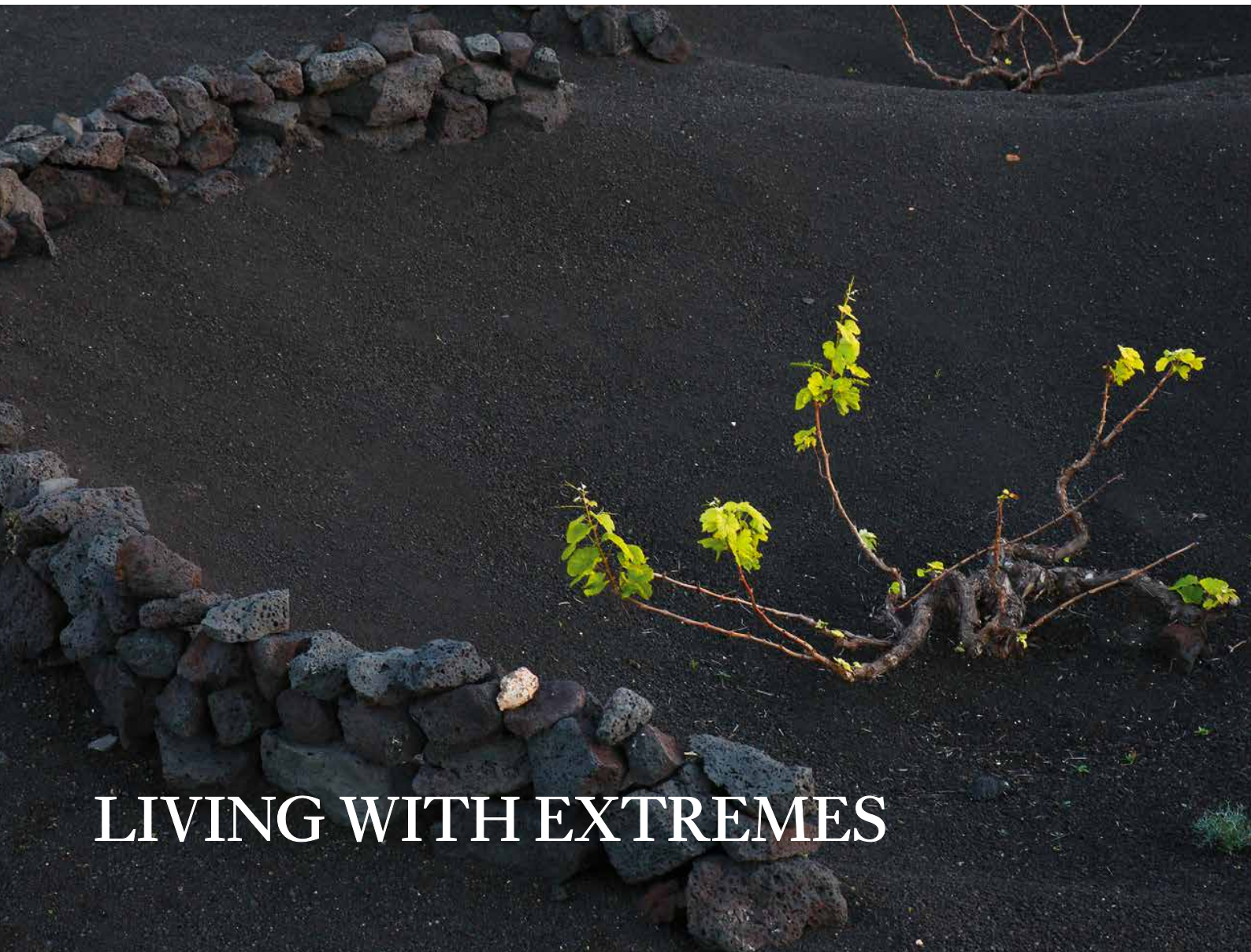
01 | 2021

MAX PLANCK *Research*

EVOLUTIONARY BIOLOGY
Viruses from primeval times

HISTORY
The empire is back

BIOMECHANICS
Cells under pressure



LIVING WITH EXTREMES

2

Vines from the ash: on Lanzarote in the Canary Islands, wine has been cultivated in the sediment of volcanic outbreaks for around 250 years. The winegrowers dig pits and plant the vines in the lapillus coat, as it is known, which is several meters thick. In the dry climate on Lanzarote, the porous stones which form the layer, and which are no bigger than a pea or a nut, store the night dew. The plants are protected from strong wind by low walls. This is an example of how agriculture can adapt to extreme conditions.

PHOTOS: PICTURE ALLIANCE / IMAGEBROKER | JUSTUS DE CUVELAND (COVER); PICTURE ALLIANCE / DUMONT BILDARCHIV | GERALD HAENEL (THIS PAGE)

EDITORIAL

Dear reader,

Our planet provides a comfortable home for the life it supports. With its water, food, warmth and light, it has everything that all kinds of organisms – including humans – need to grow and thrive. However, at certain times and places, conditions on Earth can be distinctly hostile. Heat or cold, heavy precipitation or total drought, strong winds, lightning, volcanic eruptions and earthquakes all threaten the existence of many living beings. The only way they can survive is by adapting to such extremes.

Nature is constantly providing new and surprising examples of this, such as a species of algae that is indigenous to the desert. Researchers are studying how these algae can survive in such inhospitable environments and whether its properties could be transferred to crop plants.

The question of how plants can cope with drought is becoming ever more urgent. Recent summers have shown that the agricultural industry needs to be prepared for long periods of drought, even in this country. Moreover, climate research models have shown that extreme weather events will become even more common in the future. Forecasting them can help us adjust to these situations.

History has shown that humans respond to the challenges posed by their environment in many different ways. Disasters such as earthquakes and volcanic eruptions have caused great human tragedies, but they have also influenced and inspired art and culture. There are many examples of this in the Italian city of Naples.

Extremes are threatening. However, we have seen new life burgeon and new opportunities open up again and again, even in inhospitable surroundings and harsh conditions. With this in mind, we hope you will find this magazine informative reading!

Your editorial team

PHOTOS: PICTURE ALLIANCE/DPA | CHRISTOPHE GATEAU (ABOVE LEFT); MARCUS ROCKOFF (ABOVE RIGHT); TOM HEGEN (BELOW LEFT); DREAMSTIME (BELOW RIGHT)

34 | *DRIED OUT*

In the summer of 2018, water levels in the Rhine were also very low near Duesseldorf

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The Habsburg military commander Ban Josip Jelačić fought for Croatian independence.

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SPECIES PROTECTION
WITH THE FLORA INCOGNITA APP

ON LOCATION

PHOTO: SHUTTERSTOCK/LAPA SMILE

Hiking, walking, learning a lot about flowers, grasses, and trees, and at the same time being part of a scientific project, is now possible thanks to the free *Flora Incognita* app. It is easy to use, and quickly recognizes thousands of wild plants. As a joint development of the Max Planck Institute for Biogeochemistry in Jena and the Technical University of Ilmenau, the underlying algorithm was first trained with several million images of plants. Now, it learns new data every time it is used.

So why not download the *Flora Incognita* app, take a photo and find out what plants are currently in bloom all around you? And not only that, the app can do so much more. Is this plant poisonous? Is it rare or common? Is it a protected species? *Flora Incognita* offers users quick, on-site access to a great deal of knowledge about unfamiliar plants. At the same time, scientists obtain new data and facts about plant diversity. When do certain species flower, and where? How much do plants from a single species differ from each other? How does the composition of plant species change at a particular location? With this Citizen Science project, anyone can help to investigate biodiversity and how it is changing, for example through climate change or agriculture. And with a little help of artificial intelligence, a wildflower meadow – here in the Bavarian Alps – becomes a research location.

floraincognita.com

PHOTO: IRENE BÖTTCHER-GAJEWSKI/MPI FOR BIOPHYSICAL CHEMISTRY

Relics of Late Antique prosperity: the Late Antique Little Ice Age in the 6th century A.D. saw settlements in the Near East, like this one in Syria, expand as a result of increasing precipitation and improved water management.

LEARNING FROM PAST CLIMATE

Climate changes throughout history, such as the Little Ice Age between the 13th and 19th centuries, have often been associated with famines, crises and wars. However, there are also many examples of how populations and politicians have been able to use changing climatic conditions to their advantage, or at least to maintain stability. An interdisciplinary research team, which includes scientists from the Max Planck Institute for the Science of Human History, is therefore using a new approach to study how societies react to climate change. This focuses on societal resilience and ensures that climate data and historical facts are analyzed more carefully than was formerly often the case. The team has already used this guideline to put together case studies, e.g. of the Late Antique Little Ice Age that occurred during the 6th century A.D. These climate changes exerted great pressure on some societies, while others used them to their benefit. The inhabitants of the Eastern Mediterranean region, for example, improved their water management and used the increase in precipitation to grow larger crops. Overall, the researchers have identified five strategies for coping with climate change and now plan to explore these in greater detail: the exploitation of new socioeconomic opportunities; the utilization of robust energy systems; the use of trade to tap new resources; ascertaining politically effective reactions to extreme events, and migration.

www.mpg.de/16613100

AWARD-WINNING ✶

PATRICK CRAMER

This year, the renowned Louis Jeantet Prize for Medicine goes to Patrick Cramer, Director of the Max Planck Institute for Biophysical Chemistry, for his groundbreaking work in the field of gene transcription. This copying process enables living cells to produce transcripts of their genes that then serve as blueprints for making proteins. Cramer's research focuses on RNA polymerases, the molecular machines that implement this process.

Patrick Cramer has made the structures of many of these cellular copying machines visible in atomic detail for the first time. He was able to demonstrate how RNA polymerases translate genetic information and how they work as a team with other protein complexes. The award presented by the Swiss Louis-Jeantet Foundation is endowed with 500,000 Swiss francs.

www.mpg.de/16336063

PHOTO: ARTUR RODZIEWICZ

IN BRIEF

Versatile substance: a newly discovered nickel compound could serve as a catalyst for numerous chemical products in the future.

PHOTO: MPI FÜR KOHLENFORSCHUNG

CATALYST WITH A WIDE RANGE OF APPLICATIONS

Nickel bonded with organic partner molecules serves the chemical industry as a catalyst for the production of numerous chemical compounds. Its uses range from the production of fine chemicals to the synthesis of pharmaceutical drugs, insecticides, and pesticides. A nickel complex containing cyclooctadiene, which was discovered around 60 years ago at the Max-Planck-Institut für Kohlenforschung, has been used for this purpose for many decades. However, it is extremely complicated to use, since it is highly temperature-sensitive and immediately decomposes in air. Scientists at the same Max Planck Institute have now succeeded in developing an innovative series of nickel complexes that remain stable in air for about one month and can withstand higher temperatures than the complex previously used. In terms of their desired catalytic properties, however, they are very similar. This is why industries showed such immense interest following the first publication. The U.S. specialty chemical manufacturer Strem Chemicals has now acquired an initial non-exclusive license to produce the catalyst with the goal of supplying customers in the fields of science and research.

www.mpg.de/16305747

LOW-COST RAPID TEST

As long as vaccine is in short supply, one way of helping to contain the coronavirus pandemic could be to regularly test as many people as possible. Researchers at the Max Planck Institute for Evolutionary Anthropology and the Hospital St. Georg in Leipzig have now developed an improved method of detecting Sars-CoV-2. Known as Cap-iLamp, this method amplifies the desired target sequences of the virus at a constant temperature using minimal technical equipment. Instead of a swab, which many people find unpleasant, all that is required is a gargle lavage sample. The test result can be read visually – orange or red for negative, vivid yellow for positive – or with the help of a free smartphone app half an hour to no more than one hour after the test. This improved testing method outperforms similar tests, since it significantly reduces the number of false-positives. Moreover, it can detect a single infected sample in a pool of 25 uninfected samples. The technical cost of a pool test is approximately one Euro per person.

www.mpg.de/16536940

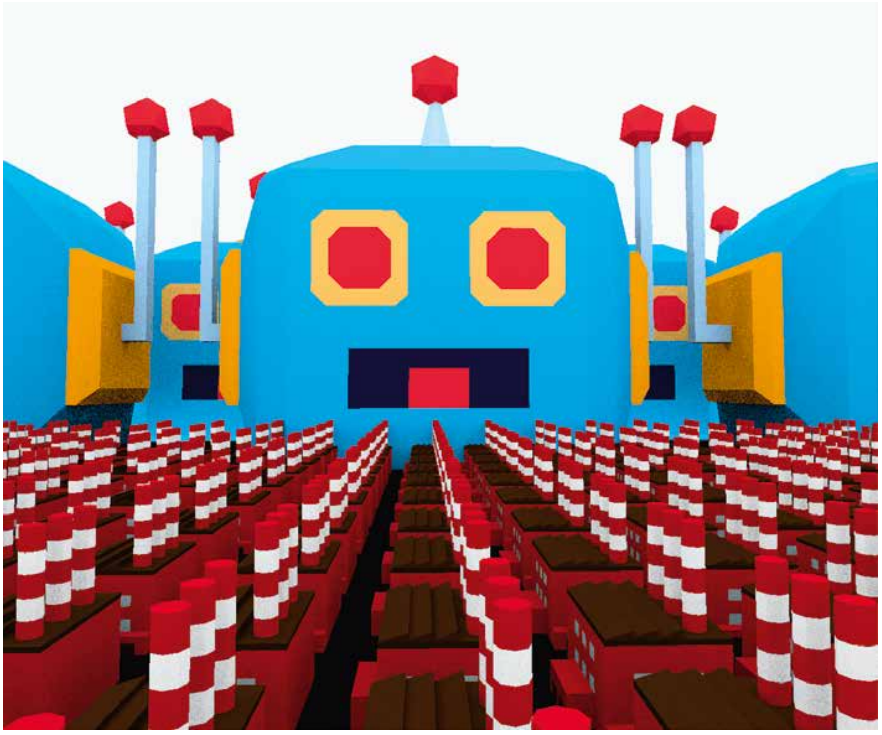

IMAGE: FRANCIS TSENG

Digital competition: robots are ready to take over the jobs of human employees, both in the gaming world and in reality.

PLAYING THE AUTOMATION GAME

We live in a world in which robots are building more and more of our cars, algorithms are trading stocks, and computers are translating texts. Robotics, digitalization, and artificial intelligence are transforming numerous professions. Some jobs are disappearing, while other new ones are being created. The online game '*The Automated Life*' is a chance to practice overcoming these challenges at work. The game was developed in the Center for Humans and Machines at the Max Planck Institute for Human Development. Players start out with a job that is severely threatened by automation. They have to save up for further training and apply for new jobs, which in turn open up new opportunities for further training programs and careers. Meanwhile, automation is advancing relentlessly, and jobs are constantly being eliminated by new technological developments. Keeping an eye on their bank balance and bearing in mind how many more years are still to go before they retire, players have to be able to make quick, smart decisions to win out against digitalization and ultimately enjoy their well-deserved retirement. Anyone who plays this game is also contributing to research: the data from each game is analyzed anonymously with the intention of understanding how humans cope with automation.

www.mpg.de/16578078

UNDERSTANDING SIGNING AS A LANGUAGE

Over 70 million deaf people around the world use some form of sign language. Thus far, however, it has been difficult to identify the parts of the brain that process both spoken and sign language. A meta-analysis carried out by scientists at the Max Planck Institute for Human Cognitive and Brain Sciences has revealed that the Broca area in the frontal lobe of the brain's left hemisphere plays a key role for both types of language. The brain's right frontal lobe, which processes non-linguistic aspects such as spatial or social information about the communicator's counterpart, is also vital for understanding sign language. The hand, facial and body movements of which a sign language consists are in principle perceived similarly by deaf and hearing people; in deaf people, however, the signs also activate the language network in the brain's left hemisphere, which includes the Broca area. Deaf people therefore perceive the gestures as gestures with linguistic content rather than pure movement sequences, as is the case with hearing people.

www.mpg.de/16461250

PHOTO: SHUTTERSTOCK

Specialized in language: the human brain specializes in processing linguistic information – regardless of whether it is spoken or signed.

YEARS OF LIFE LOST

In order to make a proper assessment of how the coronavirus pandemic has impacted mortality, an international team of researchers, including scientists from the Max Planck Institute for Demographic Research, has evaluated 1.2 million deaths that occurred in 81 countries between the start of the pandemic and the beginning of January 2021. Their goal was to ascertain the ages of the people who died from COVID-19 and calculate how much their lives were shortened compared to the average life expectancy. Middle-aged people and those of early retirement age accounted for the largest proportion of the years of life lost. A global comparison indicated that three-quarters of the years of life lost impacted people who were younger than 75 years of age. This contrasts starkly with the widely held belief that most people who die of COVID-19 only had a few years left to live in any case. In medium and low-income countries, the proportion of years of life lost is often significantly higher in the youngest population group (under 55) than in the oldest. The picture in high-income countries is quite different: more than half of the years of life lost here are accounted for by the oldest population group (over 75).

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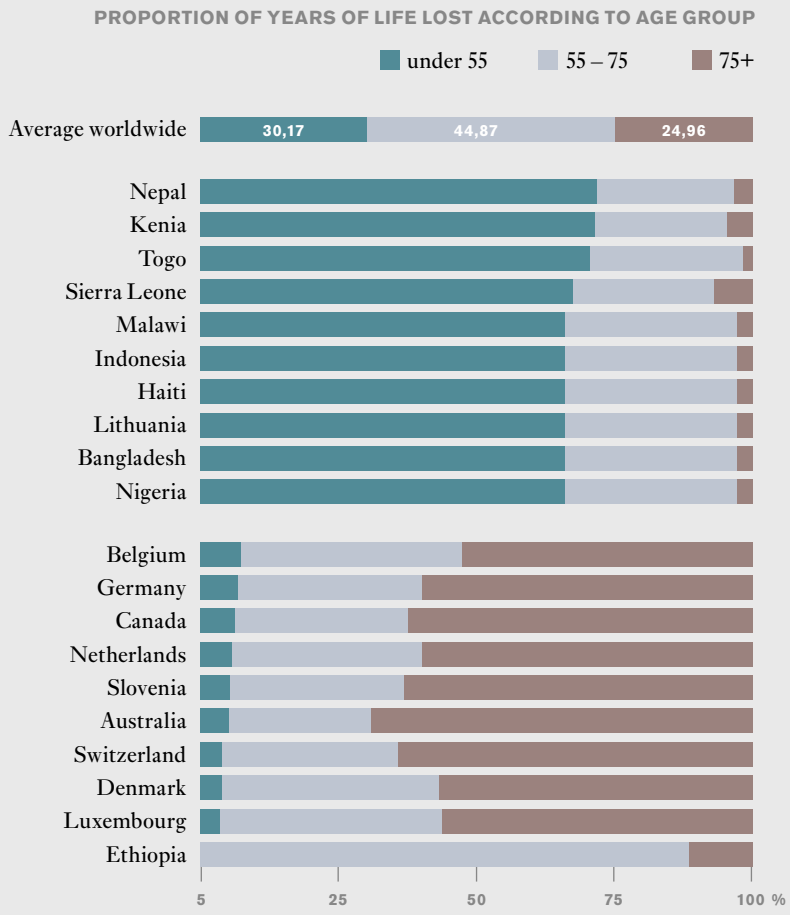

GRAPHIC: GCO BASED ON DATA FROM THE MPI FOR DEMOGRAPHIC RESEARCH

Marked differences: in poorer countries, the proportion of years of life lost tends to be highest in the youngest age group (top). In the countries where this age group accounts for the smallest proportion of years of life lost, the living standards are usually significantly higher (bottom). The research team studied 61 other countries in which these figures lay in between these extremes.

ARTIFICIAL INTELLIGENCE SUPPORTS COVID-19 PROGNOSES

Estimating the risk of patients dying is arguably one of the most difficult and stressful challenges doctors ever have to face, especially now during the COVID-19 pandemic. In ideal circumstances, they can adjust the treatment and save the patient's life. A team led by researchers at the Max Planck Institute for Intelligent Systems has now developed an algorithm and trained it using machine-based learning methods, so that it can help physicians predict mortality. The algorithm analyzes large volumes of medical data and identifies patterns that are barely discernible to humans. It can also be used to determine the mortality risks associated with other diseases. A similar algorithm analyzes medical data such as pulse, blood pressure, and information about the patient's symptoms to detect patterns indicating that their COVID-19 infection is likely to be severe. The researchers are currently testing this algorithm in a study carried out in cooperation with Tuebingen University Hospital and are still seeking participants in the German-speaking countries who have just tested positive for coronavirus.

ei.is.mpg.de/covid-19-studie (in German)
www.mpg.de/16444031

STELLAR EXPLOSION AT AN UNUSUAL LOCATION

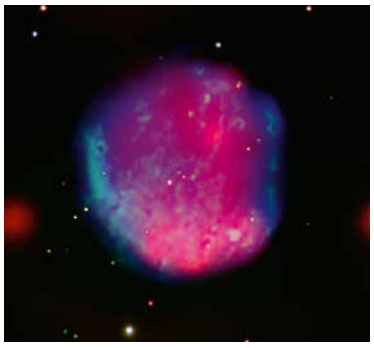

IMAGE: EROSITA/MPE (X-RAY), CHIPASS / SPASS / N. HURLEY-WALKER, ICRAR-CURTIN (RADIO)

Gaseous relic: this composite x-ray and radio image shows the supernova remnant "Hoinga".

Researchers at the Max Planck Institute for Extraterrestrial Physics have discovered a gigantic, previously unknown supernova remnant in our Milky Way using the German x-ray telescope eRosita. With a diameter of several angular degrees, it is not only its size that is surprising, but also its position in the sky: the scientists have dubbed it Hoinga, which is the medieval name for the town of Bad Hoenningen on the Rhine. The astronomic remnant is located far above the galactic plane – in a region where the birthrate of stars is actually very low and there should therefore be very few suns expiring as supernovas. Most searches for exploding stars actually concentrate on the galactic disc and not on the outlying areas of the Milky Way. To date, astronomers have only discovered around 300 of these stellar remnants in our home galaxy – far fewer than the 1,200 that should theoretically exist there. This means that the researchers have either estimated the number of supernovas incorrectly or simply overlooked the vast majority of them. Incidentally, Hoinga was already visible in data collected by the German x-ray satellite Rosat some 30 years ago; however, the object went unnoticed because of its dimness and its position.

www.mpg.de/16527751

WARNING SYSTEM FOR MARKETS

Financial markets will become more predictable in the future: an international team led by scientists at the Max Planck Institute for Mathematics in the Sciences is using mathematical instruments to recognize the early signs of bubbles and crashes. The researchers view a financial market as a network of stocks, and determine the market's dynamism and fragility using certain attributes of this network, or more precisely, using so-called Ricci curvatures. They used this approach to analyze the development of the U.S. S&P-500 and Japanese Nikkei-225 indexes between 1985 and 2016. While securities perform very differently during normal trading periods, their performance during bubbles and imminent market crashes is much more uniform, and this can be detected more efficiently using Ricci curvatures than with any other form of measurement.

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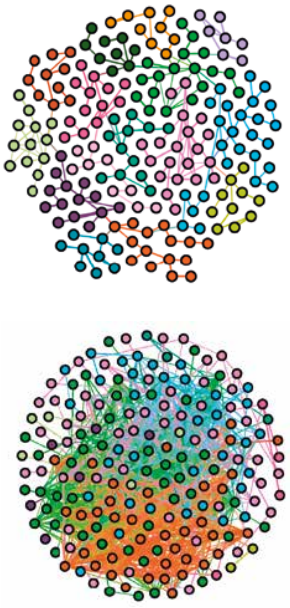


GRAPHIC: A. SAMAL | INSTITUTE OF MATHEMATICAL SCIENCES (IMSC)

Promising connections: when bubbles develop on financial markets, the correlations in the stock network are much denser (below) than in normal trading periods. The nodes are accordingly more interconnected, as can be seen from the orange coloration.

FROM LONE WARRIOR TO TEAM PLAYER

The transition from single-celled organisms to multicellular ones was a major step forward in the evolution of complex life. Some organisms, such as the slime mold Dictyostelium discoideum, can exist in both states. At home in forest soil, this mold chooses its state according to varying factors such as food supply. If slime mold cells do not find enough to eat, they amalgamate and form a long stalk that can release spores from the fruiting body at its tip. This enables the mold to survive in inhospitable conditions and colonize new habitats that may offer better conditions. Researchers at the Max Planck Institute of Immunobiology and Epigenetics in Freiburg have now discovered that sulfur deficiency is a leading facilitator in the formation of cell clusters. As a component of two amino acids, sulfur is essential to the formation and activity of proteins. If this element is lacking, the cells are no longer able to produce sufficient protein to grow and proliferate. This is how they recognize that there are not enough nutrients in their environment. They then amalgamate and form a fruiting body with spores in order to access new resources.

www.mpg.de/16476527

The European free-tailed bat not only hunts for insects near the ground but also climbs to high altitudes.

