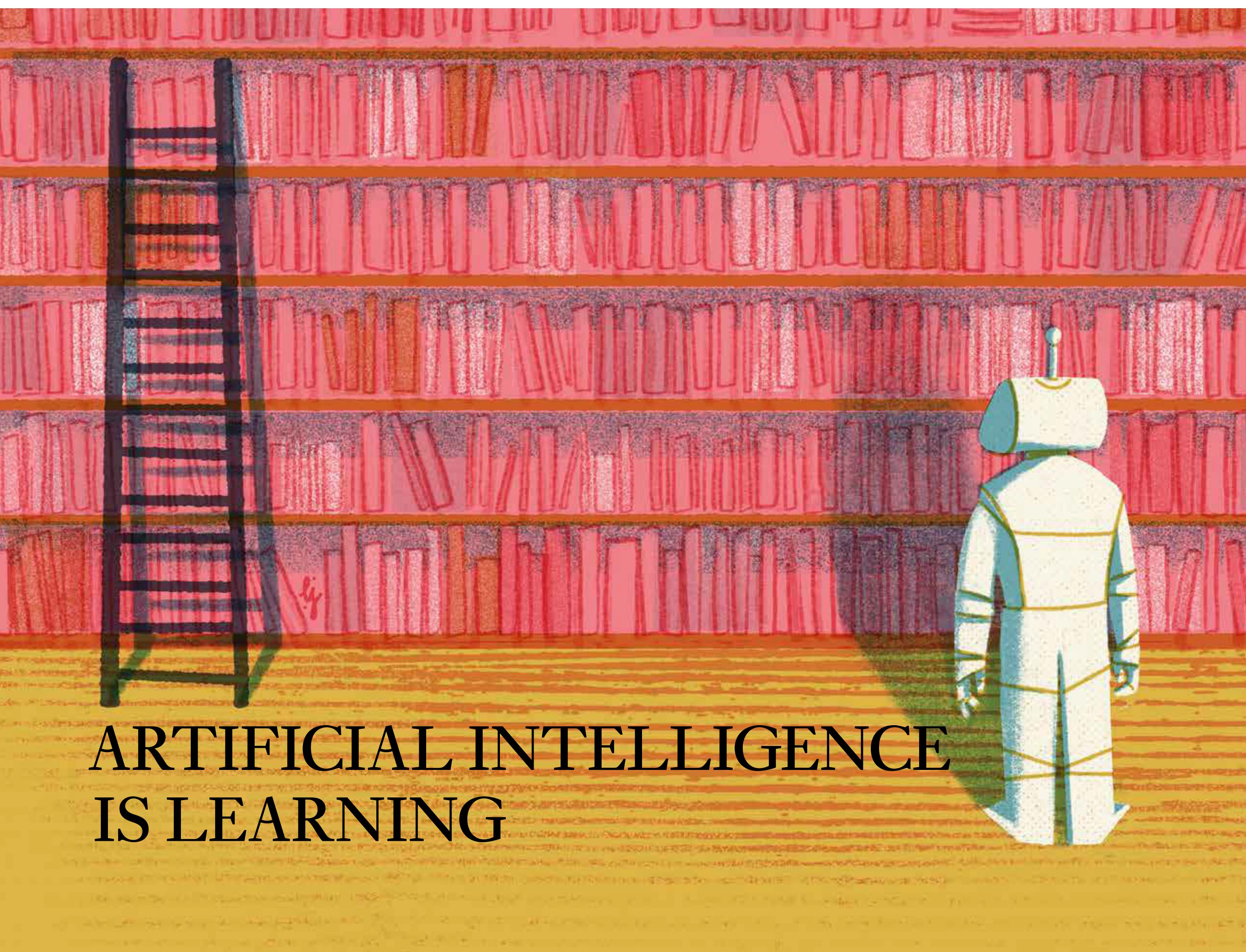
03 | 2021

MAX PLANCK
Research

DEMOGRAPHY
Digital demography

ENERGY
Fuel from the steelworks

ASTRONOMY
The dark heart of Centaurus A



ARTIFICIAL INTELLIGENCE IS LEARNING

ILLUSTRATION: LUISA JUNG FOR MPG

Learning, learning, learning: computers may be better at calculating than humans, but to date, they have fallen behind when it comes to basic knowledge and an understanding of the world. Scientists are working to make artificial intelligence more able to meet human requirements in the future.