PHOTO: ADRIÀ LÓPEZ BAUCELLS

BATS ON THE RISE

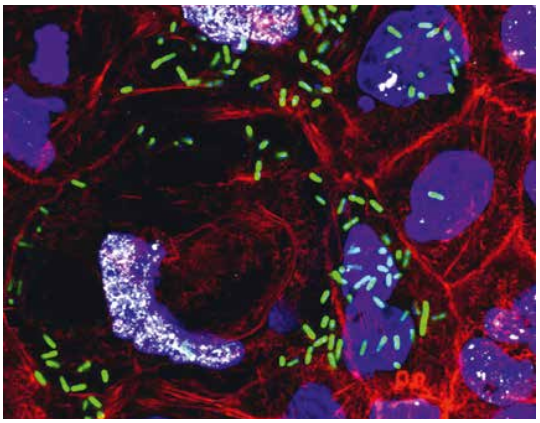
Bats are the only mammals that can actually fly. Some species travel over one hundred kilometers on their nocturnal excursions in search of food. A team at the Max Planck Institute of Animal Behavior in Radolfszell has now discovered that European free-tailed bats use updrafts for their ascents. The researchers tracked the bats using mini GPS transmitters and then linked the flight data to weather data. Analysis of the GPS data revealed that the bats often follow the natural contours of the landscape and maintain the same height above the ground. Now and again, however, they shoot upwards and climb 300 to 800 meters; one bat even reached a peak height of almost 1,700 meters above the ground. A close analysis of their flight paths showed that the animals probably use the upward movement of the air that occurs when winds encounter obstacles such as mountains. However, the wings of bats – unlike those of certain birds – are not suitable for extended gliding flights. This is why the bats plummet towards the ground immediately after the ascent. Under their own power, bats can reach flight speeds of up to 135 kilometers an hour – a velocity which in the animal world is only exceeded by nosediving birds. The power for this feat comes entirely from the bats' pectoral muscles, which are only two centimeters long.

www.mpg.de/16371261

FORESTS IN DANGER

More than half of Europe's forests are under threat from the impact of global warming. This was the result of a new study performed by an international team including Henrik Hartmann, scientist at the Max Planck Institute for Biogeochemistry in Jena. For this, the researchers used artificial intelligence to analyze satellite data gathered between 1979 and 2018. The results indicated that windthrow, forest fires, insect infestation, or combinations of several of these factors are increasingly endangering Europe's forests. Such events are likely to become more frequent and severe as a result of climate change, while heat and drought are making trees more vulnerable to damage. This knowledge could be used to restructure forests so that they become better able to withstand the impacts of climate change.

www.mpg.de/16501852



Colibactin-producing *E. coli* bacteria (green) damage the DNA (white) of epithelial cells (red) in the intestinal mucosa. The nuclei are shown in blue.

IMAGE: MPI FOR INFECTION BIOLOGY/AMINA IFTEKHAR

HUMANS MAKE MICE MORE INTELLIGENT

Fans of Tom and Jerry have long since known that if a mouse wants to survive in a house, it has to be particularly intelligent. Researchers at the Max Planck Institute for Evolutionary Biology in Ploen have now proven this scientifically. According to their findings, rodents which have lived close to humans for a long time are better at solving problems than others of their species which live away from human settlements – a phenomenon that has also been observed in birds. The scientists investigated the behavior of three species of house mouse that have lived in human environments for 3,000, 8,000 and 11,000 years respectively and have had to adapt accordingly. The results of their experiments show that the mice that have associated with humans for the longest period were best able to solve problems. These findings cannot be explained by personality traits such as curiosity, motivation or perseverance, but only through differences in cognitive skills. Since the mice investigated have been living in the researchers' laboratory for several generations, the rodents must have inherited this enhanced intelligence.

www.mpg.de/16442871 (in German)

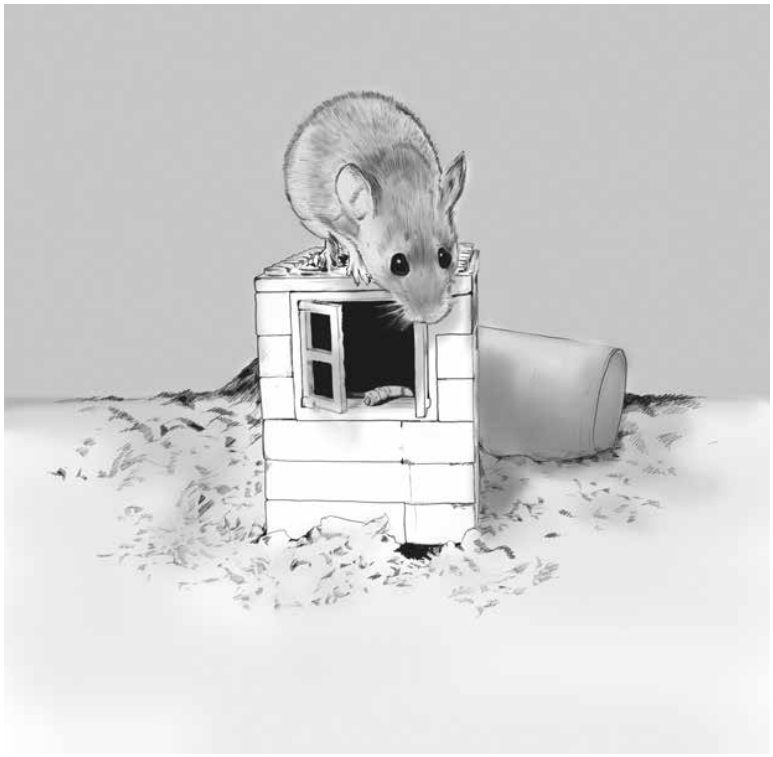


ILLUSTRATION: HENNING BRUER

A behavioral experiment required mice to open a small window to reach a morsel of food. Animals whose forebears had long lived close to humans performed significantly better.

TOXINS FROM GUT BACTERIA

Escherichia coli bacteria occur naturally in the human gut. However, some strains produce a toxin called colibactin, which harms the organism's DNA and is implicated in the development of colorectal cancer. Scientists have not succeeded in proving this connection until now. A team of researchers from the Max Planck Institute for Infection Biology in Berlin has caught colibactin in the act of changing the DNA of colon cells so that they behave like cancer cells. The researchers used colon stem cells to cultivate hollow, three-dimensional mini-organs known as "organoids". In the presence of colibactin-producing bacteria, the cells began multiplying faster after just a few hours – despite the absence of a growth factor without which cells do not normally divide. This uncontrolled proliferation is a precursor of cancer. DNA sequencing of the organoids revealed that colibactin induced numerous mutations in the DNA, including some that led to whole sections of chromosomes being rearranged or lost.

www.mpg.de/16419527

MAGNETIC FIELDS AT THE EDGE OF A BLACK HOLE

The first image of a black hole went round the world in April 2019. It showed a bright ring with a dark central region at the heart of the M87 galaxy 55 million light years away. The measurement data used for this image were collected by the antennas of the Event Horizon Telescope (EHT) sites located around the globe. The research team, which includes scientists from the Max Planck Institute for Radio Astronomy in Bonn, has continued analyzing this data in recent months – in a sense, they are placing sunglasses with polarized lenses on the data in the computer. In this way, they discovered that a significant proportion of the radio emissions surrounding this monstrous cosmic mass are in fact polarized, i.e. they curve in one direction. This polarization is caused by the magnetic fields immediately surrounding the black hole. The image produced with the polarization filter now shows the course of the magnetic field lines. The region is particularly interesting because it is the source of a high-energy jet, a gas stream several tens of thousands of light years long, the formation of which appears to have been influenced by magnetic fields. The observations should help elucidate the mechanisms behind it.

www.mpg.de/16630569

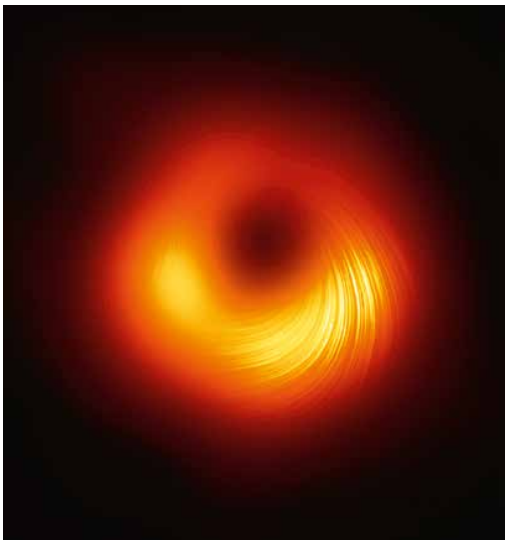


IMAGE: EHT COLLABORATION

Magnetic gravity trap: curved polarization field lines showing the course of the magnetic field have been sketched into this image of the shadow of the black hole at the center of galaxy M87.

COOPERATION BY EXAMPLE

"Together against corona" is the motto for fighting the pandemic. At present, the best way of containing it is for everyone to keep their distance, wear a mask, and minimize contact with others. However, the temptation to make an exception in one's own case is great. After all, it is enough if everyone else is following the rules – right? The more dependent we are on mutual cooperation, the more egotism threatens our common goals. Economist Matthias Sutter explains the circumstances in which people can nonetheless cooperate successfully.

When I talk about the value of cooperation and present my research on this topic to the public, I like to begin with an ancient Chinese parable. In my view, it not only effectively illustrates the advantages of cooperation, but also shows why it can fail. The parable goes like this: a bridal couple did not have much money but were still keen to have a lot of people come and celebrate their wedding. Happiness doubles when shared, or so they thought. They decided to organize a big wedding with lots of guests. In order to make this possible, they asked everyone invited to bring a bottle of wine. There would be a large barrel at the entrance into which everyone would be able to pour their wine; this meant that everyone would be able to drink the wine donated by others, and everyone would be relaxed and in high spirits. When the celebration began, the servers went to the barrel and scooped out its contents. But everyone was horrified to find that it contained only water. Everyone stood or sat frozen in shock at the realization that everyone had had the same thought: "Nobody will notice or taste the one bottle of water I pour in. And today I want to celebrate at somebody else's expense."

→

VIEW POINT

MATTHIAS SUTTER

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Matthias Sutter initially obtained a diploma in Catholic theology and then went on to study economics at the University of Innsbruck, where he completed his doctoral degree in 1999 and his habilitation in 2002. Following professorships in Innsbruck, at the European University Institute in Florence, and in Cologne, he was appointed Director of the Max Planck Institute for Research on Collective Goods in Bonn in 2017. His experimental laboratory and field research mainly focuses on the determinants of cooperation, including the importance of patience and the economic decision-making behavior of children and adolescents. He became known to the public primarily for his research into the positive effects of quota regulations on competitiveness among women, and for his book *Die Entdeckung der Geduld* (The Discovery of Patience), which spent several weeks on Austria's bestseller lists.

The parable accurately pinpoints the problem of cooperation in social groups. Everyone is tempted to make the smallest possible contribution to the group (in this case by bringing cheap water instead of expensive wine) but hopes that everyone else will contribute as much as possible (e.g. by donating wine instead of water). Common interests cannot thrive if everybody acts in this way – just like the celebration in the parable turned into a washout. However, if everyone contributes something, everyone can benefit – and have a great party.

THERE ARE MANY REASONS TO CONTRIBUTE LITTLE OR NOTHING TO THE COMMON GOOD

The parable of the wedding can be applied to many areas of life. Soccer teams are demonstrably more successful when every player runs for the others, i.e. goes the extra distance to make up for other players' mistakes. Research teams are more likely to bring their projects to a successful conclusion if everyone pulls their weight instead of expecting someone else to put in the spadework. Joint ventures are more likely to be successful if the companies involved coordinate their research and development efforts. Work teams function better when important information is shared and passed on quickly. The list could go on almost indefinitely, and in times like these, it also includes collaborative research into the development of new vaccines or treatments for COVID-19. Even the attempt to contain the pandemic through social distancing can only succeed if everyone cooperates.

When looking at the bigger picture, the benefits of cooperation in the examples mentioned are relatively apparent to everyone involved. Yet from an individual viewpoint, there are many reasons to behave like a freerider and contribute little or nothing to the common good in the respective situation. After all, we often benefit from other people's cooperation even if we do not behave cooperatively ourselves (e.g. by neglecting our part of the team's work or not providing all the relevant information in the case of cooperative business ventures). This tense relationship between self-interest and the benefit of mutual cooperation is characteristic of any situation that is usually described as a social dilemma. So how do humans develop a willingness to cooperate, and what does this depend on?

It has been shown that cooperation works very well even among children. In our experiments with children aged from three to six, we found that even small children understand that they benefit from mutual cooperation in a group. Children who watch other people cooperating behave more cooperatively themselves. This is particularly true in the case of repeated inter-

actions. If a child had good experiences with another child in the past, they are more likely to behave cooperatively towards this particular child in the future. Apart from actual experiences with another child, even expectations can be enough: children who expect cooperation from other children will behave more cooperatively themselves, even when the other children have not yet proven their willingness to cooperate. There also appears to be a correlation with the degree of cooperation shown by their parents. Cooperative parents have more cooperative children. Moreover, a child's willingness to cooperate increases with the level of education attained by their parents. Apparently this is because cooperation is more likely to be normal social behavior among better-educated parents, and this is then reflected in the child's behavior.

IT IS NOT ENOUGH FOR EVERYONE TO KNOW ABOUT THE BENEFITS OF COOPERATION. THE TOPIC HAS TO BE DISCUSSED

Regardless of age, communication between group members is probably the most important factor in cooperation. It is not enough for each member to be aware of the benefits of mutual cooperation. A discussion about them must also take place. Studies in the field of behavioral economics have revealed that showing a video demonstrating the advantages of cooperation to every member of a group before they interact does not improve cooperation within the group. Only when the members talk about the video and discuss the advantages and disadvantages of specific behaviors does their willingness to cooperate increase. Besides addressing the value of mutual cooperation, these discussions also appeal to standards of social fairness. In concrete terms, this means that freeriders (who contribute water instead of wine) are declared to be behaving unfairly and antisocially. This appeal to social norms during the group discussion together with the mutual assurance that cooperation will enable everyone to achieve the best results changes the other group members' expectations of the cooperation and thus increases their willingness to cooperate.

However, appeals lose their effect over time, which is why incentive mechanisms also have to be used as effective instruments for promoting cooperation. These include rewarding cooperation and sanctioning freeriding behavior. It does not really matter whether these (positive and negative) incentives are provided by the group members themselves or by people outside the group. Incidentally, the results of behavioral economics studies indicate that sanctions work better than incentives in the long term. This is because of an asymmetry that is easily overlooked. Possible sanctions have a disciplinary effect even when they are not

applied, as long as the belief persists that freeriding behavior can be punished. Rewards only work if they are applied. However, the use of rewards as incentives gives rise to typically human behaviors like habituation effects, because people soon come to regard a certain level of reward as normal – and, in the individual's view, well-deserved. This is why studies have shown that cooperation levels decline over time if there is a constant flow of rewards. This is also consistent with the evidence that productivity in companies initially increases when bonus payments are introduced, but then declines to the same level as before, usually over a period of two years.

In conclusion, I would like to shed some light on the importance of a factor that for several years was the focus of my own research into cooperation. I specifically studied the extent to which cooperation depends on someone in a group setting a good example. We described this as the definition of "leadership". In terms of methodology, we investigated this factor in laboratory experiments that presented a classic social dilemma. This meant that every single person in our laboratory studies could benefit financially from not cooperating. At the same time, the entire group benefited most if everyone offered their full cooperation. Applied to the example of the Chinese parable at the beginning of this article, this means that everyone benefits the most when each guest brings a bottle of wine so that everyone can celebrate. However, each individual saves money if they only pour water into the barrel and then drink the slightly diluted wine provided by everyone else.

IN TIME, WILLINGNESS TO COOPERATE WILL DECLINE EVEN IF IT IS REGULARLY REWARDED

In our studies, I was keen to find out whether the willingness to cooperate increased if one group member took the lead in deciding how much they were going to contribute, i.e. how far they were going to cooperate, and the other members saw this before making their own decisions. As an example, you can imagine all the wedding guests watching while the first person pours their bottle into the barrel and noting whether it contains water or wine. Only then do they decide whether they would rather contribute water or wine.

All our findings show that cooperation in groups is substantially higher if one or more members set a good example. Group members adapt to the cooperative behavior of the others. In the field of economics, this is known as "conditional cooperation". This means that people are willing to cooperate (bring wine) if they see or at least expect that others

will also cooperate. In recent years, the importance of conditional cooperation has been confirmed in studies performed all over the world. We can almost speak of a global behavioral pattern that – depending on the study – can be identified in approximately 30 to 50 percent of the test subjects.

IN TEAMS WITH EGOTISTIC LEADERS, THE TEAM MEMBERS CONTRIBUTE AS LITTLE AS POSSIBLE

Conditional cooperation is a key factor in effective leadership. Exemplary behavior has a particularly strong impact if it is voluntary. The copycat effect does not function if someone is forced to be cooperative. And if someone sets a bad example, the cooperation in the team breaks down entirely – nobody wants to be exploited by freeriders. Because of the hierarchies within organizational structures, a particularly important role is played by the respective senior member or superior. His or her cooperative behavior is particularly likely to be imitated. In teams with egocentric leaders who often expect cooperation from others but behave like freeriders themselves, the members contribute as little as possible to the team's success because otherwise they feel exploited. Leadership only functions if the leader's behavior is exemplary; as Mahatma Gandhi once said, "We must be the change we wish to see in the world." On the other side of the coin, cooperation in groups can be severely impacted by the poor example set by a prominent group member. This is why the example set daily by team leaders, directors, and other persons in positions of responsibility is so important.

←

You can watch a video clip of a conversation between Matthias Sutter and the author Marc Elsberg on the topic of cooperation at www.mpg.de/wtles (in German)

FOCUS

LIVING WITH EXTREMES

A volcano in pop art: Andy Warhol created a series of Vesuvius paintings for an exhibition in Naples in 1985.

IMAGE: ANDY WARHOL, MUSEO E REAL BOSCO DI CAPODIMONTE, NAPLES

MARKED BY DISASTER

TEXT: MARC PESCHKE

The volcanic cone of Vesuvius looms over Naples – as both a landmark and a fateful reminder for the southern Italian metropolis. For centuries, its eruptions and earthquakes have left their mark here. Elisabetta Scirocco, a researcher at the Bibliotheca Hertziana, the Max Planck Institute for Art History in Rome, examines how these natural phenomena have shaped the city's art and architecture.

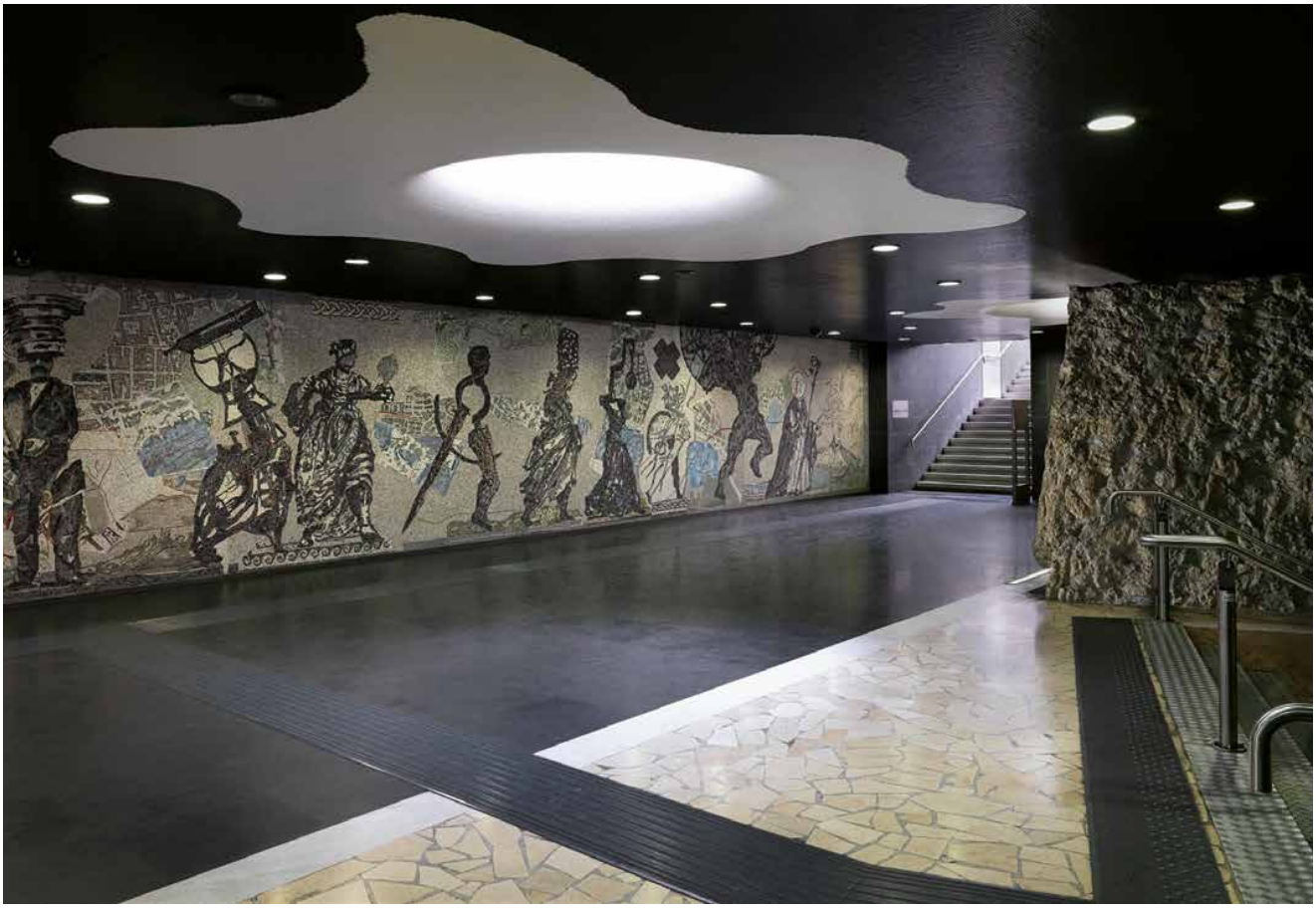


PHOTO: PEDICINI FOTOGRAFI, NAPLES/BIBLIOTHECA HERTZIANA, MPI FOR ART HISTORY

Artistically designed station: a mosaic by South African artist William Kentridge has adorned the Toledo subway station in Naples since 2012. It depicts figures from Neapolitan history moving in a procession towards the smoking Vesuvius.

In 2012, the South African artist William Kentridge created an extraordinary work for the Toledo subway station in Naples. The large-scale mosaic Central Railway for the City of Naples, 1906 (Naples Procession) depicts a procession of various prominent figures from the city's history. It is led by San Gennaro, the patron saint of Naples. Next to him is the smoking Vesuvius – rendered harmless by the protection of the saint. The internationally renowned artwork in the entrance hall of the subway station, part of a series of stations along the Neapolitan subway line, is extremely fascinating. Not only as a work of contemporary art but also because it combines multiple references to the city of Naples and its history. "Passing travelers take part in the procession in which Kentridge has condensed the entire urban, artistic, and cultural history of Naples – from its Greco-Roman origins to the present," explains Scirocco.

It is led by San Gennaro, a Christian martyr who was beheaded in Pozzuoli near Naples and who is of particular importance to Neapolitans. The saint's head and a few drops of his blood are the most valuable relics preserved in the city of Naples since the Middle Ages. Neapolitans await the "blood miracle" at all three annual festivals in honor of the saint. It is hoped that the blood of the city's patron saint will liquefy. According to popular belief, this is a good omen for the city's future. Throughout the centuries, the relics have always been presented in processions in times of great peril in the hope of averting impending natural disasters. "This is a good example of how disasters etch themselves into the history of a particular place," says Scirocco. "Not only in the past but also in the present and in the future." Thus, Kentridge's powerful image not only reflects history but also alludes to the threat that looms over the city of Naples to this day.

Disasters make history. And this is precisely Scirocco's subject area. "Naples and natural disasters: an art historical disaster research" – is her research project at the Bibliotheca Hertziana, the Max Planck Institute

for Art History in Rome. Here, under the leadership of Tanja Michalsky, Director at the Institute, a forum for new research on Naples has been created. It also includes the research area "Palimpsest Naples". "Palimpsest" is actually the technical term for parchments that were scraped or washed in the Middle Ages to be re-used for later works. In reference to Naples, this means: throughout the history of the city, the one constant has been perpetual change. Construction, reconstruction, and destruction by wars and natural disasters are a fundamental part of Neapolitan and southern Italian history.

A collective trauma

In a Zoom interview, Scirocco explains that this transformation of the city is only partial and inadvertent and that at no point in its history has Naples ever been completely destroyed. "I'm studying the palimpsest-like character of Naples, especially from the point of view of its re-birth after catastrophic events. It's not about just the destruction and reconstruction of structures but also the creation of landmarks and rituals related to disasters." Examples include the reconstruction of places of worship and representational buildings as well as the emergence of new devotional rituals and the institutionalization of these. Like most of Italy, Naples and its surroundings are prone to earthquakes. In addition, the most dangerous volcanic area in Europe, Vesuvius and the Phlegraean Fields, are in the immediate vicinity. No other Italian city of this size and cultural relevance has experienced catastrophic events as regularly as Naples, which in the 17th century was one of the most densely populated cities in Europe.

Scirocco explains that the eruption of Vesuvius in 79 C.E. is deeply etched into the historical memory of the area as a primordial catastrophe. At that time, the ancient cities of Pompeii and Herculaneum were buried under a layer of ash and rock up to 20 meters thick. An estimated 5,000 people died. From the 14th to the 20th century, Naples was repeatedly shaken by strong earthquakes. But Vesuvius remained dormant for a long time. In the mid-16th century, it was considered extinct.

But in 1631, disaster struck once again. "What happened when Vesuvius awakened – a violent explosive eruption accompanied by earthquakes – was akin to the imminent end of the world: the experience of absolute destruction," says Scirocco. "The collective trauma was recorded in texts and images and had enormous cultural and political implications – both locally and throughout Europe." Scirocco further explains that, at that time, natural disasters were not yet explained from a scientific point of view but rather in a religious context, as a punishment from God. Prayer, public penance, and processions were thus an essential part of what anthropologists call "emergency rituals". Every year on December 16th, a festival is held in the city. It features a procession carrying the relics of St. Gennaro; the very same relics that were carried in a procession through the city towards Vesuvius in 1631. According to legend, when the procession arrived at the outskirts of the city, the saint appeared in the sky and stopped the eruption of the volcano. A votive monument to the saint was erected on this spot. Many of the towns and villages around Naples have their own artistic and ritual memories of their co-existence with the volcano. But the eruption of 1631 had another effect: Vesuvius became a constant presence in Neapolitan art. With this event, "Vesuvius entered the iconography of the city of Naples," says Scirocco. The depictions of the city now changed, expanded, and showed the volcano. During the 18th and 19th centuries, the interest in its regular activities and eruptions led to the creation of numerous paintings, drawings, and studies of Vesuvius. Naples developed into one of the most important stops on the Grand Tour – the obligatory journey taken by young European nobles and the upper middle classes through Central Europe, Italy, Spain, and into the Holy Land. In Naples, the volcano was one of the main attractions for these young travelers. All this led to the city identifying itself with the volcano. Vesuvius was – and is – also a symbol of the destructive forces of nature. This can be seen, for example, in the 2019 exhibition Vesuvio quotidiano – Vesuvio universale at the Certosa di San Martino Museum in Naples.

Nevertheless, the threat posed by the volcano has played hardly any role in the research into the history of Neapolitan art. For a long time, it focused on the periods of the French Capetian House of Anjou from the 13th to the 15th century as well as on the Baroque period with its magnificent church interiors and the paintings of the Neapolitan School from the 16th to the 18th century. Furthermore, the Neapolitan Renaissance under the royal house of Aragon was predominantly viewed as a cultural import rather than a genuinely Neapolitan creation. It is precisely this 20th-century perspective that the research group at the Bibliotheca Hertziana is challenging: the idea that Naples was quasi-colonized because the city has been ruled by various foreign dynasties. Scirocco also says that for too long, the emphasis was on the dependence of Naples on artistic centers like Rome and Florence. The goal of the "Naples Forum" of the Bibliotheca Hertziana is there-

SUMMARY

Earthquakes and volcanic eruptions have shaped the culture and society of Naples for centuries.

This can be seen in the architecture of reconstructed and renovated buildings, in the visual arts, and in religious rituals.

The focus on natural disasters creates a whole new art historical perspective on the city's multifaceted cultural development.

fore also to critically examine these traditional and canonized research results and to emphasize the strictly localized nature and specific characteristics of Neapolitan artistic production.

The entanglement of several time layers

However, art history research in Naples is more difficult than elsewhere. This is due to what the author and philosopher Walter Benjamin described in the 1920s as the "porosity" of the city. The city's cellular structure, the dense juxtaposition, the intergrowth of different architectural styles from different layers of time resembles webbing, a living organism. Naples has often been described in this way throughout its history. The old town of Naples, which was declared a Unesco World Heritage Site in 1995, is a prime example of a highly diverse community with enormous social problems yet a fantastic assortment of cultural assets. In Naples, the cultural-historical vestiges from the Greek and Roman times and from later periods are layered and overlapped everywhere. A particularly impressive example of this overwriting of history as a result of the frequent earthquakes is the Cathedral of Naples where the relics of the Neapolitan city patron San Gennaro are kept. According to Scirocco, the cathedral amalgamates layers of artistic history dating from antiquity to the 19th century; this is typical of the city.

The baroque church of San Paolo Maggiore on the Piazza San Gaetano is also an excellent example of the changes and transformations caused by natural disasters. Larger parts of the Roman temple of the Dioscuri were preserved here until its collapse after the earthquake of 1688. According to Scirocco, the facade was the backdrop for urban life for centuries: "The Piazza San Gaetano was once home to the Greek agora and later the Roman forum. It was thus the heart of the city center. To this day, the private and public life of Neapolitans takes place there. When the facade of the Roman temple collapsed in 1688, the backdrop for centuries of city life was destroyed in one fell swoop. The collapse was continually evoked in texts and imagery. During the reconstruction, it was decided to preserve only two columns of the temple with an inscription commemorating the earthquake of 1688." But Scirocco's research subject is not medieval and pre-modern art alone. She also examines the 20th century such as Andy Warhol's 1985 Vesuvius series – a sort of homage to the volcano as a symbol of Naples that translates the theme of the volcanic eruption into the language of Pop Art. Scirocco has called Warhol's depiction of the erupting volcano a "synecdoche", an image that has symbolized the city of Naples itself ever since the catastrophic eruption of 1631. Joseph Beuys, on the other hand, produced an unsettling work for the influential Italian gallery owner Lucio Amelio. Exhibited in Naples in 1981, *Terremoto in Palazzo* is a composition of four fragile, unstable wooden tables salvaged after the 1980 earthquake, shards of glass on the floor, and an egg placed on one of the tables. One year later, in 1982, Warhol created the work Fate presto, based on the front page of the newspaper Il Mattino.

The works of both Beuys and Warhol are part of a collection later entitled Terrae Motus, which resulted in response to Lucio Amelio's call for contemporary artists to create works related to the terrible earthquake of 1980. At that time, violent earth tremors had shaken the Irpinia region some 80 km east of Naples, killing more than 2,700 people and causing nearly 400,000 to lose their homes. "The memory of the 1980 earthquake and its aftermath is still very much with us – as are its echoes in the media, which Warhol translated into a work of art," says Scirocco. "The date itself, November 23rd, is common knowledge. Last year, on the 40th anniversary, a series of events, debates, and exhibitions were held." Thus, traumatic disasters of the past and the risk of repetition in the future are part of the collective memory and the everyday visual experience in the city of Naples.

Dangerously close: the area around Vesuvius is densely populated. The satellite image shows the few undeveloped areas in red.

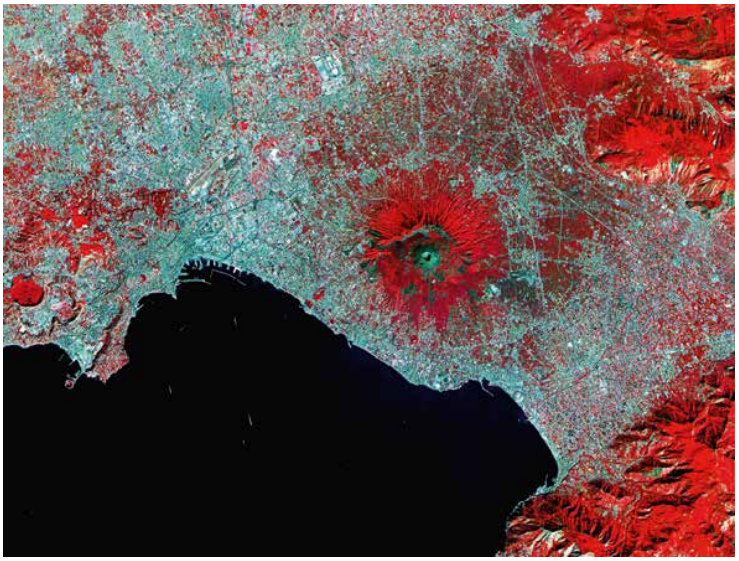


PHOTO: NASA/GSFC/MITI/ERSDAC/JAROS & U.S./JAPAN ASTER SCIENCE TEAM

Focus on natural disasters: Elisabetta Scirocco researches the art history of the city of Naples at the Bibliotheca Hertziana.

PHOTO: KATARÍNA KRAVČÍKOVÁ, BRNO

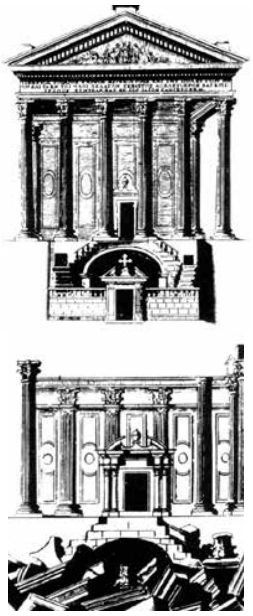


ILLUSTRATION: CARLO CELANO, NOTITIE DEL BELLO, DELL'ANTICO E DEL CURIOSO DELLA CITTÀ DI NAPOLI, NAPLES 1692

Before – after: until the earthquake of 1688, the church of San Paolo Maggiore in the center of Naples stood behind the largely preserved facade of the Roman Temple of Dioscuri (above). Only two of the ancient columns were preserved during the reconstruction.

The volcano as an identity-forming feature

Today, historical disaster research is a highly productive field of research in which the various historical disciplines establish a dialog with the social and natural sciences. A trans-disciplinary approach to this topic has been developed since 2014 at the Kunsthistorisches Institut in Florenz, which is also a Max Planck Institute, with the project "Storia dell'arte e catastrofi". Along with Scirocco, who was doing research in Florence at the time, Gerhard Wolf, Director at the Institute, and Carmen Belmonte led the group. Natural disasters are recurring events in the history of Italian cities and landscapes – right up to the present day, which underlines the relevance of the research. Recent earthquakes in L'Aquila in Abruzzo (2009), in Emilia-Romagna (2012), and in central Italy (2016/2017) have also shown how prevalent the seismic problem is. For research on Naples, Scirocco broadened the perspective, starting from the Middle Ages and continuing through the pre-modern period to the present. In her project on Neapolitan history, she combines historical, seismological, and volcanological research with architectural history, archeology, philology, the history of science, historical anthropology, and sociology.

"We are examining from a historical perspective how disasters were dealt with through the ages and how living with the volcano has become an identity-forming feature of Neapolitan art and culture," says Scirocco. "However, the role art history has played in disaster research has been marginal and mainly limited to the depiction of catastrophic events. This opens up an area for art history that has great potential for multidisciplinary dialog."

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

Border region between Egypt (left) and Gaza and Israel (right). The difference in the shades of the terrain in the uncultivated areas reflects changes in the desert soil on the Egyptian side. This makes this border one of the few that can be seen from space.

PHOTO: SCIENCE PHOTO LIBRARY/PLANETOBSERVER

ALGAL BLOOM IN THE DESERT SAND

TEXT: KLAUS WILHELM

Drought, heat, and glaring sun. A desert habitat is one of punishing extremes. If a plant is to survive here, it must be able to endure a lot. This is especially true for algae. Together with Mark Stitt and his team at the Max Planck Institute of Molecular Plant Physiology in Golm near Potsdam, Haim Treves is investigating how the alga *Chlorella ohadii* has adapted to the extreme living conditions of the desert.

"At first, we thought our measuring devices were malfunctioning. But it wasn't the instruments – it was the algae."

HAIM TREVES

Chlorella ohadii is a unicellular green alga that is named after the man who discovered it, the eminent biochemist and photosynthesis researcher, Itzhak Ohad. He was Treves' long-time mentor and friend, who died in 2016. Ohad was the first to isolate and study this organism, and his research made a major contribution to our fundamental understanding of photosynthesis. It has now been 10 years since Haim Treves was a PhD student at the Hebrew University in Jerusalem, where he regularly explored the desert. The young scientist brought back samples from his excursions to the Israeli Negev Desert of the wafer-thin sand crust that covers the desert's floor. "This crust has the consistency of cornflakes in the areas of the Negev that are farther away from the coast. It breaks with a soft crackle when you step on it. But along the coast, where the air is more humid, it feels more like you're stepping on a sponge," describes Treves.

The crust appears completely lifeless. But in fact, it harbors a unique community of microorganisms. For example, cyanobacteria – bacteria formerly known as "blue-green algae", many of which perform photosynthesis and get their energy from sunlight. Treves and his colleagues wanted to isolate these bacteria from the sand crust and grow them in the laboratory. But tiny green specks would always appear in their cell cultures after a short time. "At first, we thought we had been careless and contaminated our samples," he recounts. But they just couldn't get rid of the green specks. Itzhak Ohad finally persuaded Treves to look into the mystery. Treves identified the green specks as colonies of the green algae *Chlorella ohadii*. "I really owe him a

Cyanobacteria of the genus *Leptolyngbya* form unbranched chains. They are found in a wide variety of habitats, e.g. in thermal springs, in Antarctica, as well as in deserts. In the Negev Desert, the cyanobacteria live in the crust that covers the ground.

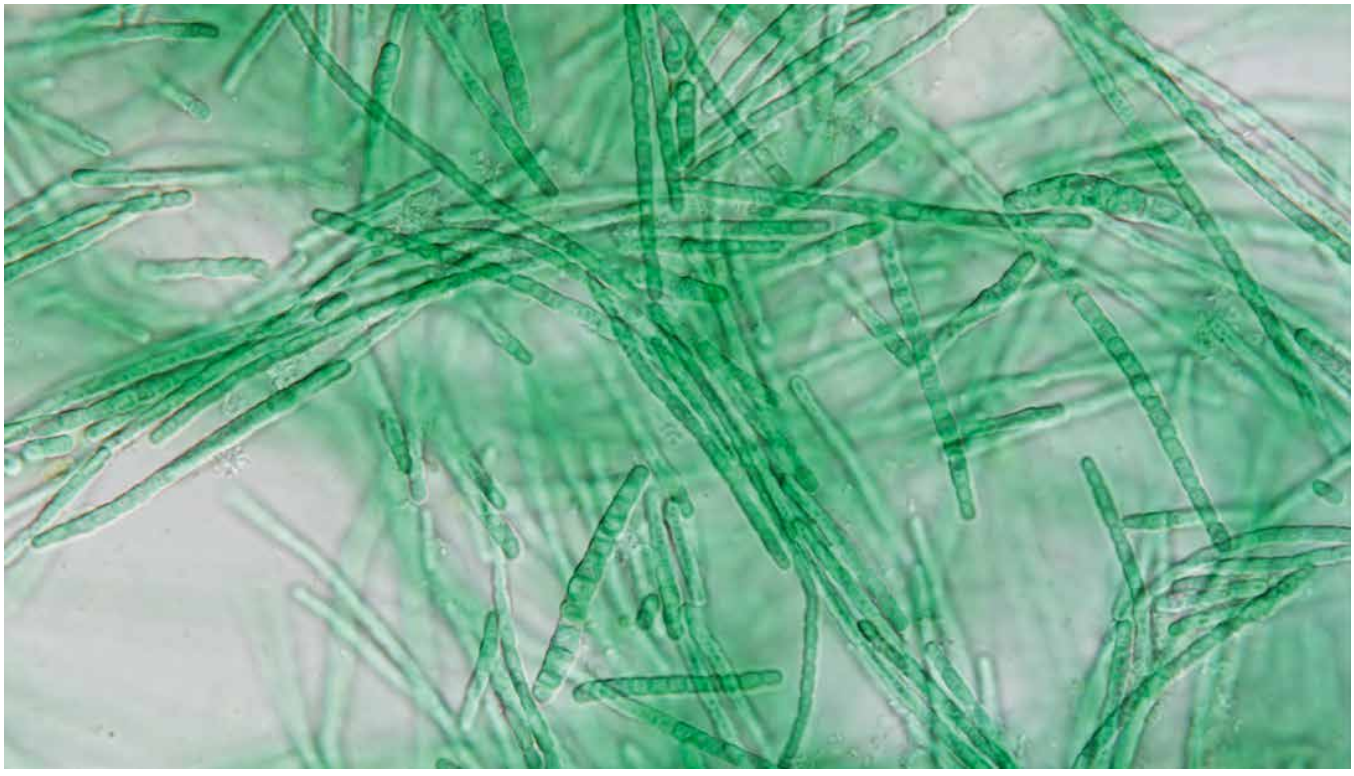


PHOTO: CCALA

PHOTOS: HAIM TREVES/MPI OF MOLECULAR PLANT PHYSIOLOGY

Border between Israel (foreground) and Egypt. In spring, flowers bloom on the Israeli side of the Negev Desert, while the Egyptian side, in contrast, is largely devoid of vegetation and is covered in sand – this is a result of the destruction of the soil crust by vehicles and overgrazing.

A layer about two millimeters thick covers the desert surface. Over many decades, microorganisms have produced carbohydrates that have combined with the sand and baked into a brittle crust resembling cornflakes. This crust stores water better than pure sand and it protects the ground from erosion and complete desiccation.

SUMMARY

The green algae *Chlorella ohadii* defies extreme drought and solar radiation in the soil of the Negev Desert. It employs various adaptations to protect its photosynthetic mechanisms against the glaring sunlight. A crust only few millimeters thick on the soil surface protects it from drying out. Bacteria form a gel-like layer by excreting carbohydrates, which can store water better than sand.

Researchers want to transfer this alga's properties to crops to enable them to photosynthesize effectively – even at high levels of solar radiation.

special debt of gratitude for his guidance and inspiration, and it makes me very happy that his legacy lives on in the name of this alga." Treves quickly recognized the alga's extraordinary abilities: not only did *Chlorella ohadii* defy extreme exposure to sunlight – the more light the researchers shone on it, the faster it grew. Even at four times the light intensity of the desert, the algae continued to flourish. "We thought it was our fault and that our meters were defective," says Treves. However, this phenomenon was not due to the instruments, but rather to *Chlorella ohadii* itself: not only does it survives in one of the most extreme habitats on Earth – it is also one of the fastest growing organisms ever discovered. Mark Stitt was also fascinated by the discovery. The former Director at the Max Planck Institute of Molecular Plant Physiology uses cutting-edge technology to research photosynthesis. Like most of his colleagues, he uses model organisms such as *Arabidopsis thaliana*, spinach, potatoes, and tomatoes because the genetic material of these plants has been decoded, and many of their metabolic pathways are known. "But sometimes it's a good idea to leave familiar territory. If we are focusing on only a few species, it is easy to overlook how differently plants can adapt to their environment. And it's under extreme conditions that plants can develop completely unexpected capabilities," says Stitt. So it was only logical that Treves should go to the Max Planck Institute in Golm after he got his doctorate, so he could conduct further research on *Chlorella ohadii*.

The life of this alga is characterized by extremes: during the day, it is not uncommon for temperatures to rise to up to 60°C; the sun and heat completely dry out the soil. At night, on the other hand, temperatures can plummet so far that frost can form. At dawn, the little moisture that there is in the air settles as dew on the ground. The proper amount of water and light that *Chlorella* needs to exist is available only in the brief period just after sunrise, before there is once again too little of one and too much of the other.

Particularly the photosynthesis of this alga is optimally adapted to such conditions. Electrons play an important role in converting solar energy into chemical energy. For every photon that is absorbed by the chlorophyll molecules, one electron is elevated into a higher energy state. These energized electrons provide the energy to 'split water' and turn it into oxygen and hydrogen atoms. However, the sun's rays are too strong in the desert. "Then the photosynthetic machinery gets overloaded and melts down – like a short circuit," explains Stitt. High light intensity can also produce "singlet oxygen" – a highly reactive form of oxygen that damages the photosynthetic apparatus.

Beyond a certain point, increased solar radiation no longer leads to a higher photosynthetic output. Instead, it stagnates and even decreases with increasing radiation. Dryness intensifies this effect, because it hampers the

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PHOTO: HAIM TREVES/MPI OF MOLECULAR PLANT PHYSIOLOGY

An electron microscope reveals the details of the photosynthesis mechanisms of *Chlorella ohadii*. The chloroplast occupies a large part of the cell. Its stacked membranes (M) make photosynthesis particularly effective. The pyrenoid (P) serves the same purpose. It is enriched with the carbon dioxide needed for photosynthesis as well as a key enzyme. The pyrenoid is surrounded by a layer of starch (light ring).

use of the light energy to drive carbon dioxide fixation and other metabolic reactions. The researchers found that *Chlorella ohadii* has evolved several mechanisms – some unique – as protection against such short-circuits. They allow the alga to quickly establish a balance between oxidation and reduction reactions. Without this balance, too many electrons would accumulate. "Like a car that shifts into a lower gear when going down a steep hill, this alga prevents damage to the photosynthetic system," says Haim Treves. Furthermore, the electrons flow within a closed circuit during photosynthesis in *Chlorella*, because only a circulatory system can prevent a surplus of energy-rich electrons under the desert's extreme conditions. Otherwise, the electrons would be stuck like cars in a traffic jam, with some even flowing backwards. *Chlorella* also produces enzymes that neutralize destructive singlet oxygen molecules.

Studies by the Max Planck researchers also revealed that *Chlorella* can effectively photosynthesize even in low light. The alga employs the very same 'tricks' when it grows in low light that it uses to cope with very high light intensities. When solar radiation increases, *Chlorella* can quickly raise its photosynthetic output and produce 60 times more starch than under low levels of light. "The growth rate of the algae increases within minutes – it's like a turbocharger gets turned on," says Treves.

But all these adaptations would not be enough if there were not another very special habitat in the Negev Desert that, together with bacteria and fungi, enables the algae to survive under the most adverse conditions: the two-millimeter-thick crust on the desert floor. It is

"Plants often develop unexpected abilities, especially under extreme conditions."

MARK STITT

formed when the pioneers of the desert – the cyanobacteria – settle on the surface of the sand layer. Over many years, they produce large amounts of carbohydrates, which form a gel-like mass. This mixes with the sand grains and creates a crust when it dries. The gel can better retain the moisture when water in the form of dew or – very rarely – rain wets the soil. It also dries out more slowly than pure sand. This allows the crust to provide more water for the microorganisms living within it. Only when over half of the stored water has evaporated over the course of the day do the microbes temporarily cease their activity. In laboratory experiments, Treves was able to demonstrate that the crust actually prevents its community of microbes from drying out: together, cyanobacteria and *Chlorella* survive the aridity typical of the desert – on their own, the algae would die. Researchers have even found evidence that this crust-dwelling organisms prepare for daily desiccation: before sunrise, the cells produce substances that will help them revive from their dry state the following night.

Tiny tubes in the crust

Treves's mentor Itzhak Ohad and his colleagues have observed other fascinating phenomena under the microscope. The cyanobacteria can form vertical tubes in which they can migrate towards the light. "When we put a piece of crust in a Petri dish in the lab and spray water on it, the bacteria come to the surface and form a green layer upon it. Other times, the crust seems to turn black, because the bacteria are shielding themselves with endogenous sun protection factors," says Treves. *Chlorella* and the other microorganisms in the crust also benefit from this light protection. Thus, without the cyanobacteria, the algae could not survive.

ADAPTATIONS TO LIFE IN THE DESERT

ROOTING
Formation of deep or extensive roots

SAVE WATER
Impermeable surface (e.g., a layer of wax)

Closed stomata during the day
Fewer or smaller stomata

Smaller or no leaves

Hair as protection against light and evaporation

SUN PROTECTION
C4-photosynthesis: Nocturnal CO_2 fixation in the form of malate and the conversion to carbohydrates during the day

Production of sun protection factors, like aloe

Minimizing the area exposed to the sun by turning away from the light

DISTRIBUTION
"Dormant" seeds that take years to germinate in drought conditions

Explosive growth of seedlings in the presence of moisture

In general, bacteria seem to be the secret rulers of this ecosystem. If resources become exceptionally scarce, the bacteria can even bring the growth of the algae completely to a halt.

The importance of the ecological function this soil crust performs is visible along the Israeli-Egyptian border. Tire tracks and other signs of human activity dominate the Egyptian side. Because the crust is largely destroyed, a sandy desert has spread out on this side of the border. The Israeli Negev on the other side is a restricted military area and may not be entered by unauthorized personnel. So there the crust is still largely intact. The significance of this becomes evident after rare rainshowers in the desert: the Egyptian Negev remains brown, but the Israeli Negev blossoms and briefly transforms into a sea of flowers. "The crust prevents the sand from spreading. So plants can thrive there after it rains," explains Treves.

The Chinese government has recognized the crust's stabilizing on sand dunes and soil fertility. In an experiment, Chinese researchers have inoculated sand dunes of the Hopq Desert with cyanobacteria and artificially irrigated them. They're hoping a sand crust and ultimately arable soil will be created in this way. It remains to be seen whether such measures will be successful. Treves takes a different approach to helping crops grow better in arid and semi-arid regions. In his opinion, *Chlorella ohadii* itself is the key: "If we understand what makes it so resistant to drought and high levels of sunlight and how it can grow so quickly, we can provide other plants with the same capabilities," says Treves. Perhaps this tiny green algae holds one of the keys to sustaining life as global warming continues. It would not be the first time that a presumed measurement error turned out in retrospect to be an important scientific discovery.

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

Bridge without a river: a drought in 2018 led to a drastic reduction in the water level of many bodies of water, such as the Rhine. As seen here in Duesseldorf, this also had a serious impact on inland navigation.

PHOTO: PICTURE ALLIANCE/DPA | CHRISTOPHE GATEAU

PREDICTABLE CLIMATE STRESS

TEXT: ANDREAS KNEBL

Droughts, heatwaves, and floods – climate change is likely to make extreme weather and climate events such as these more frequent and more intense. Markus Reichstein, Director at the Max Planck Institute for Biogeochemistry in Jena, and his team are working on predicting the impacts of such events. Reichstein uses large volumes of data in conjunction with artificial intelligence to carry out this research, which he hopes will make societies more resilient to extreme climate events.

The researcher Markus Reichstein is fond of rosemary and would ideally like to grow the Mediterranean herb in his garden in Jena, but it probably would not survive there for long. That is because there is a severe cold spell there every few years – such as that in the winter of 2020/2021 – that prevents a large rosemary bush from thriving. Nevertheless, Markus Reichstein, Director at the Max Planck Institute for Biogeochemistry, can still use rosemary to illustrate his research into extreme climate events. The sunny, warm, and dry climate in Jena is actually ideally suited to the Mediterranean plant, and the average winter temperatures are not a problem either. But just a few days at temperatures below minus 10 degrees Celsius can sound the death knell for the bush. Reichstein uses this fact to explain the different dimensions of extreme climate and weather events.

PHOTO: DAVID AUSSERHOFER

Alerted by extreme events: Markus Reichstein and his team combine meteorological measurements – such as from a weather station in Jena – with ecosystem data. Artificial intelligence helps them predict extreme climate events and their consequences for agriculture and forestry, for example.