EDITORIAL

Dear reader,

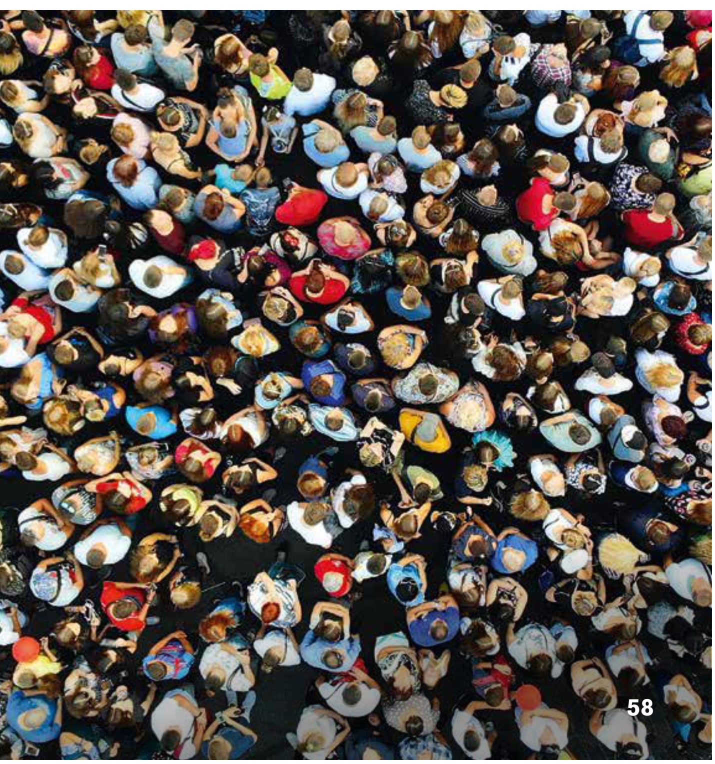
Nowadays, artificial intelligence can outperform even the most intelligent humans – yet in other aspects, AI is less capable than any toddler. This is because machine learning systems are characterized by extremely specialized knowledge – they do specific tasks very well, but nothing else. When it comes to identifying complex patterns in large volumes of data, artificial intelligence is particularly hard to beat. This is why AI is increasingly being used in medicine. Algorithms can be trained to estimate the risk of mental health disorders using a large number of physiological parameters and clinical findings.

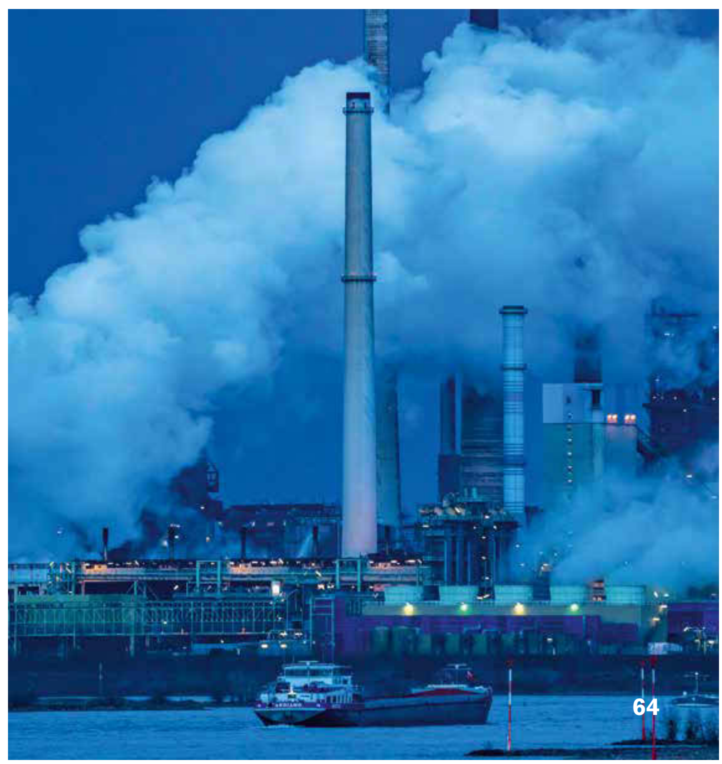
Yet they are completely useless for all tasks outside their specialized area. Moreover, it is often impossible to deduce how algorithms arrive at their conclusions, not least because the programs often fail to understand the correlations they uncover – and they have nothing like the understanding of the world around them that even small children have.