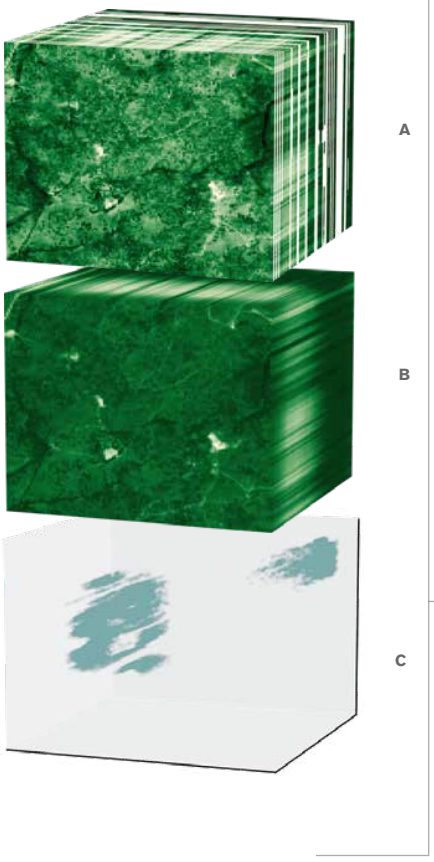
The term "extreme climate event" is used to refer to prolonged, extraordinary events, such as droughts or heatwaves. "Extreme weather" refers to short and unusually intense events, such as storms or heavy hail showers, but there is no standard definition of what is classified as extreme: "For a start, you can look at the meteorological data and determine how frequently, or indeed infrequently, a specific event occurs at a given location – such as temperatures below minus 10 degrees Celsius," Reichstein explains. "But you can also look at an event like this differently and analyze how far the value deviates from the mean. It is even more compelling, however, to consider what effects the event has and whether its impacts are just as extreme – that is, unusually intense." After all, native plants can easily handle a few very cold winter days – and the effects are not extreme by their standards, but they certainly are extreme for rosemary.

In the last few years, it has been hard to overlook the far-reaching consequences of extreme climate events in Germany – some of which were quite unexpected. The hot and very dry summer of 2018 created serious problems for foresters and farmers alike, and caused increasingly visible damage to German forests. In some parts of Germany, the extreme drought even led to extensive forest fires. These direct consequences were to be expected. What was more surprising, however, was that a low water level in the Rhine would lead to bottlenecks in supply and that power plants would run out of cooling water. The extreme climate conditions therefore had a serious impact not only on humans but also on the natural world – and were an area of intense public interest.

But for many ecosystem researchers, including Markus Reichstein, the wake-up call had already come in the form of another extreme event – namely the heatwave that hit Europe in the summer of 2003. Back then, the high temperatures and increased air pollution due to various climatic effects led to several tens of thousands of deaths. As well as affecting humans and the economy, the heatwave also had a serious impact on the natural world. Based on extensive data from measuring stations and remote-sensing satellites, researchers were able to conduct a detailed analysis of the heatwave's effects on ecosystems. At that time, Markus Reichstein's research focused on the carbon cycle and particularly on the carbon balance between the biogeosphere and the atmosphere. In other words, the researcher was trying to work out how much carbon dioxide was being absorbed from and emitted into the air by plants and soils, for example. The data from the 2003 heatwave also clearly demonstrated the profound influence of extreme climate events on the global carbon cycle: normally, the plants on the European landmass absorb large quantities of CO_2 during their growing season over the summer period. This is described as a "carbon sink" – as opposed to a "carbon source." But the effects of high temperatures, and especially of a shortage of water, meant that the plants grew significantly less in 2003. As a result, not only were the car-

"The aim must be a society that is resilient to extreme climate events."

MARKUS REICHSTEIN



GRAPHICS: GCO, BASED ON A TEMPLATE BY VITUS BENSON, CHRISTIAN REQUENA-MESA, WWW.EARTHNET.TECH (2021)

Localized warnings: for various locations in Europe (green squares), the team in Jena is analyzing how ecosystems have developed as a function of climate in the past and producing corresponding data cubes (A). The researchers then use climate forecasts to predict future changes in the ecosystem (B) and identify extreme climate events within them (C).

bon sinks across Europe much weaker, but European ecosystems even became sources of carbon dioxide.

This finding sent shock waves through the research community. Until then, researchers had assumed that anthropogenic climate change would cause plants at middle and high latitudes to absorb more CO_2 in the future. The theory was that warming and the increased level of carbon dioxide in the atmosphere would cause plants to grow earlier in the year and more vigorously – and that this would slow down not only the rise in carbon dioxide levels due to anthropogenic emissions, but therefore also the process of climate change itself. "However, the 2003 heatwave was an eye-opener," says Markus Reichstein. Even then, everything scientists had learned thus far suggested that climate change would lead to more extreme events, such as droughts and heatwaves, in the future – and it turned out that an event of this kind was capable of temporarily converting a carbon sink into a carbon source. Indeed, if vegetation dies off or experiences permanent damage, this effect can even intensify over the years. Reichstein's team discovered that extreme climate events exert approximately the same degree of influence on the global carbon cycle as that of all carbon sinks on the Earth's landmasses combined. And if extreme climate events become more frequent, the CO_2 content of the atmosphere could continue to rise – creating a feedback loop between the atmosphere and the biogeosphere that would further accelerate climate change.

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PHOTO: SHUTTERSTOCK/HIKRCN

At the mercy of climate change: a heatwave in 2011 forced a million people in East Africa to flee their homes and land. Forecasts of these events could allow people to take precautions against disasters of this kind.

SUMMARY

As our climate changes, extreme meteorological events such as heatwaves, droughts, storms, and heavy rain look set to become more common. In some cases, this interrelationship has already been proven.

Researchers from the Max Planck Institute for Biogeochemistry are using meteorological and ecological data in conjunction with artificial intelligence to improve their understanding of – and ability to predict – extreme climate events and their impacts.

By adopting this approach, they have been able to demonstrate that the heatwave and drought that affected Russia in 2010 led to a collapse in plant growth in agricultural regions, as expected, but was also linked to increase in biomass production at latitudes dominated by woodland.

Predictions of extreme climate events and their consequences could help societies to be better prepared.

Of course, the degree to which extreme events affect humans and nature also depends on their frequency and intensity. Accordingly, predictions as to whether climate change will lead to more extremes help us to assess what is coming our way. For a long time, these kinds of forecasts were based on abstract considerations. It wasn't possible to make detailed forecasts, because insufficient data was available on rare extreme events in the complex system of climate and weather. However, fundamental thermodynamic considerations led researchers to conclude that climate change would make extremes more likely and therefore more frequent. The reason for this is that the global rise in temperatures means there is more energy in the Earth system. More water evaporates, and the atmosphere can also hold more water. This means that the generation of weather events gains momentum – and results in more extreme events such as heatwaves, heavy rain, or storms.

Over the last few years, climate scientists have been proven correct in their reasoning, as they have actually succeeded in attributing the increase in extreme events to climate change. Their analysis is based on improved global and regional climate models that run on powerful computers. At present, the attribution works best for heatwaves, while the statements are less reliable for other extreme events such as droughts, heavy rain, or floods. Rather than establishing a causal relationship between climate change and a specific event, the researchers calculate how much more likely an extreme event of this kind has become due to climate change. This involves comparing the probability of an extreme event in a world without anthropogenic climate change with the probability in a world with climate change. This is rather like throwing two dice numerous times to compare how often a certain number occurs. Climate change has loaded one of the dice – the one from our real world. In the case of the devastating bush fires in Australia in 2019 and 2020, for example, an analysis by the World Weather Attribution research initiative found that climate change has increased the risk of an event of this kind by at least 30 percent.

Markus Reichstein hopes to go one step further: he not only wants to attribute extreme climate events to climate change retrospectively, but also to predict these events for a region or location as accurately as possible. For this, his group uses large quantities of data in conjunction with artificial intelligence to develop a better understanding of extreme climate events. By doing so, they hope to pave the way for forecasts of extreme climate events – and above all of their effects – with high spatial resolution and therefore to contribute to the development of an early warning system. To this end, the scientists gather large volumes of data that allow them to correlate a wide variety of information, such as meteorological measurement data and data that describes ecosystems. Artificial intelligence techniques help them to process and combine the data, allowing them to compare, for example, temperature and precipitation values with the plant activity determined from satellite images, as well as analyze the carbon dioxide concentration measured near the Earth's surface. This enables the researchers to produce a world map for all variables that characterize the state of an ecosystem. For example, this results in a drought stress map that covers many previous points in time – in other words, it has high temporal resolution. Along with the degrees of longitude and latitude, the slices of time form the third dimension of this "data cube." This ultimately allows the researchers to assess, for example, the extent to which the drought has damaged – and will damage – the vegetation as time goes by. The key strength of this approach is that it reveals spatial relationships and illustrates the development over time, allowing the scientists to detect anomalies. For these deviations from the norm, which indicate an extreme event, they then analyze a range of variables and volumes in order to obtain a multidimensional picture of the complex interactions.

An extreme climate event with ambivalent consequences

To examine how various factors contribute to the occurrence of an extreme climate event and influence its effects, the scientists studied one extreme event in particular: a heatwave that took place in Russia in 2010. The prolonged period of abnormally hot weather saw temperatures rise to over 38 degrees Celsius and exceed average temperatures by more than 10 degrees Celsius for a period of several weeks. This was accompanied by a period of severe drought – producing a devastating combination that resulted in crop failures, forest fires, and peat fires. The heatwave also led to tens of thousands of deaths, not only because of the high temperatures but also because of the air pollution caused by the drought, heat, and fires. However, in the data cube analysis, Reichstein's team discovered that the consequences were not as unequivocally negative for the natural world, because the time and location of

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the extreme meteorological event did not quite match up with the development of plant productivity. The anticipated effect appeared at the middle latitudes, which are dominated by agriculture: here, the hot and dry summer caused the plants to stop growing and wither. Plant productivity collapsed. At the higher latitudes with extensive forest cover, however, the mild spring and unusually hot summer triggered early and vigorous plant growth. In other words, the extreme meteorological event had very different effects on the ecosystems in different regions.

Accurate to the nearest 20 meters

In order to predict extreme climate events reliably, the key thing is to learn from as many different examples of these events as possible. Indeed, it is only by analyzing a large volume of data in detail that researchers can produce a clear and generally applicable picture of these complex relationships. That is precisely the strength of artificial intelligence – and specifically of methods based on machine learning, which can spot patterns in unfamiliar data. To this end, Reichstein's research group is working with Bernhard Schölkopf, Director at the Max Planck Institute for Intelligent Systems, as well as other researchers from the European Lab for Learning & Intelligent Systems (ELLIS), to refine machine learning algorithms and apply them to Earth system research. With the help of artificial intelligence, the researchers in Jena are not only analyzing the effects of extreme events, but also aim to achieve a better understanding of the causal relationships through which ecosystems and the climate influence one another. The data cubes are now accumulating increasing numbers of extreme climate events that have taken place around the world in recent decades – and the scientists hope to detect informative patterns in this data with the help of artificial intelligence. Moreover, it may also be possible to link risk factors or indirect consequences to an extreme climate event in an association that other approaches probably wouldn't have identified. "If we combine the results of these analyses with models and established climate knowledge, it may one day be possible to predict the risk of an extreme climate event – and above all its effects – down to the nearest 20 meters," explains Reichstein.

With the findings that the geoscientist and his colleagues around the world have obtained in relation to extreme climate events, Reichstein now wants to put his case to the general public and the world of politics. He is being supported in these efforts by Dorothea Frank at the Max Planck Institute for Biogeochemistry: "We want to raise awareness of the dangers caused by the fact that climate change is making extreme weather and climate events increasingly likely," says Frank, who is jointly responsible for numerous projects and initiatives in this context. After all, it is clear that even if efforts aimed at slowing down and stopping climate change are successful, the occurrence of extreme climate events worldwide will initially intensify. At the same time, the forces of nature are colliding with social conditions that are in a constant state of flux. The researchers in Jena therefore want to use findings from various scientific disciplines in order to better prepare society for the challenges associated with climate change. "Particularly in the case of systemic risks that arise from the interaction of natural systems with the economy, politics, and individuals, our understanding of these risks relies on our ability to consider developments from scientific, economic, psychological, sociological, and historical perspectives," says Reichstein.

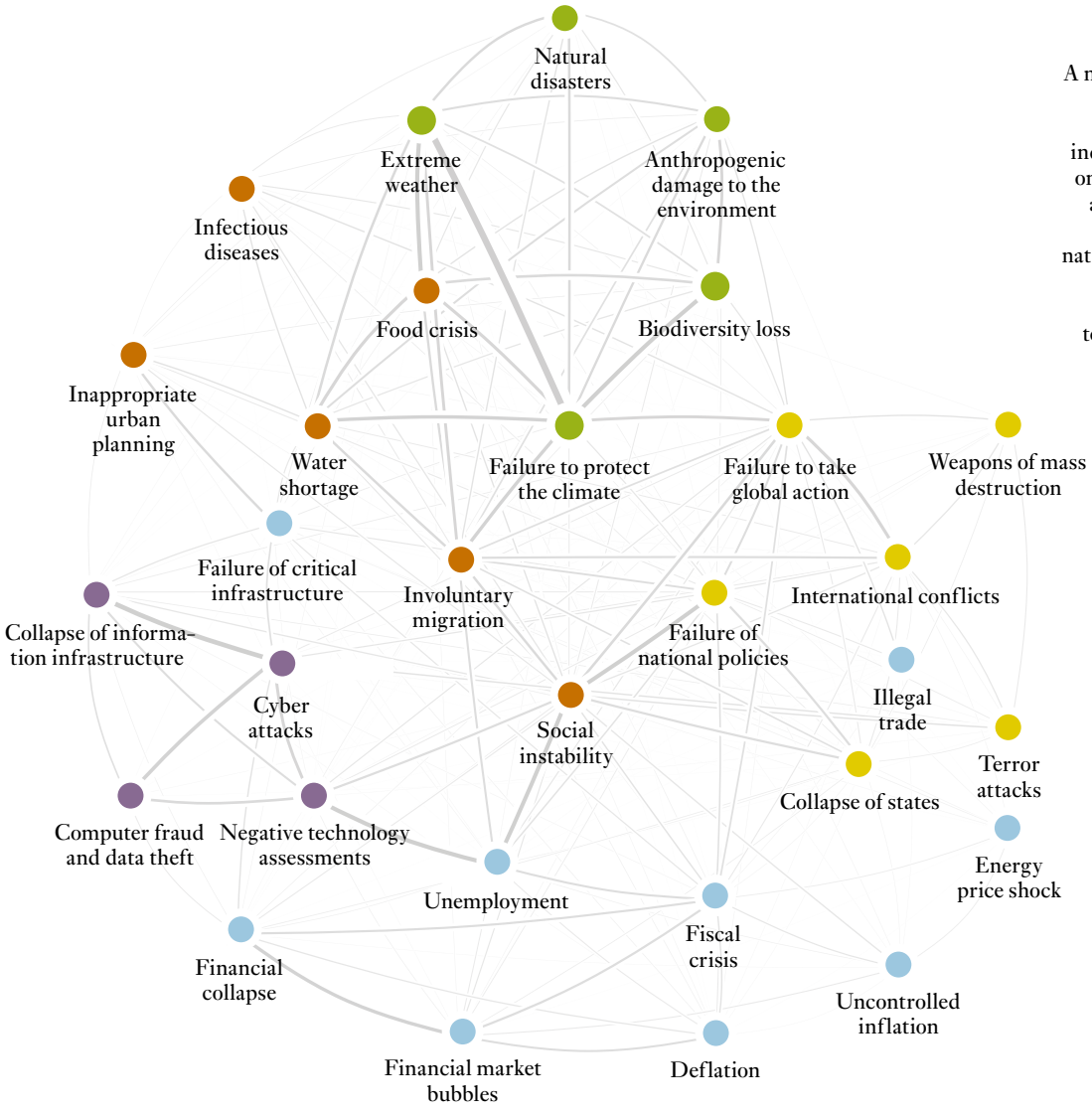
Frank and Reichstein are currently attempting to bolster scientific dialog in relation to extreme events, disaster preparedness, and governance through the Risk KAN initiative, which brings together numerous international colleagues. Together, they want to draw up recommended courses of action for dealing with systemic risks. After all, extreme climate and weather events are increasingly putting states and societies to the test – and whereas wealthy and highly developed countries are often able to avert the most serious consequences of extreme events, the resulting disasters threaten many human lives in developing countries and necessitate the deployment of humanitarian aid. One example of this is the drought that affected East Africa in 2011, along with the resulting famine in countries such as Ethiopia and Somalia. This disaster put more than 10 million people at risk, caused several hundred thousand deaths, and forced almost a million people to flee their homes and homelands. The World Bank estimates that by 2050, up to 143 million people could become climate refugees, many of them due to the effects of extreme climate events. With this in mind, it is vital that we take immediate action, adopt preventive measures, and make the necessary investments. "The aim must be a sustainable society that is as resilient to extreme climate events as possible," says Reichstein. There are a variety of possible measures, which depend heavily on the location in question: near coastlines or rivers, it may be necessary

GLOSSARY

EXTREME CLIMATE EVENT
A prolonged, unusual event such as a drought or heatwave. In contrast, extreme weather is a short, unusually intense event such as a storm or heavy rain.

CARBON SINK
A part of an Earth system that absorbs more carbon – primarily in the form of carbon dioxide – than it emits. Land and ocean together absorb more than 50 percent of anthropogenic carbon dioxide emissions.

MACHINE LEARNING
An artificial intelligence approach in which algorithms spot patterns in large volumes of data – for example, in order to identify the relationship between meteorological data, such as rainfall figures, and reduced plant growth. Researchers can then predict these kinds of consequences in advance.



A network of risks: extreme climate events can have numerous direct and indirect consequences, not only for nature (green) but also for human existence and health (brown), national and global political systems (yellow), the economy (blue), and technical security (violet).

GRAPHIC: GCO ACCORDING TO WORLD ECONOMIC FORUM GLOBAL RISKS PERCEPTION SURVEY 2019–2020

to build higher dams and flood walls, whereas other locations require the introduction of new crops that are more resistant to drought.

Reliable predictions of the effects of extreme climate events, such as those being developed by Reichstein's team, help to make societies more robust. For example, the team is currently collaborating on a large EU-funded research project aimed at establishing this approach in Africa. After all, an early warning system gives people in an affected region time to prepare themselves for extreme events – and the necessary financial resources could be released in advance in order to help local people and prevent a disaster from occurring. Although forecast-based disaster relief is already in use today, it could see significant expansion in the future and would benefit from access to reliable and accurate predictions. Markus Reichstein is convinced of the potential of his data-based research approach and believes it could even be extended to other areas: by using artificial intelligence to analyze climate, ecosystem, and socioeconomic data, researchers could also examine the vulnerability of societies to extreme climate events. However, even if vulnerable societies are identified or the alarm is raised by an early-warning system based on data cubes, it all ultimately depends on how people react to this information. In this regard, the coronavirus pandemic – of all things – has provided Dorothea Frank and Markus Reichstein with some reassurance. "Because this crisis has demonstrated that our society – in Germany and around the world – is absolutely in a position to act quickly and decisively," says Frank. "That same determination is now needed to tackle the climate crisis and avert the huge impact of extreme climate events."

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

THERE'S SOMETHING IN THE AIR

An aerosol is a suspension of small solid or liquid particles in air or another gas. The smaller the particles, the longer they hover in the air.

THE EFFECTS OF AEROSOLS

Light-colored aerosol particles (e.g., sulfate particles) reflect sunlight and thus have a cooling effect on the climate. On the other hand, dark particles (e.g., those made of soot) absorb sunlight. They therefore contribute to the warming of the atmosphere.

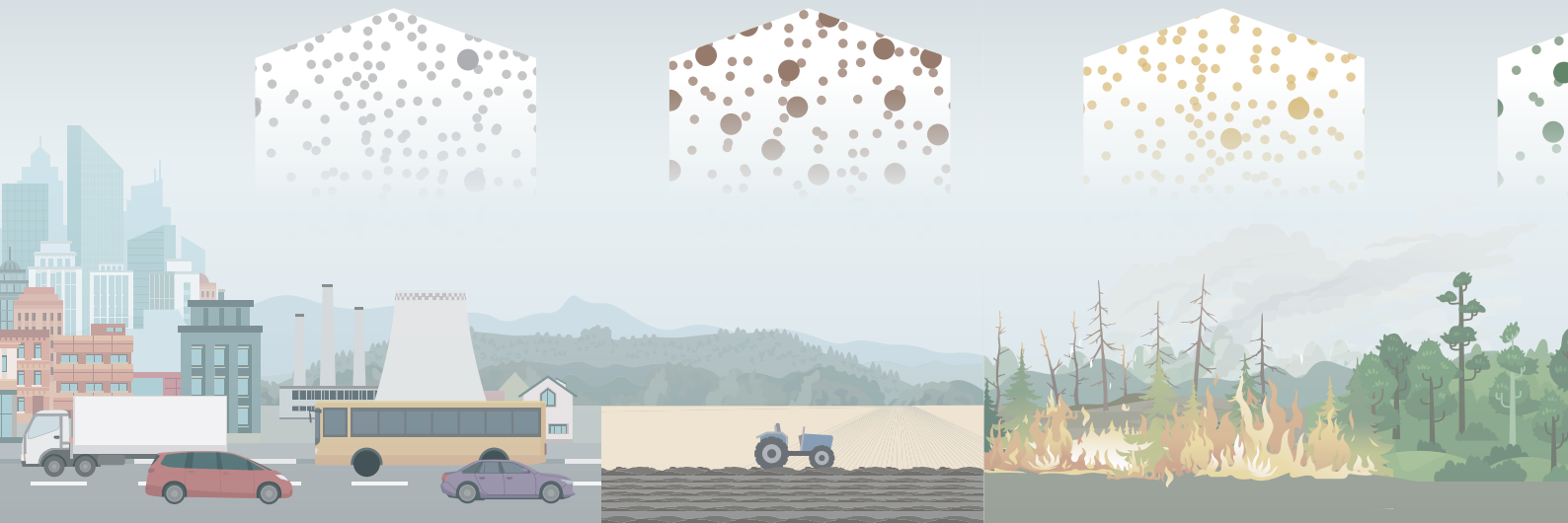
Aerosol particles also serve as condensation nuclei for the formation of cloud droplets (dark blue), which also have a cooling effect. Ice crystals (light blue hexagons) can also form on some particles – such as desert dust, bacteria, and spores – in higher atmospheric layers, thereby contributing to the formation of rain, snow, and hail.

Biological aerosol particles such as pollen and fungal spores play an important role in the reproduction of plants and fungi. They can also cause allergies.

Some pathogens (e.g., viruses and tuberculosis bacteria) are exhaled and transmitted as fine aerosol particles. Apart from infectious diseases, particulate matter generated by combustion processes, industry, agriculture, and other sources can trigger inflammatory reactions and lead to respiratory and cardiovascular diseases.

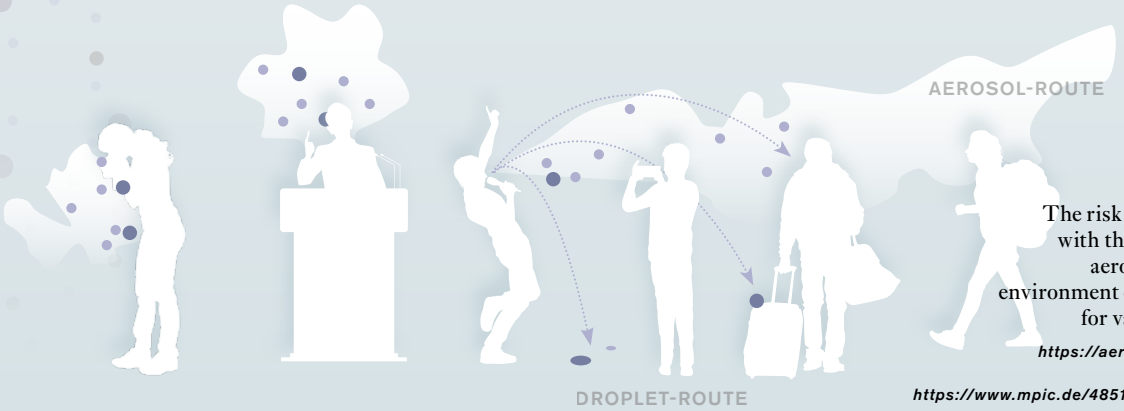
SOURCES AND PROPORTIONS

Aerosols come from various human-made and natural sources. The sizes and quantities of the particles can vary greatly. Volcanoes eject many small and large particles high into the atmosphere, while other sources release particles closer to the ground.



AEROSOLS AS DISEASE VECTORS

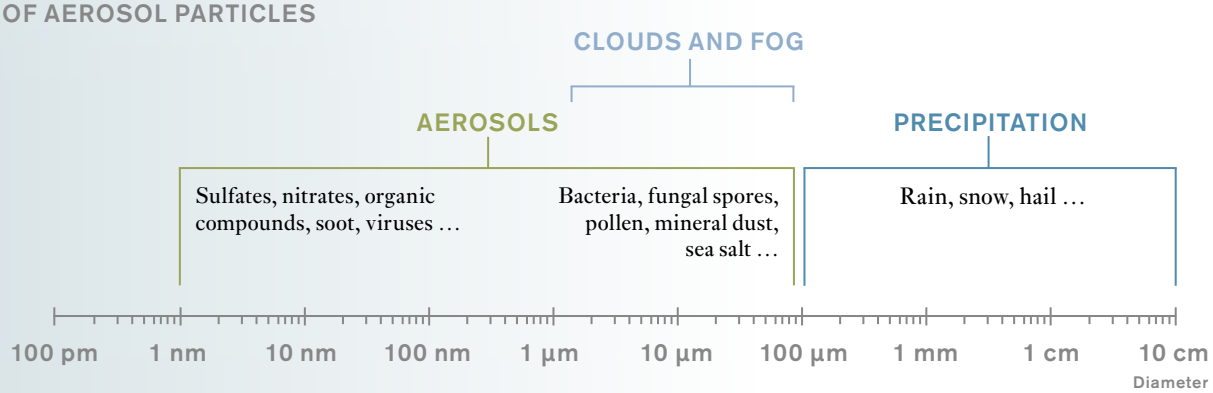
Infectious diseases such as COVID-19 are transmitted by various routes. Aerosols play an important role here – especially indoors – where they can accumulate over a long period of time.



The risk of being infected with the coronavirus via aerosols in an indoor environment can be calculated for various situations.

https://aerosol.ds.mpg.de/en/
or
https://www.mpic.de/4851094/risk-calculator

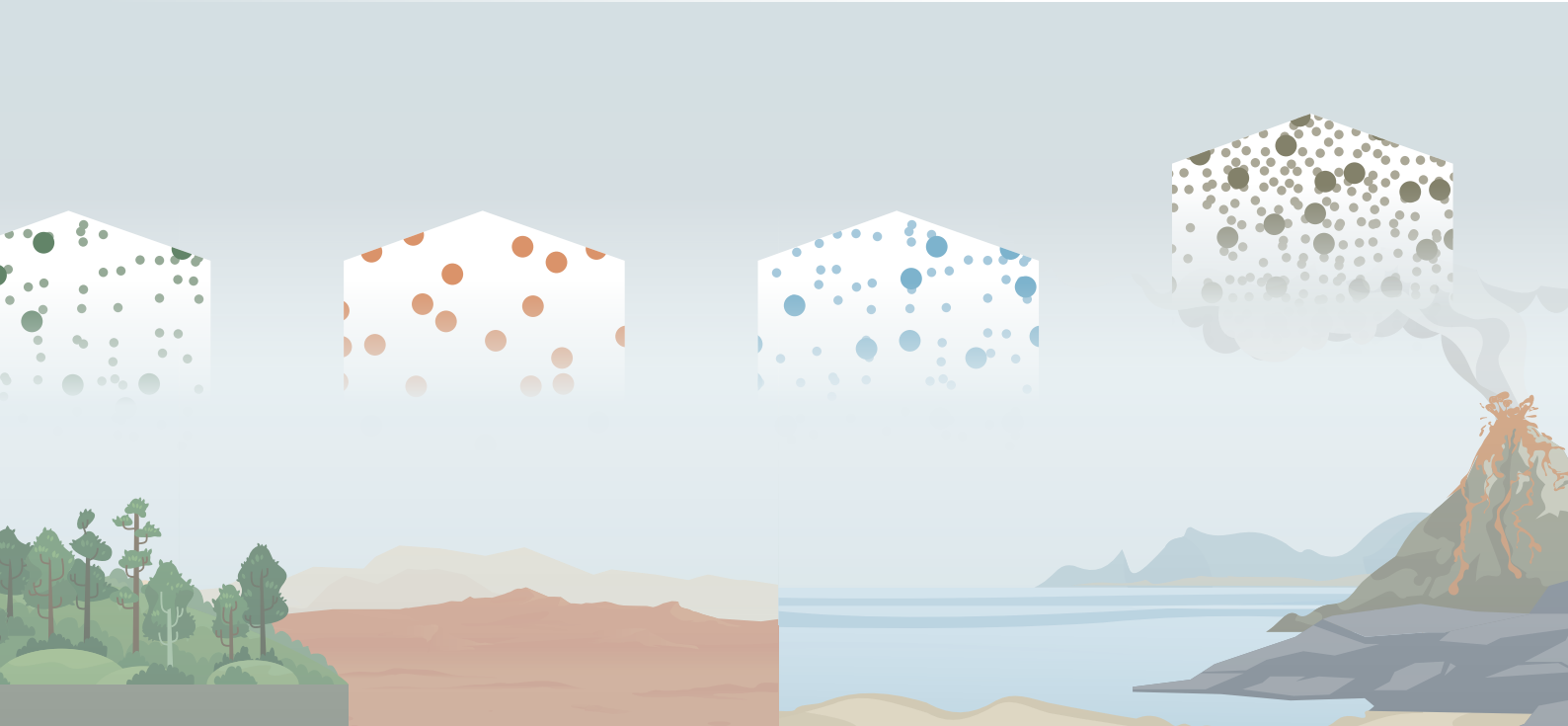
SIZES OF AEROSOL PARTICLES



Aerosol particles range in size from about 1 nanometer (nm) to 100 micrometers (µm). Larger particles quickly fall to the ground as precipitation. Primary aerosol particles (e.g., dust) enter the atmosphere as solid particles or droplets, while secondary particles (e.g., sulfate particles) are formed in the atmosphere from condensable gases and are usually smaller than 100 nm.

The most obvious example of aerosols in the atmosphere are clouds, which consist mainly of condensed water. In atmospheric science, however, the term aerosol traditionally refers to suspended particles, most of which are not composed of water.

GRAPHIC: GCO, ISTOCK.COM



GENDER GAP – EVEN IN THE GENOME

Men and women possess different sex chromosomes. Nature, however, manages to reconcile this genetic gender gap. Asifa Akhtar, the Director of the Max Planck Institute of Immunobiology and Epigenetics in Freiburg, and her team are researching the sophisticated epigenetic mechanisms responsible for this process. As the Vice-President of the Biological and Medical Section in the Max Planck Society, she is also committed to reducing the gender gap in science.

TEXT: STEFANIE REINBERGER

Asifa Akhtar is running a little late. Even though our appointment is scheduled for early morning, she has already attended a meeting beforehand. And it's gone on a little longer than planned. She appears, holding a cup of coffee. "My first cup of coffee today. My schedule is pretty crazy these days," she says. The pandemic is making work trips almost impossible, and meetings are mainly being conducted on-line. "That means there's usually no respite – from one meeting to the next with only brief breaks in between," she says. "It's exhausting, but very efficient." And Akhtar has to rush right off to her next appointment after our conversation as well. Akhtar, 50, is the Director of the Max Planck Institute of Immunobiology and Epigenetics in Freiburg. Her research at the Institute examines the mechanisms involved in packaging genetic material in the chromosomes so that it can be meaningfully read. Such mechanisms are the prerequisite enabling individual cells to take on their proper characteristics and fulfill their intended functions in the body. Akhtar's main focus is the X chromosome.

Her research has already earned her several awards. Most recently, she received the Leibniz Prize, Germany's most important research funding award: "It's hugely satisfying to know that your work is not only being noticed but also being recognized at such a high level. My team in particular were completely over the moon; I'm extremely proud of what they've achieved," emphasizes Akhtar.

In 2020, she became the Vice President of the Biological and Medical Section of the Max Planck Society, the first woman from abroad in the role, and also the youngest. It's something that has also aroused a great deal of interest in her home country of Pakistan, and elicited a number of questions from the press. Moreover, Akhtar is also a wife and mother of two children, a son and a daughter. So life's really busy for her right now – but it doesn't seem to show.

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VISIT TO

ASIFA AKHTAR

PHOTO: MARCUS ROCKOFF

Asifa Akhtar joined the Max Planck Institute of Immunobiology and Epigenetics in Freiburg in 2009 as a Max Planck Investigator. In 2013, she was appointed Director of the Institute leading the Department of Chromatin Regulation.

PHOTO: MARCUS ROCKOFF

As Vice President, Asifa Akhtar is committed to supporting young researchers in their careers, especially young women: "It's up to us to create the conditions that make a career in science possible for women, including when they have children," she says.

Quite the opposite, she comes across as energized at our interview, coffee cup in hand, and her smile is genuine – relaxed and approachable. Bouncing from one appointment one task to the next seems to come easily to her, even while she's talking to me. She has an almost playful ability to switch the conversation between science, her personal interests, and gender issues – a topic that is close to her heart.

"The different countries and cultures I've had the opportunity to experience have taught me, above all else, to be open-minded and tolerant of others."

This incredible versatility may have something to do with her personal history. Asifa Akhtar was born in 1971 in Karachi, Pakistan. Her upbringing, however, was international. When she was a child, her family moved from Karachi to Abu Dhabi for a few years, before returning to Pakistan. Then her family moved to Paris when Asifa was 15. "My school was on a street just off the Champs-Élysées," recounts the scientist. "Try and imagine that – from Karachi to the Champs-Élysées; it was overwhelming." After graduating from school in the early 1990s, she moved countries once again – this time without her family. She went to London to study biology at University College London.

"The different countries and cultures I've had the opportunity to experience have taught me, above all else, to be open-minded and tolerant of others," Akhtar says. "And to stay flexible and be able to adapt to my new environment." What surprised her most about Germany was how people stick to timetables, arriving at a bus stop shortly before the bus is scheduled to depart. Buses that are reasonably punctual was a novel experience for her at the time. "My general impression of Germany was that it's very clean and tidy. It made it easy for me to settle here." Nevertheless, when Akhtar arrived in Germany in 1997 as a postdoc (more specifically, to work at the European Molecular Biology Laboratory (EMBL) in Heidelberg), she couldn't speak the language, which, she recalls, was "quite discouraging in the early days." After her term as a postdoc, she actually planned to leave the country again. "But, at every juncture of my career, Germany has been very good at convincing me to stay. And what could be better than moving to a Max Planck Institute?" Initially, Akhtar was a Max Planck Investigator, and in 2013 she became the Institute's Director. Her research is also focused on adaptation and interaction. All organisms react to their environment, and that includes individual cells. And despite the fact that all cells in the body possess exactly the same genetic information, they develop profoundly different properties and functions, "depending on where they end up, in which tissues and in which organs," Akhtar explains. The key to this phenomenon is epigenetics, the regulatory level beyond that of genes.

Epigenetics incorporates various mechanisms that determine which genes are switched off and which are switched on, and to what extent. "DNA is like an official operating manual for a complicated machine. Not every page of the manual is needed to get the device running. Epigenetics works a bit like a text highlighter pen; it tags important passages," explains Akhtar. Such tagging activates the highlighted information, causing it to be read and translated into proteins. This, in turn, makes other passages essentially unreadable, or "silent" in the language of molecular biology. The whole process is impacted by molecular factors, such as developmental signals and growth factors. However, stress and a person's lifestyle – sport, nutrition, smoking – also leave marks in the genome, which in some cases are even passed on to the person's descendants.

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The Max Planck Director from Freiburg is particularly interested in how this occurs at the level of complete chromosomes. What are the molecular biological mechanisms that govern why large areas on chromosomes are muted while others are activated? The central focus of Akhtar's work is the X chromosome, one of the two sex chromosomes in humans. Men possess one X chromosome and one Y chromosome; women, two X chromosomes. To prevent women from having a double dose of all the proteins encoded on the X chromosome, however, this imbalance between the sexes needs to be compensated for.

There are a host of factors that render the chromatin of the single X chromosome in Drosophila males as active as the two X chromosomes in the females. "We've demonstrated that the decisive factor in the process is an enzyme called MOF," says Akhtar. It chemically modifies the histones (the protein spools upon which the DNA thread is wound), tagging them with so-called acetyl groups, making the associated regions easier to read. A typical feature of dosage compensation in Drosophila is that one particular histone, termed the H4 histone, undergoes "hyperacetylation", meaning it is tagged with a large number of acetyl groups.

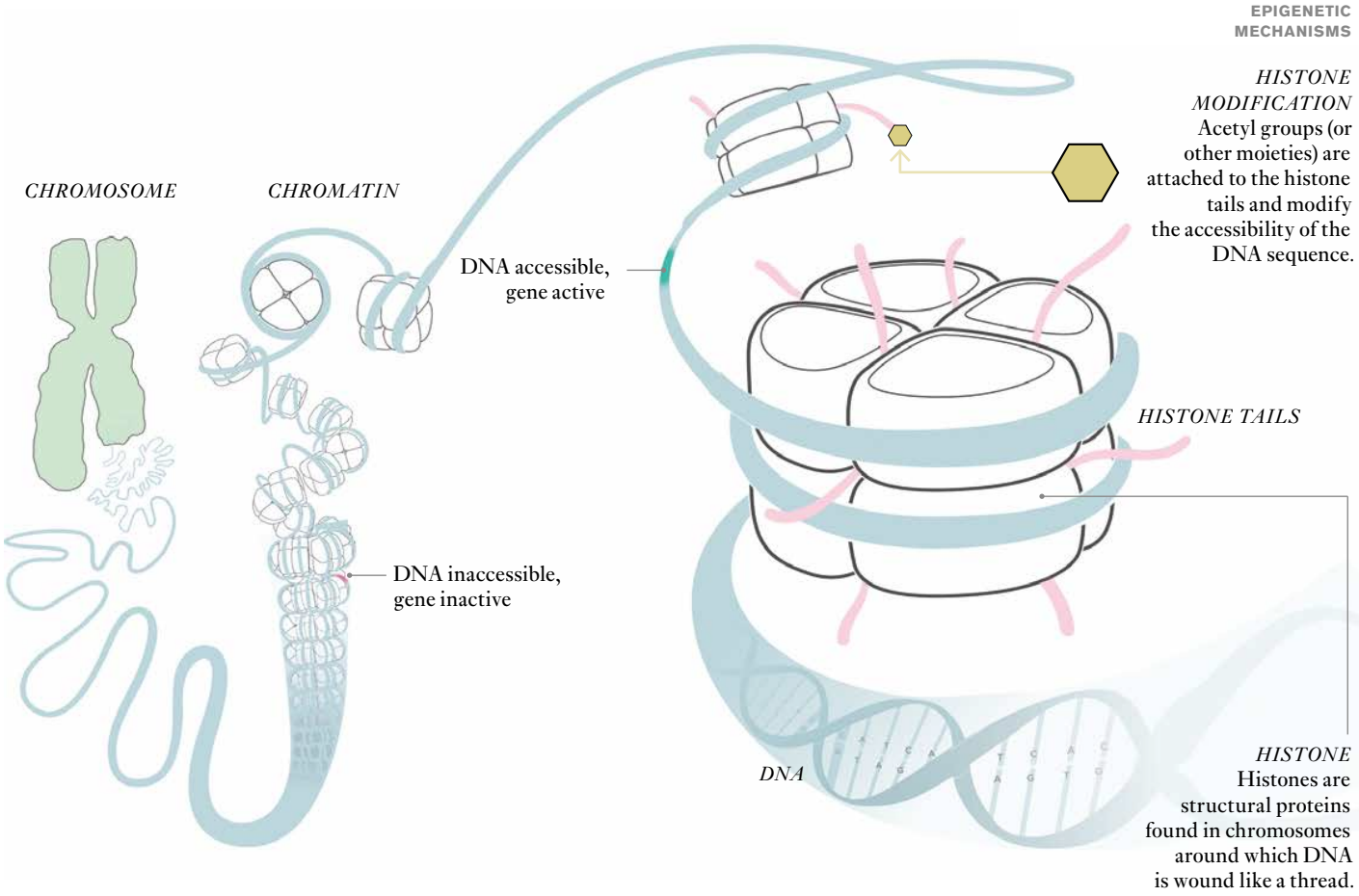
"I don't think I'll ever lose my fascination for this field of research."

"An overdose of active genes has serious consequences for cells and the organism," Akhtar says. This can occur, for instance, in the case of trisomies (three copies of one chromosome), and in conditions in which certain sections of the genome are duplicated, as well as in cancers involving unevenly distributed chromosomes. "In other words, a dosage compensation needs to occur," she explains. In humans and other mammals, this is done by inactivating one of the X chromosomes in females. In contrast, in the fruit fly Drosophila – Akhtar's favored animal model – the single X chromosome in males doubles its activity.

Akhtar has been working on the X chromosome and the phenomenon of dosage compensation since her post-doctorate phase. "I don't think I'll ever lose my fascination for this field of research." What drives her is curiosity, coupled with the excitement of knowing that experiments that are currently underway may reveal new, unimagined insights: "You never know in advance what the outcome of an experiment will be. Back when my duties were still lab-based, I often couldn't sleep at night, because I was so excited about seeing the results," says Akhtar. That's actually still the case, she adds, even though these days her team members perform the hands-on work in the lab. "If that were ever to change, I'd stop doing scientific research."

"We then explored the question as to what role MOF plays in mammals, in which dosage compensation follows the inverse principle," recounts Akhtar. The answer took the researchers by complete surprise. They detected MOF in mice not only in the cell nucleus, but also in the mitochondria, the power generators of the cell. Mitochondria, crucially, are the only cell organelles apart from the cell nucleus that possess their own genetic material. "And as we discovered, MOF is also involved in regulating gene activity in mitochondria, just as it is in the nucleus," Akhtar explains. Based on this finding, a direct link exists between metabolism and gene regulation. "This may explain how nutrition, for example, can influence epigenetics and thus gene activity. Or what effect stress has."

The research conducted by Asifa Akhtar and her team represents pure basic research, in keeping with the remit of the Max Planck Society. Anyone conducting research on fundamental biological mechanisms mechanisms, especially on fruit flies, needs to be prepared to explain how their work can benefit society as a whole. "Basic research is absolutely essential to understanding disease. If we don't know how our body works when it's healthy, we won't know what's wrong with it when we get sick," Akhtar stresses. Or to quote Max Planck, the physicist after whom the society is named: "Application must be



GRAPHIC: GCO BASED ON A DESIGN BY THE MPI OF IMMUNOBIOLOGY AND EPIGENETICS

preceded by knowledge." Asifa Akhtar has long since proven this maxim in her research into epigenetics. In 2018, together with her team and French colleagues from the University of Dijon, she succeeded in deciphering the molecular basis of a rare disease. Mental development is severely delayed in children who suffer from it. Among other problems, they have difficulty eating and with body tension (hypotonia), their gait is often unstable, and their language skills are limited or non-existent. Until recently, no one could say why this is so. Using modern high-throughput sequencing techniques, the French team searched specifically for genetic abnormalities in sufferers – and discovered a mutation in the "MSL3" gene. "MSL3, as we already knew at the time, acts as a type of volume control. It has the ability to activate a gene precisely to the required level," Akhtar explains. The researchers discovered that the defective MSL3 gene also interferes with the functioning of the MOF enzyme. As a result, certain genes become insufficiently acetylated and are thus inadequately transcribed. Development as a whole is thrown out of equilibrium. It's like a botched performance of a symphony in which the flautist misses the conductor's cue, causing all the other instruments to also come in late.

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The good news is that, at least in theory, epigenetic dysregulation can be reversed. "There's a particular drug that is currently being used to treat cancer. It targets precisely this mechanism," says Akhtar. In vitro, the drug successfully compensates the adverse effect of the mutant MSL3. Needless to say that the road from the Petri dish to a medicinal product is long, but there's hope that one day we'll be able to treat the children affected by the disease in a targeted way.

The syndrome has now been named "Basilicata-Akhtar syndrome" after the two scientists from Freiburg who were primarily responsible for elucidating its mechanism. Asifa Akhtar probably never imagined as a child that a disease would one day be named after her. "I never dreamed of becoming a scientist when I was a young girl," she says. "In Pakistan, I had no scientific role models." Only after completing her Bachelor of Science degree did she decide to embark on a PhD: "I wanted to find out how science works." That got the ball rolling.

However, she doesn't just have her talent and curiosity to thank for her storybook scientific career. A large portion of perseverance and great dedication have also been required. "I've had to work hard at every stage of my career – it's not something that just lands in your lap," she stresses. She has only been able to balance family and science thanks, in part, to the good childcare affiliated with the research institutions where she has worked. However, her husband, who is a firm believer in equal rights, is also a big part of the story. "A well-organized daily routine and an understanding partner are enormously important," emphasizes Akhtar.

As Vice President, Asifa Akhtar is committed to supporting young researchers in their careers, especially young women. One of her goals is to play a role in closing the gender gap in science. "Nature intended that women are the sex that bears children and, initially, provides them with nourishment," Akhtar says. "But it's up to us to create the conditions that make a career in science possible in spite of that." She is not simply referring to ensuring a good infrastructure and flexible working hours. "Equality needs to start in the home," she says. "If both parents want to pursue a career, then it should go without saying that they also share the work at home." And, of course, society has a role to play. As long as women continue to be labeled bad mothers if they put their children in childcare at an early age, it should come as no surprise that many of them won't have the courage to pursue their careers. "A lot more action needs to be taken," urges the scientist.

"If both parents want to pursue a career, it should go without saying that they also share the work at home."

Asifa Akhtar's research shows that with the help of sophisticated mechanisms, nature has managed to compensate for inequalities between the sexes. Achieving gender equality in society, however, is something we humans still need to work on.

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VIRUSES FROM PRIMEVAL TIMES

TEXT: CATARINA PIETSCHMANN

No life is free of viruses. On Earth, at least, no organism seems to be spared from them. Susanne Erdmann and her team at the Max Planck Institute for Marine Microbiology in Bremen are studying viruses of the archaea, tiny single-celled organisms that lack a cell nucleus. Her research team investigates virus-like DNA elements, which may help us to explain how viruses actually originated.

As life on Earth emerged, the weather was bad, really awful. It rained – continuously – for 40,000 years and that was how the oceans formed. At the time, Earth was a rather unpleasant place in other ways as well. Meteorite impacts devastated the still young planet, and volcanoes ejected ash and sulfurous gases into the atmosphere. From the deep ocean floor, mineral-rich water at temperatures of up to 300 degrees Celsius bubbled up from hydrothermal vents.

Approximately four billion years ago, against all odds and adversities, the first cells formed: the "last universal common ancestor" (LUCA) of all bacteria, fungi, plants, animals – and archaea. Previously referred to as archaebacteria, these single-celled organisms have, to this day, retained many of their original characteristics: like bacteria, the cells possess no nucleus and no organelles. They are surrounded by a simple cell membrane of unique lipid molecules that are only found in the membranes of archaea protected by an outer layer composed of protein. In addition to the similarities they have with bacteria, archaea also share fundamental properties with nucleated cells.

Archaea, that are thought to be "ancient", also have to deal with pathogens likely from equally ancient times. "It's hard to believe, but even cells this small, on average just a thousandth of a millimeter in diameter, are infected by viruses," says Susanne Erdmann. While bacterial viruses have been studied intensively, very little is known about archaeal viruses. "More than 3,000 bacterial viral genomes have been sequenced, but not even 300 archaeal viruses. Of these, just under 100 viruses have actually been isolated, and all but one are from extreme environments." While the shape of bacterial viruses are already odd, reminding of space probes, the archaeal viruses are even more extraordinary in shape. Many of the archaeal virus particles, resembling for example spindles or bottles, are unique and unlike any bacterial viruses or viruses infecting nucleated cells.

Not always harmful to their hosts

Since 2019, Susanne Erdmann is a group leader at the Max Planck Institute for Marine Microbiology in Bremen, researching the special relationship

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PHOTO: TOM HEGEN

KNOWLEDGE FROM

BIOLOGY & MEDICINE

In southern France, seawater evaporates in artificial ponds to extract salt. Depending on the salinity, microorganisms color the water in different nuances. Such extremely saline lakes are also the habitat of archaea.

PHOTO: ACHIM MULTHAUPT FOR THE MPG

between archaea and their viruses. "Every virus I've ever isolated reveals a new surprise," says the biologist. What is particularly perplexing is that a great number of viruses do not seem to harm their hosts. They don't destroy the cells and only minimally affect their growth. The researchers are attempting to find out why. Viruses essentially consist of genetic material and a capsule of proteins. Many archaeal viruses also possess an envelope of lipid molecules. They are not cells and lack any metabolism of their own. They need a host cell to reproduce. As such, they are not considered to be living organisms. Erdmann and her team are hoping to find out more about the origins and evolution of viruses from the relationship between archaeal hosts and their parasites. Were today's viruses, which are frequently pathogenic, originally beneficial to their hosts? What was their original function, and how did they evolve into what they are today?

Some researchers suspect that viruses pre-date cellular life, which only later developed from those early viruses. However, this hypothesis assumes that the first viruses were able to replicate without cells. No evidence has been found for that so far. Another possibility is that the first viruses were small, parasitic cells that lived inside other cells. Over time, so the theory goes, these parasites lost some of their genes and came to rely increasingly on their host. Some

Left:
Archaea and their viruses are so small that Susanne Erdmann can only view them under an electron microscope.

Below:
This electron microscopy image shows pleolipoviruses at 50,000 times magnification. They infect cells of the archaea *Haloferax volcanii* without harming them. The viruses leave their host by budding off from the cell membrane. They are surrounded by a lipid membrane (light circles).

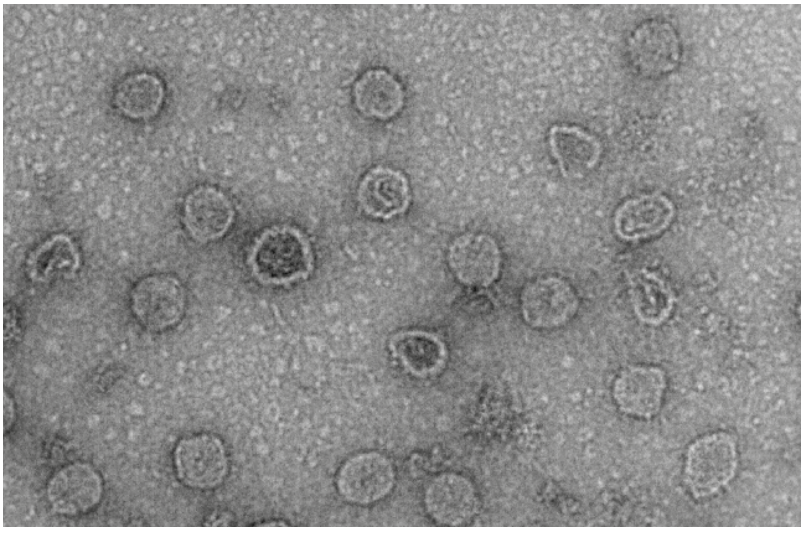

IMAGE: SUSANNE ERDMANN/MPI FOR MARINE MICROBIOLOGY

researchers suggest that the discovery of so-called "giant viruses" supports this hypothesis. In terms of their dimensions, some viruses of this kind are actually larger than bacteria and possess more than 1,000 genes (Sars-CoV-2 has only around 30 genes).