However, researchers are now developing algorithms in such a way that it is at least possible to identify the criteria they use for their decision-making. This is absolutely vital, not only in medicine but also for bank loans, road traffic, and other areas in which decisions made by artificial intelligence have far-reaching effects for humanity. It also highlights the ethical questions that arise when algorithms make decisions for and about us. For this reason, researchers are exploring the criteria that apply in such cases. After all, we humans should be able to dictate what algorithms can and cannot do.

This issue focuses on artificial intelligence with the aim of providing some food for thought. We hope you will find it exciting reading!

Your editorial team





IMAGES: LUISA JUNG FOR MPG (TOP LEFT), MOHAMAD ALMEDAWAR/MPI OF MOLECULAR CELL BIOLOGY AND GENETICS (TOP RIGHT), ISTOCK/DMYTRO VARAVIN (BOTTOM LEFT), PICTURE ALLIANCE / JOCHEN TACK (BOTTOM RIGHT)

CONTENT

CLEAN ROOM
WORLD RECORD

Anyone wishing to listen in on the music of the universe needs fine instruments – instruments such as those installed in LIGO. On September 14th, 2015, the twin detectors of the U.S. Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves. It was a world first – and people in the village of Ruthe near Hanover, Germany celebrated. The reason for celebrating was that nearby, there is another trap for such space-time vibrations – which were first predicted by Albert Einstein. At GEO600, researchers – including those from the Max Planck Institute for Gravitational Physics – investigate new detection techniques that will then be used in other, larger detectors around the world.

All such instruments are based on the principle of interferometry. This involves splitting laser light into two beams, which are then directed at right angles away from each other along two long arms. At their ends, they are reflected back again by mirrors and finally recombine and overlap with each other. From the resulting interference pattern, scientists can tell whether or not a gravitational wave has passed through the equipment. Such measurements are extremely challenging, and, as a result, the interior of GEO600 resembles a clean room in a virology laboratory. All personnel are required to wear protective goggles and specialized overalls, as a single speck of dust would compromise the sensitive measurements.

The laser beams run through two 600-meter stainless steel tubes that, together with the tank (on the left in the picture), form part of a sophisticated vacuum system. The optical table in front of the three researchers generates “squeezed light.” This is one of the tricks the scientists employ to increase the sensitivity of a gravitational-wave detector. It mutes noise caused by quantum effects in the laser light by a factor of 2! With that, the GEO600 has set a new world record.

ON LOCATION

PHOTO: FRANK VINKEN FOR MPG

NOBEL PRIZE IN CHEMISTRY

BENJAMIN LIST

PHOTO: FRANK VINKEN, MEDAILLE: PICTURE ALLIANCE / SZ PHOTO | ALESSANDRA SCHELLNEGGER

“You think: maybe this was a really stupid idea.”

Left- or right-handed? This makes a big difference in chemistry as well. Many molecules, especially those involved in biological processes, exist in two variants. The components of these variants are arranged as mirror images of one another – just like the fingers of our hands.

In chemical reactions, the two variants usually occur in equal proportions. But in biology, they usually have very different effects. This is particularly relevant when it comes to medicinal substances. Benjamin List, Director at the Max-Planck-Institut für Kohlenforschung in Muelheim an der Ruhr, and David W. C. MacMillan of Princeton University independently discovered in the year 2000 that even relatively small, often inexpensive and non-toxic organic molecules can shift a chemical reaction in favor of a single variant. For this, they will receive the Nobel Prize in Chemistry 2021. Before the two researchers made their discovery, this selective effect was known to occur only in enzymes or in relation to elaborate catalysts that often contain expensive or toxic metals.