Max Planck scientist Matthias Fischer from Heidelberg is researching such giant viruses (see Max Planck Research 3/2019). However, he suspects they evolved not from cells but from smaller viruses that over time picked up more and more genes from their hosts. Another theory suggests that viruses initially arose from small fragments of cellular genetic material that excised and went on to replicate independently of the rest of the cellular genome. These fragments of genetic material could then have exited the cell in a vesicle formed from the cell membrane and entered other cells, collecting new genetic information over time. "The first 'viruses' probably passed from one cell to the next in membrane vesicles," says Susanne Erdmann. Archaea love extreme habitats; they really flourish in hostile biotopes. *Pyrococcus furiosus*, for example, lives in and around geothermal vents on the ocean floor and can withstand temperatures of up to 113 degrees Celsius, thanks to its heat-insensitive proteins. For *Haloferax*, on the other hand, conditions can not be salty enough. These cells live in the extremely salty Dead

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Sea and can also make themselves at home in sea salt extraction plants. Others, for example *Sulfolobus acidocaldarius*, would find even pure vinegar too bland. They grow best at a pH of 2.0 in acidic, sulfur-rich volcanic springs. However, archaea also live in very ordinary habitats – but, once again, they do so with distinctiveness. Some of them – the only living organisms to do so – are capable of generating methane. Methane is a greenhouse gas, which is produced when microbes break down biomass in the absence of oxygen. They inhabit oceans, swamps, rice fields, muddy soils, and even the digestive tracts of some herbivores.

An early love

Susanne Erdmann first heard about these 'strange microorganisms' while training to become a nurse. "I thought they were so cool – especially the ones living in extreme habitats." The microbes with their incredible diversity sparked her interest. That fascination steered her away from a career in a hospital to the University of Halle, where she studied biology. Her first direct contact with archaea was during an internship in Copenhagen. "I got to study the viruses of archaea from hot springs, which was really fun. They are much smaller than the archaea, and yet they are incredibly diverse and creative when it comes to controlling their hosts. But in order to study them, I had to spend four weeks sleeping in my car, because Copenhagen is expensive, and I couldn't find any affordable accommodation," says Erdmann. Subsequently, for her undergraduate research project she studied the proteins of a very unusual archaeal virus that is capable of changing its shape, and for her doctoral thesis she isolated several previously unknown viruses.

Susanne Erdmann was also particularly interested in the archaeal immune system, known as the CRISPR system. Difficult to pronounce, this antiviral defense has become very famous in recent years. Last fall, the Nobel Prize for Chemistry was awarded for the discovery of one of gene technology's sharpest tools – the CRISPR/Cas9 "gene scissors." The genome editing technique based on the CRISPR system allows researchers to modify DNA far more easily than in the past.

SUMMARY

Archaea are similar to bacteria, but represent a separate branch that splits off early from the rest of the ancestral tree of life. Archaea have retained some of their original characteristics to this day.

Like other forms of life, archaea are affected by viruses. However, these viruses frequently do no harm to their hosts.

In archaea, researchers have discovered a potential transitional form between a mobile DNA element and a virus. The discovery supports the hypothesis that viruses originated as segments of the cellular genome that were able to surround themselves with an envelope and bud off the cell.

CRISPR is an adaptive immune system that enables archaea and bacteria to specifically adapt to a particular type of virus. However, the CRISPR system does not get activated against some of the viruses that Susanne Erdmann has studied in the lab – just why not is still unclear. Instead, some of these viruses seem to live in a kind of symbiosis with the archaea: they reside permanently in the cells, multiplying and producing viral particles. The host cell remains intact and receives new genetic information in exchange.

After her residence in Copenhagen, Susanne Erdmann moved to the University of New South Wales in Sydney. She became interested in the habitat being studied there: the Deep Lake in Antarctica. Its water is saturated with salts, so it does not freeze, even in extremely cold weather. The lake is almost 40 meters deep and the water temperature at the bottom is minus 14 degrees Celsius. "That means the lake's organisms have to deal with two extremes: the high salinity and the cold. Four species of archaea can cope with it, and they constitute almost 90 percent of the lake's total biomass," says Erdmann.

Erdmann isolates the viruses in the lake from samples that have been concentrated by using ultra-fine filters, so that the viruses can be studied in the laboratory. If typical bacterial viruses are transferred onto a petri dish covered with potential host cells, holes form in the bacterial lawn where the pathogens have destroyed the cells. However, many archaeal viruses do not destroy their host cells, but instead, bud off from the host cell like membrane vesicles. Therefore, Erdmann needs to maintain the cells in a liquid culture and then analyze the liquid for possible virus particles. Using this technique, she has discovered several unknown viruses so far.

Her discovery of a very specific virus-like particle raised her interest in particular. "We analyzed its genome and found that it wasn't a genuine virus, but a "plasmid" that can be transported in vesicles," explains Erdmann. Plasmids are circular DNA molecules from bacterial and archaeal cells that can be passed from one cell to another. In this way, they can rapidly spread important traits, such as antibiotic resistance, throughout a population. The function of most of the genes of the virus-like element are still unknown. However, some seem to be responsible for packaging the plasmid itself into a kind of membrane vesicle. "I think the particle we discovered is likely to represent an intermediate form between a plasmid that

PHOTO: SUSANNE ERDMANN/MPI FOR MARINE MICROBIOLOGY

Lake Tyrrell is a naturally occurring saline lake in southeastern Australia. It is an El Dorado for Susanne Erdmann, because almost 90 percent of the organisms living in it are archaea. In this environment, that is deadly to most other organisms, she has discovered unknown archaea and viruses so far.

by chance ended up in a vesicle and a virus that is actively engaged in this packaging process. So it could be an evolutionary precursor to a virus."

Means of transport for genes

Do viruses serve any purpose? "We suspect that viruses originally arose as very beneficial elements promoting exchange of information between cells. They distribute genes between organisms and thus generate diversity. Eight percent of the human genome, for example, is viral in nature. However, as soon as information is exchanged and organisms compete with each other, elements that replicate at the expense of others can also emerge. In this light, many of the viruses we see today that from our point of view seem to do nothing but harm their hosts probably represent an inevitable consequence of life." After her study of the inhabitants of Antarctica, Erdmann is now turning to the archaeal viruses from temperate latitudes, for example from the North Sea, in her research at the Max Planck Institute in Bremen. Compared to the difficulties in accessing Deep Lake, the project at first sounds more straightforward. In fact, it poses a different set of challenges, because the temperate seawater is home to countless microorganisms, unlike the icy lake in Antarctica. Just one to two percent of these are archaea, and it is precisely those that the researcher and her team need to locate and isolate.

In the coming years, Erdmann is planning to focus, amongst other things, further on the evolutionary history of viruses. "My dream is to find more viruses and virus-like elements that will help us better understand viruses," she says. That would enable her to tell the whole evolutionary story of the host and the virus – starting way back when the earth was still devoid of life.

THE EMPIRE IS BACK

TEXT: JEANNETTE GODDAR

The Habsburg Monarchy and the Ottoman Empire are long gone – but in many European cities, they are still very much alive. In Vienna, for example, remembrance of the times when the city was besieged by the Turks is fostered, while the tens of thousands of Viennese citizens of Turkish origin are ignored. At the Max Planck Institute for the Study of Religious and Ethnic Diversity in Goettingen, a team led by Jeremy F. Walton is studying the way in which former empires are treated today.

Visitors to Vienna are keen to tour the city in one of the many traditional and comfortable horse-drawn carriages that solicit customers all day long throughout the city center. The "Fiaker" (coach drivers), some of whom still address their passengers in old-fashioned parlance like "Gnae' Frau" ("Ma'am") and "die Herrschaften" ("sirs"), take their fares to the Stephansdom cathedral and the Hofburg former imperial residence, Schönbrunn and Belvedere palaces, and the Prater amusement park. To put it another way: in most cases, it is not the capital of Austria that people are shown in their first encounter with this city, but the hub of the Habsburg dynasty, which came to an end just over a hundred years ago. However, such city tours also take them past reminders – some of them more visible, some less – of the two sieges of Vienna by the Ottoman Empire. In 1529 and 1683, Ottoman troops stood on the outskirts of the capital of the Danube Monarchy. They were unsuccessful in their attempts to seize the city, but to this day, the story is firmly anchored in Austrian historiography. Even the most important church bell in the Stephansdom – which is something of a sacred national symbol for the Austrian people – was cast mostly from the metal of Ottoman cannons in 1711. In 1945, a fire caused the first bell to crash into the nave at the foot of the South Tower, coincidentally destroying the "Tuerkenbefreiungsdenkmal", the monument commemorating the liberation from the Turks. Today, the place is marked by a plaque, with the following inscription in Latin: "Once, Maria came to save us from suffering at the hands of the Turks. Proud stone figures expressed the gratitude of their city."

There is more to this story: a number of buildings in Vienna are decorated with shimmering golden "Turkish cannonballs" that symbolize the Ottoman bombardment of the city. There are stone sculptures showing Ottoman horsemen, a park called "Tuerkenschanzpark" (Turkish entrenchment park), and of course, a plethora of monuments showing proud Habsburg victors. Even the roof design of the Belvedere Palace, the construction of which began in 1712, was inspired by the Ottoman tents that were once erected there. As Annika Kirbis explains: "Once you start looking for the traces of the 'first and second Turkish siege' as it is known here, it soon becomes clear

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A resurrected hero: Ban Josip Jelačić, a Habsburg military commander, is now revered again in some parts of Croatia. During the Soccer World Cup in 2018, fans draped his statue in Zagreb with the colors of the Croatian coat of arms.

PHOTO: DREAMSTIME

that there are countless numbers of them! There are more than a hundred sites in Vienna alone that serve as a reminder of these events. And there are many, many more throughout the rest of Austria." Kirbis, a social and cultural anthropologist from Germany, who is conducting her doctoral research at the Max Planck Institute for the Study of Religious and Ethnic Diversity in Goettingen, initially moved to Vienna to work on her master's thesis. Her original plan was to study the present-day experiences of Turkish immigrants to the city. However, initially every database and Internet search yielded only events that took place hundreds of years ago, even though between 200,000 and 300,000 people of Turkish origin have been living in Austria for decades. Many of them came as so-called "guest workers" or followed their families to the country, and hold Austrian citizenship by now.

Grandchildren of the Ottomans

But what is it like for people whose roots lie in the former Ottoman Empire to be surrounded by all this symbolism? To find out, Annika Kirbis interviewed Viennese citizens with Turkish roots, often during walks around the city. Their responses to her questions varied widely. Some had remained unaware of all the monuments over the decades, while others felt insulted by the images of saber-wielding horsemen in harem pants. A few of them told her that visitors from Turkey like to visit the sites of decisive battles, and rather than seeing the campaigns as a failure, they felt a certain sense of pride that the Ottoman forces had advanced as far as Vienna. Others, who are labeled as being Turkish but who do not necessarily identify themselves as such – Kurds, for example – noted wryly that "It was a good thing that the Viennese kicked them out." The longer Kirbis studied the issue, the more fragmented people's memories seemed to be. At the same time, one thing became clear: "History continues to be negotiated in debates about immigration, in speeches about integration, as well as in discriminatory remarks. Often, it is also due to the use of a kind of siege rhetoric, which everyone growing up in Vienna is familiar with."

It's also not hard to find tangible examples of conscious efforts to keep history alive. For example, in September 2020, to mark the anniversary of the victory of the Habsburgs, the right-wing populist FPÖ party invited citizens to a "liberation celebration", which in the words of the deputy mayor of Vienna was intended "to demonstrate that we do not tolerate parallel Islamist societies (...)." On the other hand, in 2014, during a visit to Vienna just before the Turkish elections, the Turkish president Recep Tayyip Erdoğan appealed to his supporters in the city, calling them all "grandchildren of Sultan Suleiman and Kara Mustafa," the two men who had led the first and second Turkish sieges. As anthropologist Jeremy F. Walton explains, this emphasis on collective strength and the securing of political power in the service of a national narrative are "typical motivations for 're-imperializing' history." However, it would be inaccurate to generalize here. Religion and aesthetics also play a role, as does everyday culture. "Even in the fashion world, designers are drawing inspiration from empires that have long ceased to exist." Walton is Head of the Max Planck Research Group, "Empires of Memory. The Cultural Politics of Historicity in Former Habsburg and Ottoman Cities", in which Kirbis conducts her doctoral research.

It is striking that, like Annika Kirbis, Walton more or less stumbled into this area of research. Walton is a U.S. citizen who moved to Turkey around fifteen years ago to write his doctoral thesis on Muslim civil society. "At

The culture of remembrance in the 19th century: people in Carinthia and South Tirol used to decorate their village fountains with these "Turk heads". Today, these heads are displayed in the Austrian Museum of Folk Life and Folk Art in Vienna.

PHOTO: ANNIKA KIRBIS/MPI FOR THE STUDY OF RELIGIOUS AND ETHNIC DIVERSITY

PHOTO: KLAUS PICHLER / WIEN MUSEUM

Culture of remembrance in the year 1983: contrary to what the plaque suggests, this Viennese house was not destroyed by the Ottomans, but by the Viennese themselves. They set fire to the suburbs in order to rob the enemy of the opportunity to hide within them.

first, the Ottoman Empire was not on my radar. But everywhere I went, it was being re-negotiated and brought to people's attention. In some cases, smaller Islamic organizations were even paying for monuments to be renovated," he explains. To recap: at that time, Erdoğan, who has been posing as a post-modern sultan for several years now, had just entered office, and Turkey as a secular state was still far more focused on the founder of the Republic, Kemal Atatürk than it is today.

This is, in short, what led to the creation of the research group, which examines eight cities that once belonged to the Habsburg Monarchy and/or the Ottoman Empire, and are now located in eight different countries. Walton loosely divides the cities into pairs. First, there are Vienna and Istanbul, the former centers of the empires, then Budapest and Sarajevo, which came under both Habsburg and Ottoman rule, and where the two empires still exert an influence over public life and political debate. Third, there are Thessaloniki and Trieste, which used to be important port cities, and which are both located in countries that certainly do not regard themselves as successors to the empire of which they were once part: Greece, where the expulsions of the Greek population from Turkish soil in the early 20th century have left deep scars, and Italy, which very consciously insists that the South Tirol and Trentino regions, along with the strips of land along the north-eastern Adriatic coast, are incontestably Italian territory. Walton himself has his research base in the former Habsburg city of Zagreb, now in Croatia, which forms the fourth pair, together with Belgrade, formerly a part of the Ottoman Empire and now in Serbia. "Observing how the recent socialist past is dealt with in these two cities as well as Sarajevo, in tandem with their imperial past, adds another fascinating layer to our research," he explains. The questions

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PHOTO: KLAUS PICHLER / WIEN MUSEUM

that interest the interdisciplinary Research Group vary widely, as do the approaches and methods used to study monuments, urban planning, cultural artifacts, discussions and collective memories. What binds them together is "Empires of Memory". The name is a reference to memory studies, an approach that has become established in recent decades among German Holocaust researchers in particular. Rather than viewing history through the prism of official documents, this research approach looks at how historical events have become a part of people's collective memory, and how they become incorporated into the overall narrative of a society as a result.

To examine how the narrative of the sieges influences the memory of today's migration society, Annika Kirbis combines memory research with approaches used in anthropology, as well as in literature and museum studies. One focus of her research is the Wien Museum, which houses the "History and City Life

"Even in the fashion world, designers draw inspiration from empires that have long ceased to exist."

JEREMY F. WALTON

Divided memory: three years ago, the Wien Museum opened up a different perspective on Austrian history with an exhibition about the lives of "guest workers", many of whom come from Turkey.

Collection". "The collection on the Turkish Wars – or 'Turkish spoils' – formed the basis upon which the museum was founded," she says. Today, the museum describes itself as an "urban universal museum." Currently, it is closed for renovation. However, what Kirbis describes from the time prior to its closure is not exactly what you would call "universal". She followed the "Migration Sammeln" ("Collecting Migration") project, which was commissioned by the City of Vienna along with the Wien Museum, and which involved the acquisition of items and photographs belonging to Viennese citizens of Turkish and Yugoslav origin, often with the support of migrant organizations. The collection was exhibited under the title "Moving History. Viyana – Beć – Vienna". And then, Kirbis explains, "On the first floor of the museum there was an exhibition about migration, to the right of the staircase, while to the left, there was the permanent exhibition, large parts of which were dedicated to the Turkish siege."

A new context for old monuments

Annika Kirbis is interested in one particular question: "Is it possible to narrate history in this way?" Basically, she already gives the answer in the working title of her doctoral thesis: "Weltstadt without migrants? Transnational memories and post-imperial nostalgia in Vienna's urban heritage". Kirbis argues that the history of migration should not simply be understood as a "gap to be filled in the city's memory", but that collective memory needs to allow for different perspectives. "Many migrants feel that they do not really belong, that they are regarded as being different and are therefore excluded, despite being Austrian citizens. This is exacerbated by historical narratives that only reflect the perspective of the so-called majority society." She points to a parallel issue that is debated in Germany: the way in which pupils are taught to remember the Holocaust in schools. "How should this topic be introduced to young people whose families had no ties to Germany previous to the Second World War? Even if it's meant well, telling these pupils 'your grandparents weren't involved' excludes them from the process, and prevents remembrance of the Holocaust from being kept alive in an immigration society."

Similarly, the question arises as to how a narrative with a broader range of perspectives can be created about the siege of Vienna, for example. "First, it would be important to step back and take a critical look at the issue; to ask ourselves what memory this city is trying to preserve and whether it reflects today's society," she explains. As a next step, the existing monuments to the siege could be contextualized: "Why not also tell people about the period in which they were erected, and what collective perceptions were prevalent at the time?" This would entail questions as to how the sieges were differently commemorated in 1933, then later on in 1983 to mark the 300th anniversary of the second siege. At the same time, this would create an opportunity to ask which images are still being uncriti-

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SUMMARY

Empires like the Habsburg Monarchy and the Ottoman Empire are alive and well in the collective memory, and the myths surrounding them are often consciously cultivated.

In Vienna, there are a large number of monuments dedicated to the Turkish sieges of 1529 and 1683. They contribute to the preservation of the image of the 'Turk' as the enemy, and marginalize Turkish immigrants as a result.

Research into this area is just beginning to examine the influence that former great empires have on present-day societies. Researchers recommend taking a critical approach to a country's imperial past.

cally reproduced today and which ones tend to be excluded from the collective memory. For example, it was the Ottomans who brought coffee to Vienna, which in turn led to the establishment of the famous Viennese coffee houses. Also, legend has it that the crescent-shaped "Vanillekipferl" cookie was inspired by the Islamic half-moon. As Kirbis says, "Most Viennese are aware of these influences. But to date, they have still not lessened the impact of all those images that convey the concept of 'the Turk as the enemy' to this day." Overall, she concludes that simply adding a few new memories here and there is not enough: "Migration history demands that we question and rethink existing narratives such as the one relating to the siege."

The challenge for the Research Group is not only describing which images and symbols are kept alive and thereby frequently adapted to suit the era in question. "Often, the most interesting aspect is what is not shown, since this reveals what is allowed to be shown and what must be kept hidden," Jeremy F. Walton explains. However, this is where memory studies run into their biggest problem: things that have not been preserved cannot enter collective memory. "How can we find out what was suppressed in the past?" Walton asks. "Whenever this is not possible, we must at least be aware of the fact that there are gaps." Steps have been taken to ensure that answers continue to be found to these questions, as well as others relating to the Habsburg Monarchy and the Ottoman Empire. After the Research Group at the Max Planck Institute in Goettingen has completed its project, Walton plans to move to the University of Rijeka in Croatia to pursue a grant from the European Research Council. The name of the planned research group borrows from the word for one who has returned from the realm of the dead – or those who are thought to have died. "REVENANT: Revivals of Empire – Nostalgia, Amnesia, Tribulation". The empire is back, at least as a revenant.

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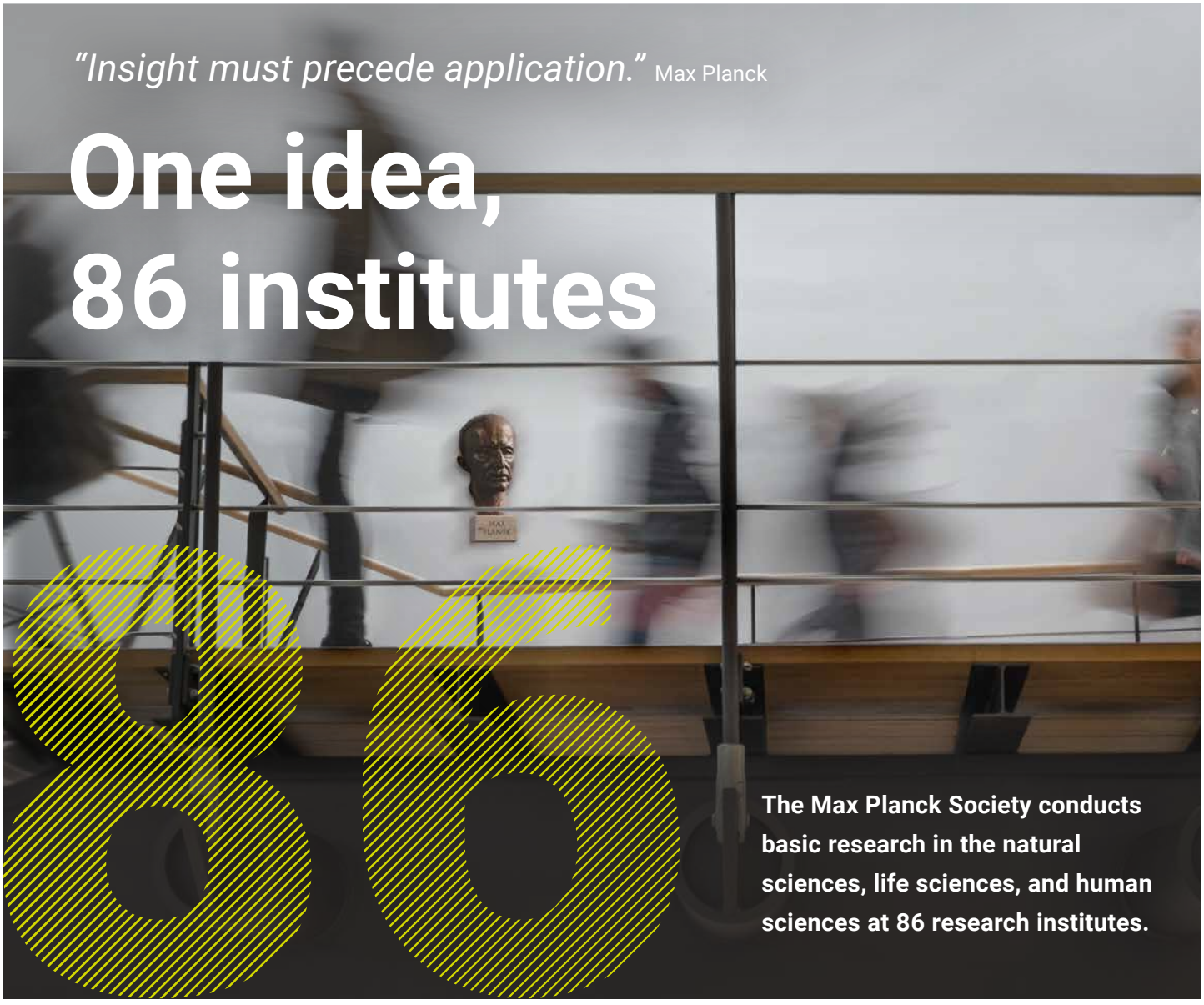
Glorification of the past: during the 1990s, the Turkish government arranged for the monstrous busts of the Ottoman sultan Suleiman (right) and his opponent, the commander Miklós Zrínyi, to be erected at the site of a historic battle in Szigetvár in Hungary.

PHOTO: JEREMY F. WALTON/MPI FOR THE STUDY OF RELIGIOUS AND ETHNIC DIVERSITY

“Insight must precede application.” Max Planck

One idea, 86 institutes



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NERVE SCAFFOLDING FROM A TEST TUBE

TEXT: ANDREAS KNEBL

Numbness, immobility and, in the worst case, paraplegia – the severing of a nerve pathway – often has permanent consequences. This is because the extracellular matrix, which provides support for the neurons, is also damaged during the injury. Tanja Weil and Christopher Synatschke, who work at the Max Planck Institute for Polymer Research in Mainz, are looking for a replacement for this support material. And they have already made an important find.

Weil quickly got to the bottom of things. Her colleagues had observed something puzzling about a peptide from the envelope of the HI virus. Peptides consist of amino acids, the basic building blocks of all proteins, and perform countless functions in living organisms. In the case of the peptides from the HI viral envelope, the question arose as to what role they play in the infection of host cells. Initial tests showed that the effect of the peptides changed when they were left in a solution for a long time. When the researchers led by Weil examined the solution in question, they found that after some time, the peptides in it had arranged themselves into fibrils. Their fibrous structure caused the peptides to become sticky and provide support for both the HI virus and the host cell. "In the scanning electron microscope images, we were able to see the cells clinging to the fibrils," says Weil. This accidental discovery launched a whole new research project.