When Benjamin List first tested the catalytic effect of an organic molecule, namely the amino acid proline, he was rather skeptical: “I was completely unsure. You never think: Wow! I designed that! Now I’ll become world famous! Instead, you think: hmm… maybe this was a really stupid idea. I’m sure others have already tried this and know why it doesn’t work…”. But in fact, no one had tried it yet. And it did work. Today, organic molecules are often used as catalysts, not only in research but also in industry.

“Benjamin List has begun a new chapter in catalysis with great application potential,” Max Planck President Martin Stratmann explains. “He is the first to succeed in developing organic catalysts with high stereoselectivity – a very rare breakthrough.”

NOBEL PRIZE IN PHYSICS

KLAUS HASSELMANN

PHOTO: PICTURE ALLIANCE/DPA | J.J. GUILLEN

“We’ve been warning people about climate change for almost 50 years.”

A certain amount of provocation is often necessary, especially in science. With his work, Klaus Hasselmann challenged climate research – and thus laid the foundation for the realization that global warming can be clearly attributed to increasing CO_2 levels in the atmosphere. For this, the former Director at the Max Planck Institute for Meteorology will receive the Nobel Prize in Physics 2021 together with Syukuro Manabe from the U.S. and Giorgio Parisi from Italy.

Hasselmann introduced the element of chance into climate research, explaining long-term climatic developments as the result of the meteorological background noise, which manifests itself in short-term weather fluctuations. Until then, nobody had ever considered the climate in this way. He also developed the mathematical tool for detecting the imprint of human CO_2 emissions amongst the meteorological background noise.

“As the founding Director of our Max Planck Institute for Meteorology, Hasselmann, together with his colleagues in Hamburg, played a key role in advancing Earth system research in Germany in the 1970s and 1980s and in making it internationally relevant,” says Max Planck President Martin Stratmann.

In order to convey the findings of climate research to the general public and to develop effective but also practicable measures to combat climate change, Hasselmann founded what is now the Global Climate Forum together with Carlo C. Jaeger of the Potsdam Institute for Climate Impact Research. “There are many things we can do to slow climate change,” says Hasselmann, who earned his doctorate at the former Max Planck Institute for Fluid Dynamics and helped establish the Max Planck Institute for Meteorology in 1975. “But the question is whether people understand that we have to act now in order to prevent something that will happen in 20 or 30 years’ time.”

60,000

Sediment cores from Eifel maars allow researchers to look back over 60,000 years of climate history.

EIFEL MAARS FORECAST TORRENTIAL RAINFALL

Fewer than one hundred kilometers lie between the flood-ravaged district of Ahrweiler and the volcanic lakes (maars) in the Eifel region. These maars are now providing further evidence that extreme weather such as torrential rainfall could increase in the future. Researchers at the Johannes Gutenberg University Mainz and the Max Planck Institute for Chemistry have analyzed the layers of sediment cores from maar lakes and dry maars in the volcanic Eifel to precisely deduce how the climate in Central Europe has changed over the last 60,000 years. In glacial periods, the layers are very thin and barely visible. In interglacial periods, on the other hand, the layers show the course of the seasons – similar to the annual rings of a tree. In some cases, the sediment layers that formed during these phases are exceptionally thick, measuring between several millimeters and a few centimeters – this is clear evidence of flooding events. Climate fluctuations consequently appear to have been greater in these periods and the weather conditions more extreme.

www.mpg.de/03202101en

MILK MADE MIGRATION POSSIBLE

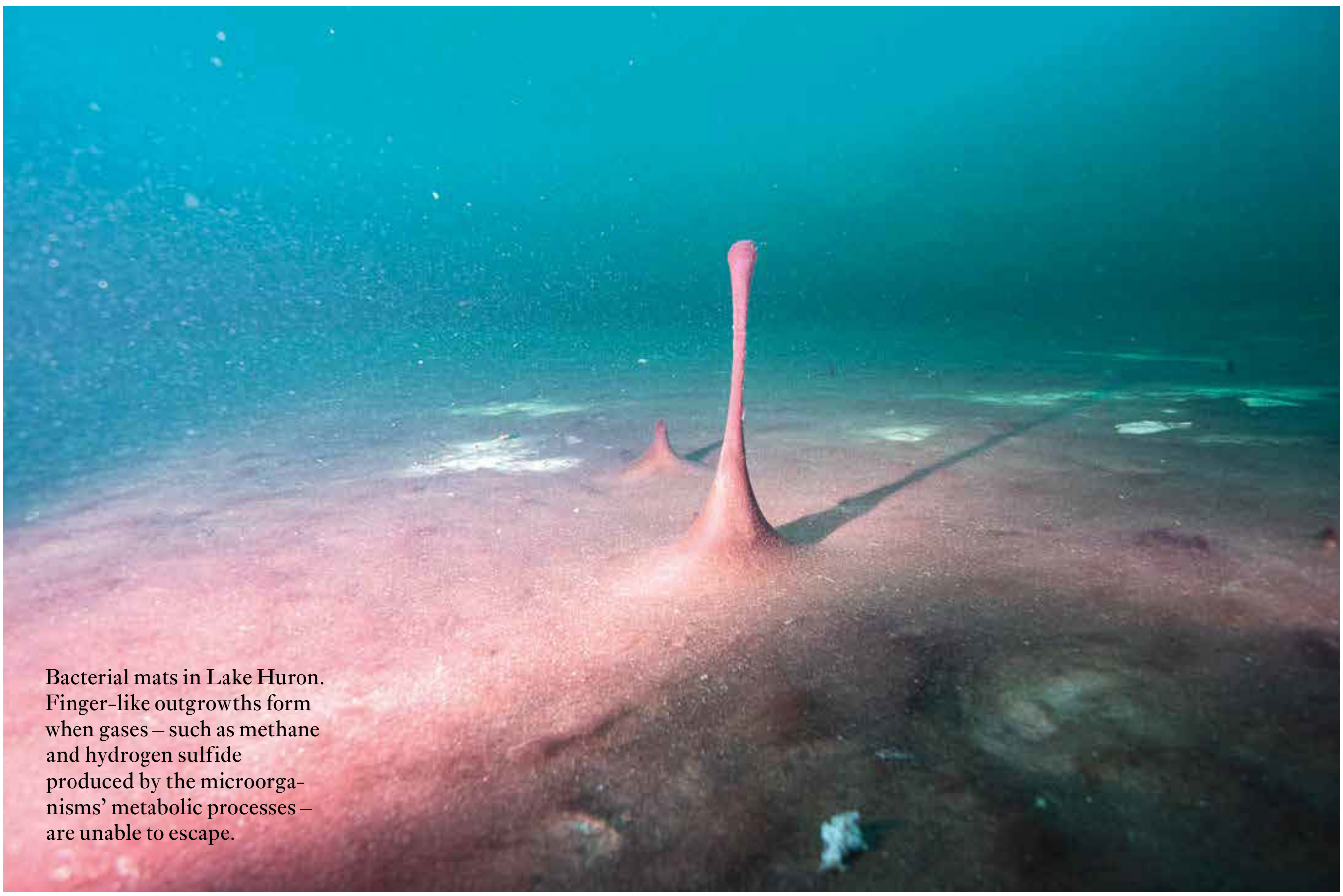
More than 5,000 years ago, the Yamnaya, a tribe of herders from the Eurasian steppe, migrated over vast areas of land. Evidence of their genes has been found in regions as far-flung as Scandinavia and Siberia. Until now, it has remained a mystery how people managed to travel such enormous distances during the Bronze Age. According to a study led by researchers from the Max Planck Institute for the Science of Human History, a dietary shift towards the consumption of dairy products may have played a key role in their migratory behavior. This is because milk contains water and important nutrients that are otherwise not often available in the steppes. The researchers sought evidence of the dietary change by examining tartar on the teeth of preserved skeletons. Before the Bronze Age, there were absolutely no signs of milk consumption, while almost all of the early Bronze Age individuals examined were found to be milk drinkers. The shift to dairy farming accordingly took place at exactly the time when the pastoralist tribes began migrating eastward. It also seems highly likely that domesticated horses played an important part in this development: the herders ate their meat, drank their milk, and used them as a means of transport.

www.mpg.de/17544984

Horses in the Eurasian steppes: 5,000 years ago, herders used them as a source of milk and a means of transport for migrating to far-distant regions.