At the time, Weil was working as a polymer chemist at the University of Ulm. But word of her observation quickly spread among her colleagues. One of them was Bernd Knöll. The cell biologist works on therapeutic approaches to repairing injured nerves. At the time, his office was on the same floor as Weil's. The short distances enabled a lively exchange. And so the two developed the idea of using the peptide fibrils as a kind of trellis or scaffold for nerve cells.

Replacement for the supporting matrix

The research approach was as follows: if the host cells of the HI virus can cling to the peptide fibrils, nerves should be able to do the same. If this assumption is confirmed, the peptide fibrils could help injured nerves to heal. In most cases, severed nerve fibers do not grow back together on their own.

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Chemical customization: a Max Planck team in Mainz is creating specific peptides that form networks and support the healing of nerves.

PHOTO: KATRIN BINNER FOR THE MPG

This can result in numbness and paralysis. A deep cut in the hand, for example, can leave a person unable to feel or move a finger. After a severe injury, a nerve lacks the necessary support to heal independently. This is because not only the nerve but also its extracellular matrix is damaged. This complex protein scaffold provides support for the nerves. When that support is missing, there is a gap that the two ends of the injured nerve cannot bridge. At that point, only surgery can help the severed nerve to heal. The surgeon attempts to suture the two nerve endings together or connect them with a piece of nerve taken from another part of the body. But Knöll and Weil are taking a different approach. They rely on peptides delivered to the wound site to replace the extracellular matrix, thereby allowing the nerves to regenerate.

The collaboration continued even after Weil moved to Mainz to become the Director of the Max Planck Institute for Polymer Research. There, Christopher Synatschke joined their "Synthesis of Macromolecules" working group. The chemist had already gained experience with peptides in various international working groups. As a postdoctoral researcher and later group leader, he now took over responsibility for the cooperative project with Knöll in Weil's working group. Two years later, the team reported its first success. By using peptide fibrils, the researchers succeeded in improving the regeneration of injured nerves.

Weil and Synatschke agree that self-assembling peptides, such as the

On the way to a new therapy: Tanja Weil and Christopher Synatschke are looking for peptide structures that can be used to treat nerve damage – maybe someday even spinal cord injuries.

PHOTO: KATRIN BINNER FOR THE MPG

sequences from the HI viral envelope, are the ideal substitute for the extracellular matrix. "They allow us to imitate nature," says Synatschke. "We are creating a structure that is close to the natural environment of the nerves – yet much simpler." Self-assembling means that the peptides assemble themselves into larger structures without external influence. Some of these self-assembling peptides (SAP) form fibrils. These fibrils are only about 10 nanometers thick and 0.1–1 micrometer in length. The fibrils of some SAP consolidate to form larger networks. These can serve as scaffolds for nerve fibers that are up to 20 micrometers thick. For comparison: a human hair has a diameter of about 50 micrometers.

The special features of SAP arise from the interaction of the individual amino acids. The peptide sequences that Synatschke works with consist of only a few amino acids. Each of these amino acids has certain properties. For example, one building block may be positively charged on the surface, while another is hydrophobic (i.e., water-repellant). The characteristics of the individual amino acids give rise to completely new and not easily predictable properties in the peptide compound – such as the tendency to form fibrils.

Multi-variant peptide structures

In order to better understand how peptide sequences and self-assembly are related, Synatschke and his colleagues studied numerous sequences. Synatschke's team specializes in the targeted production of peptides with a desired sequence of amino acids. Once the peptides have been synthesized, the scientists end up with SAP in a powdered form; this is added to a solvent and mixed with water. In addition to the sequence, the conditions within the solution also play a role in how the SAP behave. If the researchers change how acidic or basic the solution is or how long and at what temperature it is stored, the properties of the structure that emerges from the SAP also change. Synatschke started his experiments with 27 sequences based on the peptide from the HI viral envelope discovered in 2011. His working group first investigated whether and to what extent the different peptide sequences lead to the formation of fibrils. In collaboration with Knöll's working group, the researchers next applied a thin layer of each of the materials to individual Petri dishes. They then cultured nerve cells in them, before going on to examine the cultures under the microscope to see whether the cells found support on the substrate and, if so, how well the nerve fibers had developed.

SUMMARY

Severed nerve tracts usually do not heal on their own because the extracellular matrix surrounding them is also damaged.

At the Max Planck Institute for Polymer Research, researchers are replacing the scaffolding structure of injured nerves with fibril-forming peptides so that the nerve endings can grow back together.

In mice, severed facial nerves healed better when injected with a solution containing self-assembling peptides (SAP).

In the long term, the research team also hopes to find a way to use SAP to heal nerve injuries in humans.

Weil emphasizes the importance of these basic investigations. In contrast to the highly complex extracellular matrix of nerves, the peptide scaffolds are comparatively simple in structure. This allows them to conduct scientific studies that enable rapid progress. "Because we are familiar with the building blocks of the SAP, we can replace them individually and thus change the properties. We can then examine the structure in detail, study the effect of the SAP within the biological system, and learn from it."

The researchers quickly found several properties that are important for the interaction between SAP and nerves. For example, SAP that have positively

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charged surfaces interact strongly with nerve cells. The number of the solubilized SAP that attach to each other to form fibrils is also important. If this proportion is large, these peptides are particularly well-suited to forming a support structure. The research team also discovered that SAP that form thicker fibers provide a better scaffolding for nerves. But a survey of all 27 sequences presented Synatschke with a puzzle: there were peptide sequences that were positively charged and formed high numbers of fibrils. However, they did not act as scaffolds for the nerve cells in the Petri dishes. Collaboration with Tuomas Knowles from the University of Cambridge helped the team in Mainz to figure out what the peptides were missing. Knowles found what he was looking for in the infrared spectra of the various SAP. His detailed evaluation showed that those SAP that are particularly suitable as nerve scaffolds form fibrils with a high ß-sheet content. At the molecular level, this structure of the amino acid chains looks like an accordion or a sheet of paper folded in a zigzag pattern and describes how the individual peptide chains are arranged within the fibrils. Synatschke and Weil thus found another crucial characteristic that SAP must have in order to provide a scaffold for nerves.

The team led by Knöll then took the three best SAP from Synatschke's 27 candidates and tested them on living mice that had lost control of their whiskers because of an injury to the facial nerve. The researchers injected a solution of SAP at the sites where the nerves had been severed. Then, over the next three weeks, they studied how the nerve fibers regenerated. They initially saw no clear difference between mice injected with peptides and the control group. However, as the study progressed, it became apparent that the nerves healed better when a peptide scaffold replaced the injured extracellular matrix. A prerequisite for this was that the peptide structures remained as a stable framework at the wound site throughout the healing process – even though they are biodegradable.

Improved nerve function

The positive influence of the peptide scaffold on the regeneration of the facial nerve was verified by the scientists through various observations. They demonstrated that severed nerves in the mice tissue that were supported by a peptide scaffold re-connected better than the nerves of the control mice. This result was also confirmed during the functional check. The mice that the researchers had injected with a solution of scaffold-forming peptides recovered better from the injury and were able to move their whiskers in a more controlled manner than the control animals after three weeks.

The experiments in the Petri dishes and on the mice made it clear that the scientists had found an ideal material when they discovered SAP. "By accurately differentiating the distinctive features of SAP, we have developed an understanding of their fundamental relationships," says Synatschke. "We want to build on this." Together with the group led by their colleague Tristan Bereau, the researchers are now using computational methods to search for peptide sequences that are even better suited as a neural scaffold

Healing bond: the fluorescence microscope image shows how a nerve cell (green) uses special proteins (red) to attach itself to conjoining nanofibers (purple) that are made of peptides.

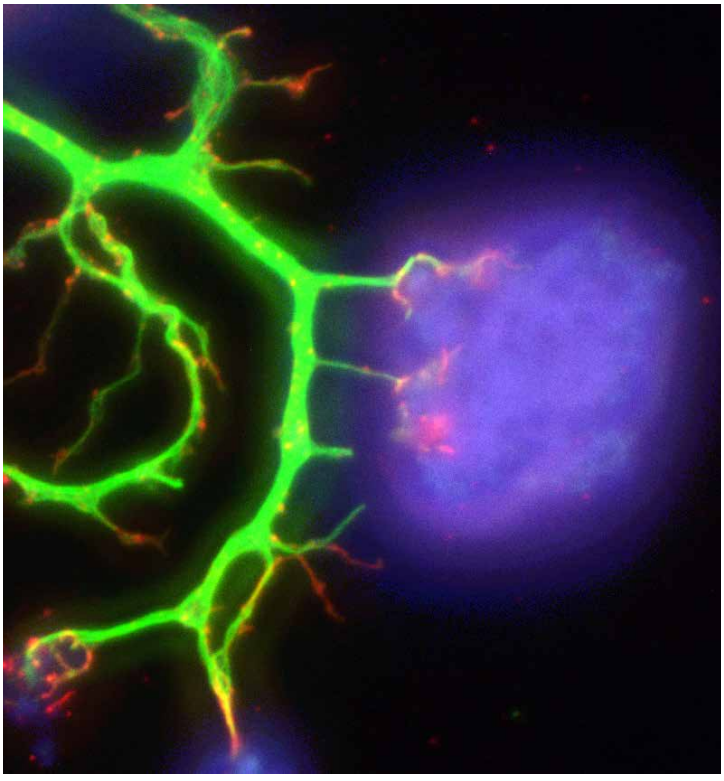


IMAGE: BERND KNÖLL/MPI FOR POLYMER RESEARCH

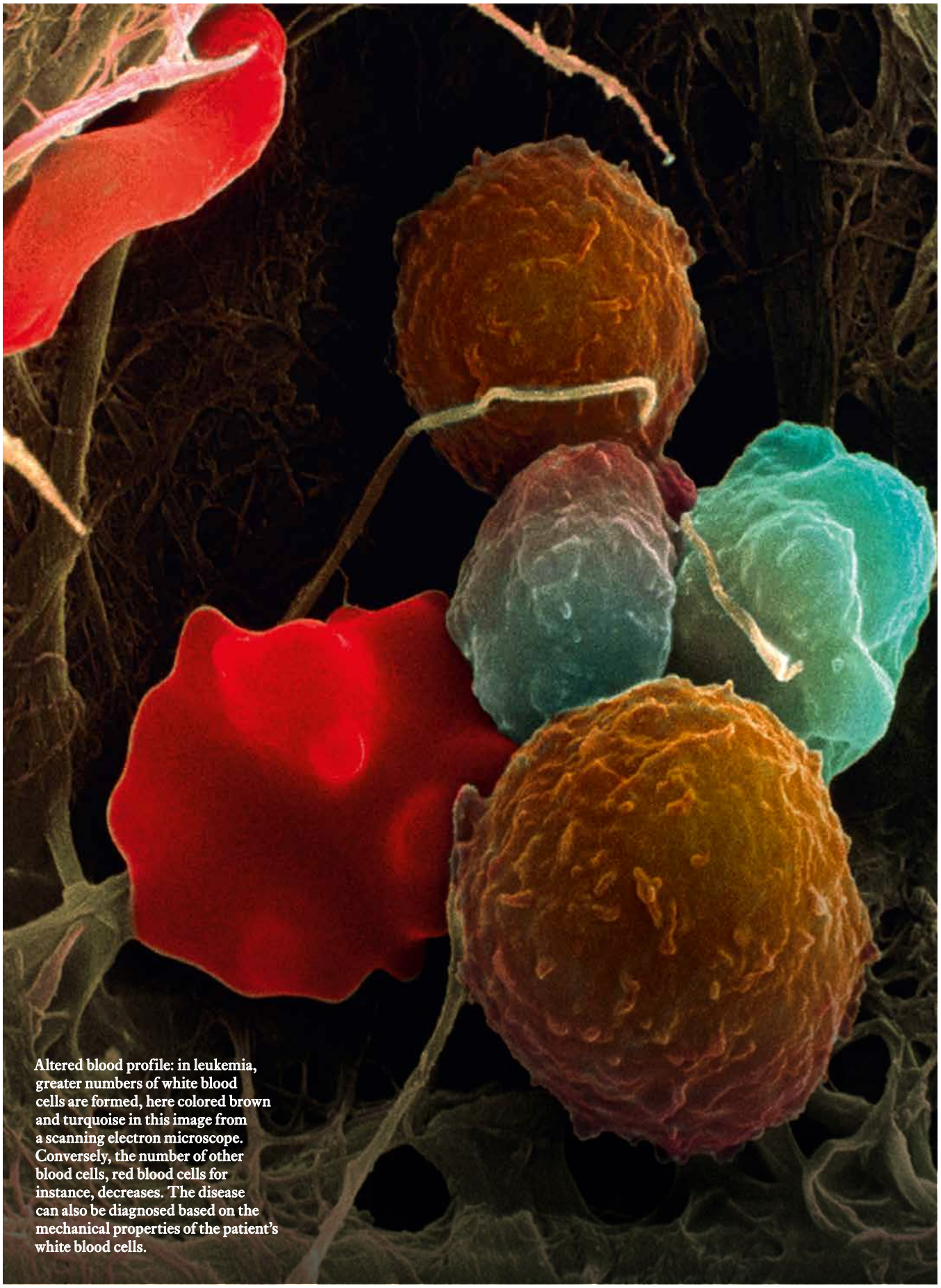
than the sequences from the HI viral envelope. Using new approaches from computer science and the processing power of modern computers, they can screen millions of possibilities in search of the three desired properties without having to conduct elaborate experiments. They can then test the most promising candidates in the laboratory. "This speeds up the research process immensely," says Weil. "By doing so, we hope to find novel sequences that have no prototype in nature but which have exciting properties."

The next research collaboration with Knöll is also already in the pipeline. After successful experiments in the peripheral nervous system, the researchers are now venturing into the central nervous system. The challenge of healing nerves in the brain and spinal cord is much greater because the nerves here generally do not regenerate at all. Accidents in which the neck or spine is severely injured often lead to paraplegia. In the coming years, Bernd Knöll, Tanja Weil, and Christopher Synatschke want to modify the peptide scaffolds in such a way that they also enable the healing of nerve damage in the body's central control centers.

GLOSSARY

EXTRACELLULAR MATRIX
is the name of the tissue component consisting of proteins and carbohydrates in which cells are embedded. Nerve cells require the extracellular matrix in order to grow.

SELF-ASSEMBLING PEPTIDES (SAP)
These are short amino acid chains that autonomously form larger structures such as fibrils.



Altered blood profile: in leukemia, greater numbers of white blood cells are formed, here colored brown and turquoise in this image from a scanning electron microscope. Conversely, the number of other blood cells, red blood cells for instance, decreases. The disease can also be diagnosed based on the mechanical properties of the patient's white blood cells.

IMAGE: SCIENCE PHOTO LIBRARY/GSCHMEISSNER, STEVE

CELLS UNDER PRESSURE

TEXT: ROLAND WENGENMAYR

To date, medical science has shown little interest in how easily cells deform. As Jochen Guck, Director at the Max Planck Institute for the Science of Light in Erlangen, and his team have discovered, this attitude is unjustified. As it turns out, the mechanical properties of cells can be used to diagnose cancer and possibly also inflammation. The scientists are currently testing the method together with University Hospital Erlangen – and have already gathered useful insights into COVID-19.

It could lead to a whole new way of testing blood that can be monitored directly on a screen. Small, dark shadows stream through a funnel-shaped narrowing into a slender channel. Within this, they accelerate, become deformed and are then swept back out again. They're blood cells, and the images were taken by a high-speed camera fitted to a microscope. "The channel is just 20 micrometers in diameter and 300 micrometers long," explains Martin Kräter – in other words, its diameter is about the same as that of a fine human hair, and on the lab-on-a-chip that the biologist is showing, the channels can only be discerned by the indistinct way they reflect light.

With a PhD in hematology, Kräter is an expert on blood, and the laboratory is located at the Max Planck Institute for the Science of Light in Erlangen, Germany. It is an unusual place for biology-based research. That can be explained by Jochen Guck's career, which has transcended the boundaries between specialist disciplines and was one of the reasons he joined the Institute as its Director in October 2018. Guck is a physicist who, among other things, uses laser light as a tool. And that's why he fits the profile of the Institute, in particular because his field of research is physics and, more specifically, the mechanics of living cells. This is precisely what his work on blood cells is all about. As a young researcher, Guck performed experiments on cancer cells in which he observed that they are mechanically softer than their healthy counterparts. When a force is applied to them, they deform to a greater degree than healthy cells do, and this can be seen under the microscope as they pass through the channel. Scanning cells in this way could become a new method of medical diagnostics, for example in cancer therapy and screening, as well as to identify inflammation. Looking at the mechanical properties of the cells should also help in understanding certain diseases, such as COVID-19.

This technique has opened up a new dimension in medicine, and Jochen Guck's team has now advanced it to the point where it has even given rise to an award-winning start-up company, Zellmechanik Dresden. The first generation of such blood testing devices has now been launched on the market. However, its use is still limited to research purposes and the market is therefore very small, but Guck expects this to change. Indeed, some of the devices are already running in test mode in a laboratory at the children's hospital at Erlangen University Hospital. Guck's team is working on site with the oncologist and physician Markus Metzler and his research group. They are testing whether the technique can aid in diagnosing leukemia, the most common childhood cancer. This cooperation also exemplifies the research of the Max Planck Zentrum für Physik und Medizin in Erlangen, in which

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the Max Planck Institute for the Science of Light, the University of Erlangen-Nuremberg and University Hospital Erlangen are collaborating. The center's new building is currently under construction, and Guck's team will move into it in 2024, as one of its five major working groups.

As a young physicist, Jochen Guck never imagined that one day he would become involved in biomedical science. "I opted out of biology at school," he says with a grin. Biology, he felt, was too unstructured, requiring too much rote memorization of facts. He was drawn to math and physics. And so Guck went on to become a physicist specializing in lasers and, in a roundabout way, this led to his meeting Josef Käs in Austin, Texas, who was interested in capturing and investigating the biomechanical properties of cells with the aid of lasers (a technique referred to as "optical tweezers").

Laser tweezers deform cells

In encountering Käs, Guck also came upon the scientific field that drives him to this day. "I was into laser technology at the time," he says. "The fact that it involved cells was something I tended to put up with." He seized the opportunity to set up a laboratory tailored to his needs and wishes. Being accessible to disabled people was a must; Guck uses a wheelchair. "I made sure the optical tables were high enough to park a wheelchair under them," he stresses. At the time, he discovered experimentally that cells react to laser light quite differently than hard glass or plastic particles of a similar size. The device Guck built consisted of two opposing laser beams. A channel transporting the cells ran between them. If a cell entered the light field, it was captured. But instead of being compressed by the opposing laser beams, as the physicists had expected, to Guck's surprise the opposite happened: the cells reacted to the pressure of the laser light by elongating along the beams. The optical tweezers unexpectedly turned into an optical stretcher. Guck managed to solve the riddle. "That was my first scientific eureka experience," he recalls. And it fired up his fascination for cells. Back then, scientific evidence was already emerging that the mechanical behavior of cells could reveal something about their internal state: cancer cells had been found to be softer than their healthy counterparts. His discovery led Guck to systematically investigate this observed behavior and to show that it could be used as a marker for cancer.

By the time he arrived in Erlangen in 2018, Guck was already envisioning the development of a routine testing procedure based on the biomechanical analysis of cells that could be employed in day-to-day clinical practice. His biggest challenge was to develop a method that could reliably screen a large number of cells in an amount of time that was also feasible for use in the real world. For although the optical stretcher developed by Guck in Austin was the fastest method around at the time and could analyze approximately one hundred cells per hour, it was still far too slow. Martin Kräter sums up the challenge they faced: "When you're examining a blood sample, only about one in every thousand bloods cells is white; the rest are red!" However, the diagnostic technique must capture a sufficient number of these rare white blood cells within a reasonable period of time. It's the white cells that are pathologically transformed in leukemia, and they also provide crucial information about the state of the immune system and about possible sites of inflammation.

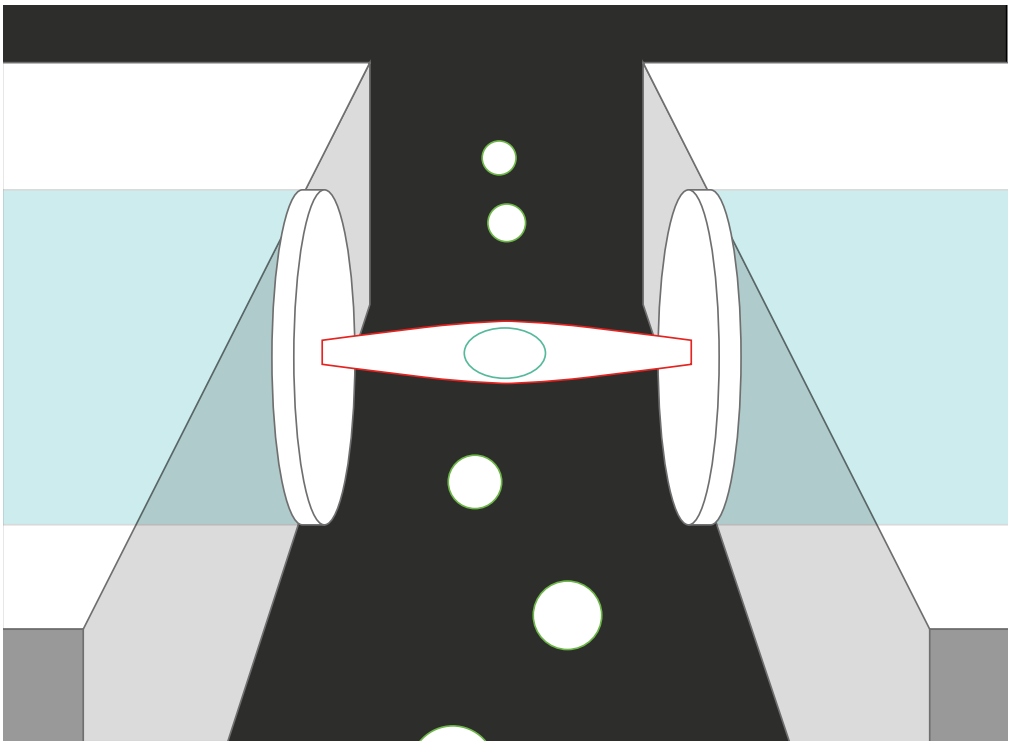
So they needed to discover a much faster process. Guck and his team came up with the idea of using "microfluidics" to capture blood cells in a rapid flow through a microscopic narrowing. This formed the basis of the method demonstrated by Kräter in the laboratory. Passing a fluid containing blood cells through a tiny channel sounds simple. However, its success as a diagnostic tool depends on precise control of the flow, allowing them to compare the deformation of similar cells under precisely reproducible conditions. A trick was required. The scientists developed an enveloping flow that surrounds the actual flow of the solution containing the cells, and both are pushed through the micro-funnel into the channel. This prevents cells from sticking to the walls of the channel. In addition, the flow of the fluid in the channel needs to be completely free of turbulence. A "laminar" (smooth) flow has a flow profile that is physically precisely calculable. The flow velocity is lowest along the wall, while it increases towards the center of the channel. This precisely predictable flow profile provides the key to reliable analysis of cell deformation. It causes the blood cells in the channel to be pushed in the direction of the flow at their center and slowed down at their lateral edges, deforming them into their projectile-like shape.

SUMMARY

Cancer cells are softer than healthy cells. The mechanical properties of cells can help to diagnose some cancers even earlier than techniques based on biochemical signals.

A team from the Max Planck Institute for the Science of Light is currently testing deformability cytometry with Erlangen University Hospital, primarily to diagnose leukemia.

The researchers are also investigating how useful the technique might be in diagnosing and studying inflammation. They have, for instance, discovered that red blood cells from COVID-19 patients deform less readily than those from healthy individuals, even after recovering from an infection. This could explain the symptoms and long-term effects of long COVID-19.



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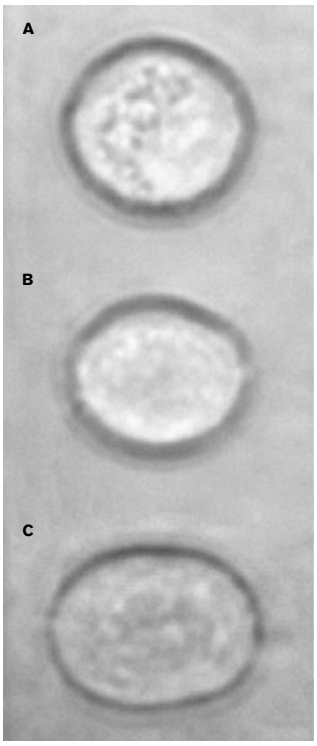

PHOTO: JOCHEN GUCK/MPI FOR THE SCIENCE OF LIGHT

Optical stretching device: intense laser beams can grip cells just like a pair of tweezers (left). Right: healthy cells (A) deform significantly less in the process than tumor cells (B). Metastatic cells are the most readily elongated (C).

A high-speed camera synchronized with a bright light-emitting diode flash can record the deformation of a thousand cells per second using this technique. "That's 36,000 times faster than the optical stretcher," summarizes Guck. "Using the stretcher, it would have taken us about a hundred years to record the same number of cells we can now analyze in a day!" It was this huge increase in throughput that was the breakthrough. "Real-time deformability cytometry" of this kind has made it feasible to detect pathological changes in cells in clinical settings.

"The term 'cytometry' simply means 'measuring cells'," explains Guck. "Real-time", however, involves processing hundreds of thousands of images in a short period of time with no delay. No human being can analyze such an enormous amount of data. The team, therefore, utilizes artificial intelligence and machine learning. The technology of artificial neural networks is now well established and is ideally suited to detecting patterns. It automatically sorts the passing cells by shape, as Kräter demonstrates on the screen. However, the system also needs to reliably recognize cell forms. To accomplish this, the AI system needs to be trained with blood samples from as many patients as possible. That's precisely what happens in Markus Metzler's laboratory at the Erlangen children's hospital.