PHOTO: A. SENOKOSOV

IN BRIEF



Bacterial mats in Lake Huron. Finger-like outgrowths form when gases – such as methane and hydrogen sulfide produced by the microorganisms' metabolic processes – are unable to escape.

PHOTO: PHIL HARTMEYER, NOAA THUNDER BAY NATIONAL MARINE SANCTUARY

A LONG DAY FOR MICROBES

Almost all of the oxygen on Earth is produced through photosynthesis, a biochemical process that is only possible in the presence of light. However, when cyanobacteria invented photosynthesis more than 2.4 billion years ago, the days were several hours shorter than they are today. They did not start growing longer until the Earth began to rotate more slowly as a result of tidal friction and the gravitational pull of the still young Moon, which at that time was closer than it is now. According to researchers at the Max Planck Institute for Marine Microbiology, the lengthening days were one factor that caused the oxygen content in the atmosphere to increase. The researchers investigated cyanobacteria in Lake Huron in Michigan, which live in conditions resembling those on the newly formed Earth. The cyanobacteria there compete with sulfur-oxidizing bacteria in the oxygen-poor waters of the lake. Every day, the microorganisms perform a little dance: while the sulfur-oxidizing bacteria form a layer above the cyanobacteria at night, the cyanobacteria rise to the surface of the microbial mat at dawn and produce oxygen by means of photosynthesis. However, it takes a couple of hours before they really get going. Moreover, the oxygen concentration that forms between the bacterial mats and the water's surface is much weaker on shorter days, and the gas is released from the water more slowly. The increase in day length throughout the course of the Earth's history may therefore have contributed to present-day oxygen levels, thus creating the conditions for life as we know it.

www.mpg.de/17315311

NUCLEAR FUSION REACHES A MILESTONE

Nuclear fusion could open up a practically inexhaustible supply of energy. A number of competing strategies are being pursued worldwide in order to tap it, each of which has various advantages and disadvantages. The Max Planck Institute for Plasma Physics in Greifswald, Germany has now achieved one of the intermediate goals set by one of these strategies using the fusion device Wendelstein 7-X. In this – the world's largest stellarator device – scientists have optimized the magnetic cage in which the fusion plasma is enclosed, so that energy losses are significantly minimized compared with earlier devices of the same type. This means that the device now fulfills one of the requirements that must be met if it is to serve as a power plant some time in the future.

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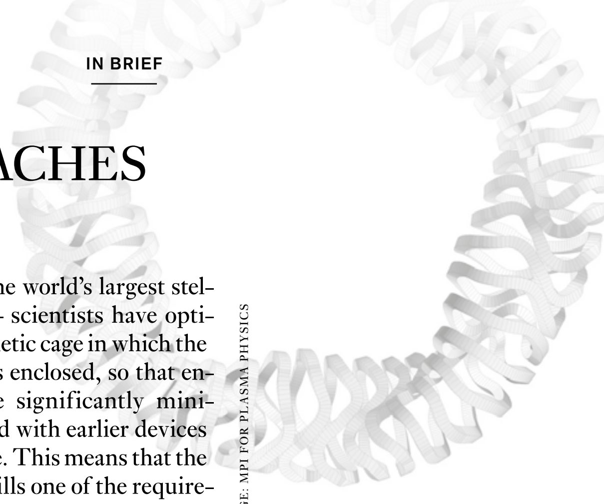

IMAGE: MPI FOR PLASMA PHYSICS

PHOTO: PICTURE ALLIANCE / GES / HELGE PRANG

Historic goal: in the quarter-finals of Euro 2016, Jonas Hector scored the decisive goal against Italy in the penalty shoot-out. The German team had previously won the coin toss.

COIN TOSS INFLUENCES OUTCOME OF PENALTY SHOOT-OUTS

Many fans still remember the quarter-finals of the UEFA European Football Championship in 2016. After the match went into extra time, the German team ended up in a penalty shoot-out against Italy. As usual, a coin was tossed to decide which captain would choose who would go first. Bastian Schweinsteiger won the toss for the German team and decided to let the Italian team go first – a move which many commentators saw as a mistake. They are not the only ones who cling stubbornly to the belief that shooting first puts the team at an advantage. Scientifically, however, this theory is not tenable. Studies have shown that the teams who shoot first only win the match about 51 percent of the time. However, a study by Matthias Sutter, Director of the Max Planck Institute for Research on Collective Goods in Bonn, and three colleagues in Duesseldorf found that the result of the coin toss did make a difference. Some 60 percent of the teams whose captains won the toss went on to win the penalty shoot-out. This is what happened in the Euro quarter-finals in 2016, which the German team ended up winning with a score of six to five.

www.mpg.de/17126111

MEMORY OF THE CORONAVIRUS

Some people have immunological memory cells that recognize the novel coronavirus SARS-CoV-2, even if they have never been in contact with it. At some point in the past, these so-called T helper cells must have had to tackle the more harmless coronaviruses that cause the common cold. A team from the Charité hospital in Berlin and the Max Planck Institute for Molecular Genetics analyzed the immune systems of almost 800 people who had previously had no contact with SARS-CoV-2. They found that the T helper cells originally produced by the body to tackle the coronaviruses that cause the common cold are also mobilized against SARS-CoV-2, thus forming a kind of cross-immunity. When faced with the more innocuous common cold, the immune system accordingly develops a kind of universal memory for all coronaviruses. This does not offer absolute protection from SARS-CoV-2, but having previously had a cold caused by coronaviruses could have a positive impact on how the disease progresses. This cross-immunity can also accelerate the effect of vaccinations: while normal T helper cells are activated step by step over a period of two weeks, cross-reactive T helper cells reacted to immunization with the Pfizer-BioNTech vaccine within just one week. However, the researchers also found that this cross-immunity declines later in life.

www.mpg.de/17434954

DON'T FORGET TO TAKE BREAKS

Things we learn quickly are often soon forgotten. The same applies to mice: in an experiment conducted at the Max Planck Institute of Neurobiology, the rodents were required to memorize the location of a piece of chocolate hidden in a maze. The mice had to take breaks of varying lengths between learning phases. The animals that were given longer breaks were not able to memorize the location of the chocolate as quickly, but they did remember it for longer periods. During the test, the researchers measured the activity of neurons in the prefrontal cortex, a part of the brain involved in complex thinking tasks. The activation pattern in this part of the brain fluctuated more after short breaks than after long ones. It appears that different neurons are activated for the task if the pauses are short. After longer pauses, however, the animals again used the neurons activated in the first learning phase. Our memory may therefore benefit from the fact that connections formed between cells are strengthened after longer breaks. ***www.mpg.de/17302943***

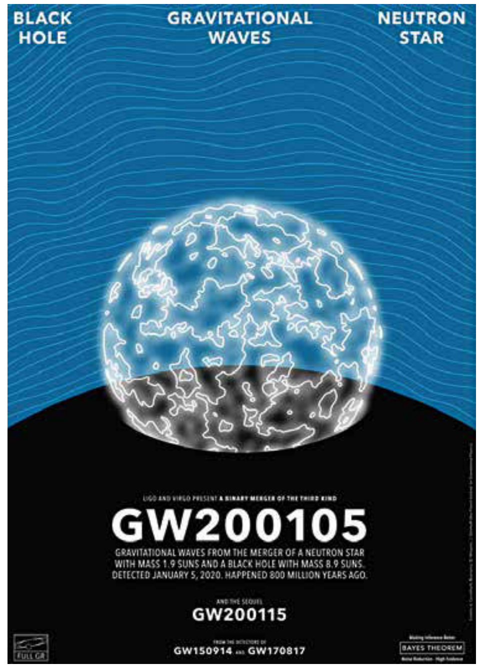

IMAGE: A. S. CARVALHO/A. BUONANNO, D. MIHAYLOV, J. STEINHOFF (MPI FOR GRAVITATIONAL PHYSICS)

Collisions in space: an artist's impression in the style of a movie poster depicting a black hole swallowing a neutron star. The image shows the gravitational wave events GW200105 and GW200115 – the first robust evidence of black holes merging with neutron stars.