Biomechanics as an early warning system

To appreciate the benefits of using diagnostics based on touch (tactile sensing) in the field of oncology, we need to take a look at the cell and its mechanics. The fact that a cell reveals something about its inner workings by means of its mechanical properties alone has to do with its "cytoskeleton," a term Guck is not a fan of. This skeleton does indeed play a role in structural support, similar to our bones. If we were single cells, however, we would be able to change our shape, just like Harry Potter, by rapidly restructuring our skeleton. And this is exactly what a cell does continuously in order to react to its environment or to changes in its interior – or to divide. So what's the best way to visualize such a skeleton? "It's best to think of it like a gel," says Guck. If you imagine a cell as a tube of moisturizer, it wouldn't just passively sit around in your bathroom cabinet. The gel in it would take on a life of its own, constantly deforming the tube and even causing it to roam around inside the cabinet. But such continuous activity comes at a price. "A considerable amount of a cell's energy is devoted to its cytoskeleton," explains Guck, "as much as 30 to 40 percent!"

What is decisive for diagnostics is that a cancer cell, for instance, has already remodeled its cytoskeleton and sof-

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tened even before standard clinical diagnostics discover its familiar characteristics: surface-bound proteins that can be identified with color-tagged antibodies. "In a manner of speaking, we can now analyze samples blindfolded," explains Guck: "If its mechanics have altered, the function of the cell must have already changed as well." As a result, biomechanics may become an early warning system for malignant changes in cells. In addition, real-time deformability cytometry instantly provides meaningful images, without extra procedures in the lab, such as staining.

This early warning function and the ability to directly identify pathological changes are advantages that have also convinced Markus Metzler of the merits of the joint research project. "We're a really good match for each other," he enthuses, referring to the fact that his team brings clinical practice research to the table, while Guck's group contributes cutting-edge technology from basic research: "If anyone can advance this new technology, we can." Metzler is confronted with the suffering and fears of his young cancer patients and their parents on a daily basis at the Erlangen children's hospital, and this provides him with additional motivation to drive the development of new diagnostic methods forward. It is the reason why the researchers are operating their own laboratory directly integrated into the health care system. There, they perform routine examinations that are already well-established in medical practice. Alongside this, real-time deformability cytometers from Guck's group are already up and running. They're utilizing the large number of blood samples drawn by the clinic to train their AI system to detect abnormally transformed cells.

Markus Metzler even expects that the AI training phase with data from various diseases will progress reasonably quickly. And he's got his sights set on more than cancer cells. "It also works reasonably well for certain forms of inflammation," he says, referring to the fact that white blood cells can also be exploited as messengers for inflammation concealed in the body. In and of itself, this is nothing new; standard blood testing involves counting leukocytes. What is novel, however, is being able to assess their biomechanical state, which can provide additional information. How this can be used to

Automated analysis: a liquid containing cells passes through the tubing over a microfluidic chip, while a high-speed camera installed on an optical microscope records the cells. Software then identifies diseased cells that deform more in the flow than healthy ones.

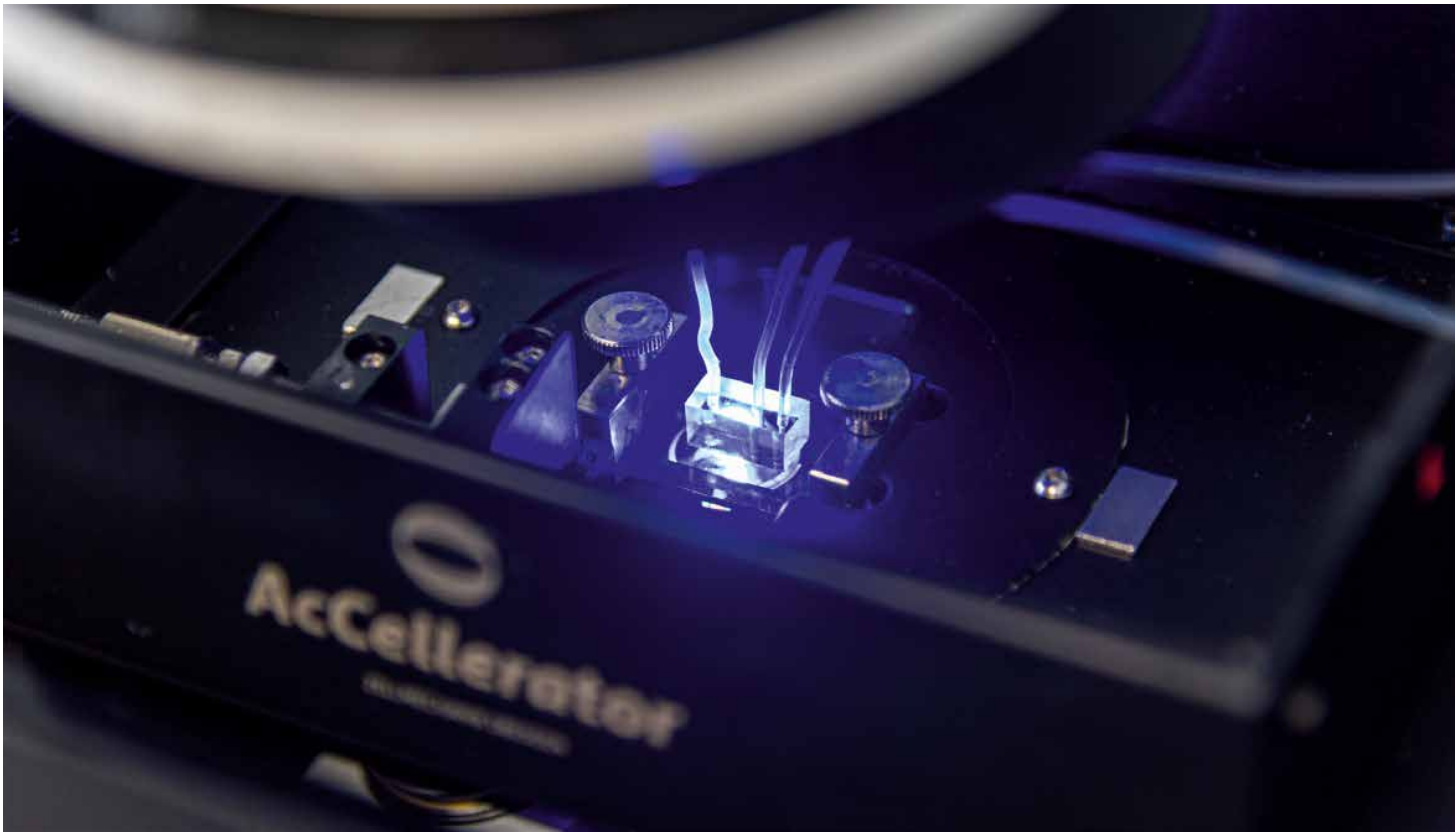

PHOTO: JOCHEN GUCK/MPI FOR THE SCIENCE OF LIGHT

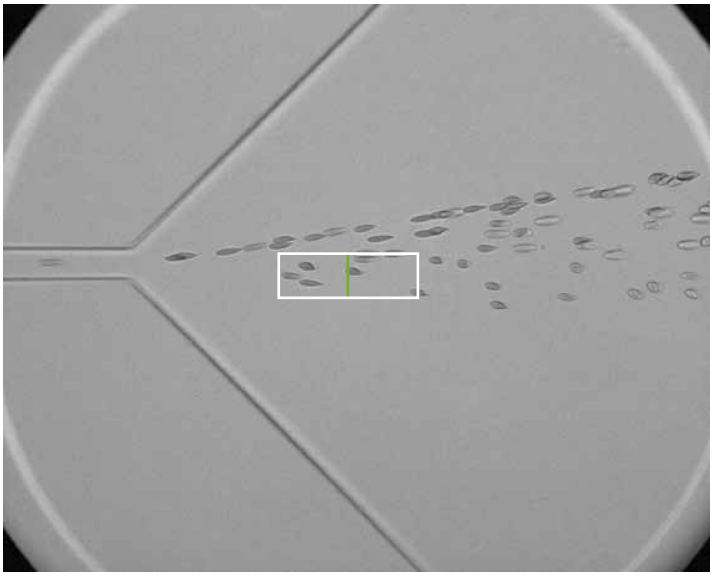

PHOTO: MARTIN KRÄTER/MPI FOR THE SCIENCE OF LIGHT

Biomechanical rapid test: the extent to which cells are distorted when they flow through a fine channel on a chip reveals whether they are healthy or diseased. The actual measurement occurs in the marked rectangle at the center of the image once this area is positioned over the channel.

improve diagnostics and therapy is a question that Jochen Guck's team are hoping to clarify with other medical research partners.

One mechanism behind COVID-19 damage

"Our method can detect a property of the cells that, to date, has remained untested," emphasizes Markus Metzler. It is a little like examining a patient with suspected appendicitis. "If we only recorded the size of the patient's abdomen and skin color, but didn't palpate the abdomen at all," says the professor of medicine, "we would be missing crucial diagnostic information." On the other hand, if the patient merely had a hematoma on her abdomen, the physician could make a correct diagnosis just by visually examining her. In precisely the same way, real-time deformability cytometry can be useful in some diseases, but in others, well-established diagnostic techniques are all that is required.

As a physician, however, Metzler is also taking the rigors of everyday clinical practice into account. Both he and chemist Manfred Rauh, head of the lab at the children's hospital, have seen promising medical innovations fail in practice. In a hospital, things need to be quick and uncomplicated: load up your blood sample, press a button and let the device do the rest – a requirement that a real-time deformability cytometer also needs to meet. Therefore, the next generation of the device is going to include an autosampler function for automated testing. Guck is already collaborating with a team at the Fraunhofer Institute for Process Optimization and Automation in Mannheim to develop the system. He envisages a time when deformability cytometry becomes a standard procedure for blood testing in all laboratories. It could potentially be used to diagnose inflammation and, even more importantly, for the early detection of leukemia and other types of cancer, such as lung cancer. Beyond this, the technique could eventually become an element of regular monitoring during and after tumor therapy. Metzler believes that medicine first needs to discover the specialized ways biomechanical diagnostics can establish itself in routine practice.

In the current situation, the technique can apparently help to explain some of the symptoms and long-term effects of COVID-19. Examining the blood of COVID-19 patients in the Erlangen intensive care unit has revealed, among other things, that the erythrocytes (red blood cells) of patients had become less elastic compared to those of healthy individuals. "However, the erythrocytes need to be able to deform in order to pass through the fine blood capillaries," explains Martin Kräter: "If they can't, they can block the finest blood vessels, such as those in the lungs – and this, significantly, is one of the leading causes of death from COVID-19."

Especially interesting is the finding that such changes in the blood are still observable six months after patients have recovered from the disease. This could provide the physiological explanation for why some people who have seemingly recovered often still experience respiratory problems, reduced physical fitness, and even neurological deficits. "Some of the patients we studied experienced, among other things, reduced concentration capabilities," says Kräter. In such cases, the mechanical properties of blood cells could, for the first time, conclusively clarify health problems that were previously inexplicable. "Our pre-publication results are creating quite a stir," says Guck. This highlights how helpful biomechanics might be in medical research and diagnostics. And Jochen Guck is convinced that this will also hold true for a variety of other diseases.

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GLOSSARY

DEFORMABILITY CYTOMETRY
A technique based on studying the mechanical properties of cells to better understand various diseases and to improve our ability to diagnose them.

PHOTO: LEA HECKMANN/MPI FOR PHYSICS

Eyes into space: the two MAGIC telescopes on the Roque de los Muchachos register particle showers in the Earth's atmosphere and use them to make indirect observations of gamma light from the depths of the universe.

Max Planck researchers cooperate with partners in more than 120 countries. Here they write about their personal experiences and impressions. Lea Heckmann from the Max Planck Institute for Physics is spending two months working on the MAGIC telescopes on La Palma in the Canary Islands. She talks about unforgettable sunsets and explains what La Palma has in common with Ireland.

Welcome to the city of telescopes! This is what went through my mind when I first saw all the observatories on the Roque de los Muchachos. Up here, at more than 2,200 meters above sea level, I will be spending the next eight weeks working on the two MAGIC telescopes. MAGIC is an acronym and stands for "Major Atmospheric Gamma Imaging Cherenkov". As their complicated name suggests, these are no ordinary optical instruments, but rather so-called "Cherenkov telescopes".

The MAGIC telescopes detect Cherenkov light, a kind of blue flash lasting only a few billionths of a second when high-energy gamma rays interact with the Earth's atmosphere. Two mirrors, each with a diameter of 17 meters, enable the telescopes to collect this light and record it on camera. The data allow conclusions to be drawn regarding the initial gamma rays.

My research focuses on so-called "blazars". A blazar is an active galaxy with a supermassive black hole at its center that consumes surrounding matter. Blazars are some of the most energetic objects in the universe, because particles evading the devouring black hole are accelerated towards the Earth in an extremely high-energy stream known as a relativistic jet, which in turn triggers the emission of gamma radiation. You could essentially compare blazars with particle accelerators like CERN in Geneva, but with inconceivably larger dimensions and energies.

I am specifically observing the two blazars closest to the Earth – although 'closeness' is naturally a very relative term in the vastness of space. The radiation we capture with our telescopes today was actually emitted at the time the first complex life forms were evolving in the Earth's lakes and oceans – in other words, several hundred million years ago!

Since we are studying the night sky, our work usually begins late in the afternoon and finishes in the early hours of the morning. First we have to configure the electronics, calibrate the telescopes, and get everything ready for the measurements. The observations begin after sunset; that means we sit in the control room, watch several monitors to ensure that all the systems are working properly, and direct the telescope towards various light sources.

POST FROM

LA PALMA

This might sound rather monotonous, but in reality it hardly ever gets boring since you constantly have to deal with the problems arising. However, the most exciting things happen at the beginning and end of each shift, when we go out and either secure the telescopes or release them so that these 60-ton giants can be moved. They can make one full rotation around their axis in less than a minute – a really impressive sight.

More than 20 institutions are involved in MAGIC, and we usually are around five people on site at the same time. There are currently researchers from Spain, Italy, Japan and the U.S. keeping me company. That means you could also see the whole thing as a kind of social experiment: what happens when you lock up five physicists on a mountain? Although it goes without saying that we aren't really locked up! We always have three days at work followed by one day off. I often use my free time to go down to the city, relax on the beach, or explore the island.

La Palma only measures around 700 square kilometers, less than double the area of Vienna, the city where I studied. Nonetheless, its geographical diversity is fascinating. Like all of the Canary Islands, La Palma is volcanic in origin, as you can clearly see from the black sandy beach, the dark volcanic rock, and the crater-pocked landscape in the south. The north, on the other hand, is dominated by dense jungle, remote villages and steep rocky cliffs that remind me of Ireland.

The sunsets above the clouds are unforgettable, and I can enjoy them almost every day. However, the most wonderful moments definitely happen at night, when I step out of the control room into the fresh air and gaze up at the sky. I look at the stars, let my thoughts wander, and am constantly reminded of how small we are here on Earth. That's one reason why I find the name MAGIC so appropriate for these telescopes. Or does anyone seriously want to dispute the magic of the universe?

PHOTO: PRIVATE

Lea Heckmann

27, studied Technical Physics at the Vienna University of Technology (TU Wien) and the KTH Royal Institute of Technology in Stockholm. Since January 2019, she has been working towards her doctoral degree in astroparticle physics at the Max Planck Institute for Physics in Munich. The scientist's research focuses on blazars, active galaxies with supermassive black holes lurking at their centers that are among the most energetic objects in the cosmos. Lea Heckmann has also been acting as the spokesperson for the Max Planck PhDnet since the beginning of 2021.

SIGNIFICANT INCREASE IN APPLICATIONS TO MAX PLANCK SCHOOLS

The Max Planck Schools, a joint initiative of German universities and non-university research institutions, continue to increase their profile. This is reflected by the most recent figures: compared to the first call in 2018, all three schools saw a significant increase in applications, with the Max Planck School for Cognition still receiving the largest number. The Max Planck School Matter to Life was able to almost quadruple its number of applications compared to 2018.

For the three pilot schools – the Max Planck School of Cognition, the Max Planck School Matter to Life, and the Max Planck School of Photonics – nearly 1,100 applications were received in the third round of applications; three times as many as in the first round of applications in 2018. This is evidence that the schools are becoming increasingly well known, both nationally and internationally, and have succeeded in attracting the brightest minds from all over the world with their interdisciplinary programs. "The pool of applications this year is again very diverse, interdisciplinary, and international. Our School received over 500 applications from students in the U.S., Russia and Australia from a wide range of disciplines – from psychology to neuroscience to data science," said Arno Villringer, Director at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig and one of the spokespersons for the Max Planck School of Cognition. "We have significantly more suitable applications than available places," he added.

With their multi-stage procedures which are specific to each school, the three pilot schools are in the process of selecting their new PhD students, who will then start their doctoral studies in October 2021. The initiative now involves 27 universities and more than 30 institutes of non-university research institutions. The German Federal Ministry of Education and Research is funding the five-year pilot phase with EUR 45 million. ***www.maxplanckschools.de/en***

TRIPLE RECOGNITION FOR THE MAX PLANCK SOCIETY

The European Research Council (ERC) has awarded Advanced Grants to 209 researchers in the current application round. Of the 40 lucrative grants awarded to Germany, three went to researchers from the Max Planck Society. Endowments of up to EUR 2.5 million each will put them and their teams in a position to be able to pursue their project ideas, all of which have been rated as excellent.

The European Commissioner for Innovation, Research, Culture, Education and Youth, Mariya Gabriel, drew particular attention to the increasing number of women among the grant recipients: "It also gives me great pleasure to see more women applying for and receiving these prestigious grants." Since the start of the Horizon 2020 program, for example, the percentage of female Advanced Grant recipients has increased from around 10 percent in 2014 to over 22 percent in 2020. Female researchers submitted 22 percent of the applications in the current funding round: 23 percent of the grants were awarded to women, including one from the Max Planck Society.

In a Germany-wide comparison, the Max Planck Society, which was awarded 3 grants, ranks second alongside the Technical University of Munich (also 3 grants) and just behind the Leibniz Association which garnered 4 grants. The research grants were awarded to institutions in 14 European countries. Germany, which has 40 approved grants, is in second place behind the United Kingdom (51 grants). The ERC received more than 2,600 research proposals in the latest Advanced Grants round, eight percent of which were approved, whereby scientific excellence is the sole selection criterion. ERC funding for the grants totaled EUR 504 million.

The MPG's 2020 Advanced Grant award winners – the happy recipients of millions of euro in research funding (from left): Marina Bennati of the MPI for Biophysical Chemistry, Didier Stainier of the MPI for Heart and Lung Research, and Johann Anton Zensus of MPI for Radio Astronomy.

PHOTOS: HELGE HORN, MPI FOR LUNG RESEARCH; IRENE BÖTTCHER-GAJEWSKI / MPI FOR BIOPHYSICAL CHEMISTRY

COMMUNITY NEWS

EXEMPLARY COMMUNICATION ON ANIMAL TESTING

The general public takes a dim view of animal experiments for research purposes, which makes well founded, transparent communications on the subject all the more important. The "Understanding Animal Experiments" information initiative has awarded the label for "exemplary communications about research involving animal experiments" to the online animal experiments portal on the Max Planck Society's main website.

The objective of the "Understanding animal experiments" initiative is to show how universities, institutes and organizations can inform the public about the research they carry out involving animal experiments. It is supported by the Alliance of Science Organisations in Germany, of which the Max Planck Society is a member. The label for "exemplary communications on research involving animal experiments" honors institutes and organizations that demonstrate an exemplary commitment to transparent and open communications and dialog concerning animal experiments and research involving animal experiments.

Conscious of its special responsibility in terms of its own research and its wider social role, the Max Planck Society published the "Animal Experimentation at the Max Planck Society" policy paper in 2016. The paper takes a critical view of the relevant ethical conflicts and legal frameworks and provides readers with an understanding of the importance of animal experimentation in basic research.

This was followed by further processes, such as creating the role of Animal Experiment Officer who, together with the Max Planck Institutes concerned, is responsible for the central coordination of the subject, and the development of an e-learning module on animal ethics for advanced training for researchers. Another achievement is the comprehensive online animal experiments portal, which is now entitled to bear the label for "exemplary communications on research involving animal experiments".

Best-practice communication in animal research

Awarded by „Tierversuche verstehen"

Among the Max Planck Society Institutes, the MPI of Molecular Cell Biology and Genetics in Dresden serves as an example of best-practice. The Institute's website provides an excellent example of transparent and open communications on the subject of animal experimentation:

www.mpi-cbg.de/en/research/animals-in-research/

ECOSYSTEM FOR IDEAS AND CREATIVITY

The construction phase of the new Max-Planck-Zentrum für Physik und Medizin (MPZPM, Max Planck Centre for Physics and Medicine) in Erlangen is now beginning. Three highly respected organizations are behind the centre: the Max Planck Institute for the Science of Light (MPL), the Friedrich Alexander University Erlangen-Nürnberg (FAU) and the University Hospital Erlangen. The researchers of the three partners who come together in the MPZPM use modern mathematical and physical methods – especially from optics – to give new impetus to the biomedical disciplines.

"A fascinating project is emerging here," said the Bavarian Minister-President Markus Söder when laying the foundation stone. In the fight against cancer, for example, it is important to combine new methods at the cellular level with artificial intelligence or quantum computers. Therefore, the State of Bavaria is investing almost EUR 60 million in the Institute to "create an ecosystem for ideas and creativity" and to accelerate the process in which new scientific knowledge is generated.

"Great breakthroughs have been made in science by merging research fields and creating entirely new disciplines," said Martin Stratmann, President of the Max Planck Society, during the event at the construction site. However, given the differentiation of science today, it is no longer so easy to meet at eye level. Erlangen is the ideal place for such encounters because the thematic orientation of the institutions coincides and "the will of the actors to overcome borders is always noticeable."

The MPZPM research groups are still scattered all over Erlangen. At the beginning of 2024, they will move into the new building on the grounds of the Erlangen University Hospital. The building, with its modern laboratories and offices, will provide space for about 180 employees on five floors and 5,700 square meters of floor space. They will conduct research within walking distance of the doctors in the clinics and will be able to reach their colleagues in the other institutes that are currently being built via glass bridges. The architecture thus also reflects the close ties between the founders of the MPZPM.

FIVE QUESTIONS

ON PATENT PROTECTION FOR VACCINES

FOR RETO HILTY

Professor Hilty, there is a global shortage of vaccines against COVID-19. That's why India and South Africa are fighting for a relaxation of patent protection at the World Health Organization, and they have the support of over 100 countries. What would happen if their application is successful?

RETO HILTY If their proposal is accepted, every individual member state would be able to decide autonomously whether to suspend patent protection or not, with those who cannot currently afford the vaccines being most likely to take advantage of the suspension. The problem is that suspending patent protection in one's own country makes no sense if there is no domestic company that has the technical capabilities to produce such vaccines.

Which patents are affected?

Ironically, it is not only patents specifically relating to COVID-19 vaccines that are affected. The new mRNA-based vaccines in particular are based on technologies that are themselves protected by basic patents that have already been granted or are due to be granted. These technologies have other very different and promising areas of application, namely in cancer therapy. If the patent protection for vaccines were to be suspended, this would also have to apply to these basic patents. It is highly unlikely that this would increase incentives for the pharmaceutical industry to continue investing in such future technologies. Those who interfere with patent protection are therefore playing with fire.

What, in your view, would be a better solution?

In general, it is much more efficient if the players involved cooperate with each other and grant the necessary licenses on a contractual basis. In the meantime, a number of commissioned productions on this basis have become known. Of course, this industrial sector is not exactly renowned for its transparency. But I would not accuse the vaccine developers right from the start of refusing to grant licenses. The problem is that we simply do not have enough suitable manufacturers yet. An illustrative example is the cooperation between BioNTech/Pfizer and Novartis or Sanofi, after all global corporations. They are among the few that are capable of even filling the vaccine vials. By the way, without patents, such cooperation would hardly occur, because patents are precisely the prerequisite for collaboration. They create the legal certainty that ensures that the company's own technology is used in accordance with the contractual specifications.

Even so, for millions of people in the global south, the vaccination is still too expensive.

The gap between privileged and underprivileged countries is indeed alarming. However, those who minimize the problems to patent law alone and blame the pharmaceutical industry are taking the easy way out. Problems of this nature cannot be solved through market mechanisms alone. It is not without reason that some wealthy countries contributed substantial funding for the development of vaccines. And it's fantastic that they did so. But if more than their own populations are to benefit, further costs will inevitably have to be incurred in order to supply economically weak states as well. Hopefully, the EU can soon do a lot of good in this regard. If it receives and accepts all the vaccine doses it has ordered, the EU will have far more than it needs.

But isn't it the pharmaceutical industry that once again profits in the end?

Certainly, no one should be "making a killing" from the pandemic. But public funds do not have to be spent unconditionally. In this respect, however, there is also little transparency on the part of the public funders. At any rate, the fact that in the U.S. a proportion of population three times as large as in the EU has already been vaccinated indicates that the U.S. government has negotiated more farsightedly than others already in the allocation of its funds.

This interview was conducted in the beginning of March 2021.
Interview: Michaela Hutterer

Prof. Dr. Dr. h. c. Reto M. Hilty
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ILLUSTRATION: SOPHIE KETTERER FOR MPG

RESEARCH ESTABLISHMENTS

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

The Netherlands
- Nijmegen

Italy
- Rome
- Florence

USA
- Jupiter, Florida

Brazil
- Manaus

Luxembourg
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