FEAST FOR BLACK HOLES

Two cosmic disasters have occurred in quick succession more than 900 million light years away from Earth. Two black holes each engulfed a neutron star within a period of ten days – with no apparent connection between the two events. The gravitation waves emitted during these events were picked up by the LIGO and Virgo detectors. These signals are the first robust evidence of a black hole merging with a neutron star. The black holes swallowed the neutron stars in one piece. These events have allowed researchers to draw initial conclusions about how these rare binary systems form and how often they merge. "The gravitation waves come from black holes of nine and six solar masses that merged with two lighter objects of 1.9 and 1.5 solar masses respectively," says Alessandra Buonanno, Director of the Max Planck Institute for Gravitational Physics, whose Institute was involved in the discovery and analysis of the events. The signals, named GW200105 and GW200115, were observed on January 5th and 15th respectively. ***www.mpg.de/16791771***

REDUCING THE CLIMATE IMPACT OF CONDENSATION TRAILS

The condensation trails (contrails) produced by aircraft have an even greater impact on global warming than their CO_2 emissions. This is because the ice crystals inside the contrails can form cirrus clouds at altitudes of about eight to twelve kilometers that have a greenhouse effect similar to that of CO_2. This climate impact can be reduced by using sustainable fuels. These are obtained either from plants or from CO_2 and hydrogen; they not only have a significantly better carbon footprint, but also release fewer of the soot particles on which the ice can crystallize. This means that the contrails produced by aircraft that run on a one-to-one mixture of ordinary jet fuel (kerosene) and sustainable fuel only contain half as many ice crystals as those emitted by aircraft running solely on fossil jet fuel. This discovery was made by an international team of researchers from the Max Planck Institute for Chemistry in Mainz, the German Aerospace Center, and NASA. Although the ice crystals formed are larger, their smaller numbers reduce the warming effect of contrails by 20 to 30 percent. The results prove that sustainable fuels can significantly reduce the impact of aviation on climate change in the short term.

www.mpg.de/03202103en

LIFE ON VENUS? NOT A TRACE!

Venus is not a pleasant place to live. The surface is exposed to high pressure and temperatures of around 460 degrees Celsius, while violent storms rage in the dense cloud cover, which contains large quantities of caustic sulfuric acid. Could bacteria nevertheless have adapted to these extreme conditions and be surviving there? Researchers from Cardiff University in Wales believe that this is the case. They claim to have discovered tiny quantities of the trace gas phosphine in data from Venus's atmosphere received by terrestrial telescopes one year ago. This finding has sparked heated debate among experts, since the British group believes that bacteria are the most likely source of the phosphine. An international team of researchers, including Paul Hartogh from the Max Planck Institute for Solar System Research, has now reviewed the original data once again – and found absolutely no indication of phosphine. Instead, the analysis revealed that sulfur dioxide, which occurs in large quantities in Venus's atmosphere, could have been mistaken for the rare gas. This is because, under the conditions on Venus, the wavelengths of certain molecules are very close together, which makes it extremely difficult to identify their fingerprints in the spectrum.

www.mpg.de/17209676

PHOTO: NASA/JPL-CALTECH

Not a haven of life: dense clouds surround Venus at an altitude of approx. 50 to 70 kilometers. There appears to be no phosphine in the atmosphere.

PHOTO: XBLICKWINKEL/AGAMI/R.MARTIN

During their fall migration, oriental honey buzzards fly more than 700 kilometers from Japan to southeast Asia. The birds wait for optimal weather and wind conditions before embarking on this 18-hour flight across the East China Sea. Using uplift enables them to soar up to one thousand meters above the sea's surface.

TAIL WIND

Flying over the open sea can be dangerous for land birds, since they cannot land on water – unlike seagulls or albatrosses, which have adjusted to life on the ocean. This means they have to cross the ocean nonstop. However, larger species in particular are unable to rely on muscular strength alone to carry them for long distances without rest. Researchers at the Max Planck Institute of Animal Behavior have been using GPS technology to track various species of buzzard, hawk, and eagle on more than one hundred long-distance flights across the open ocean, linking their flight trajectories with global atmospheric data. The results show that the raptors take advantage of rising air masses above the water. These thermals help them conserve their energy and enable them to cover long distances nonstop. Researchers had already discovered that birds take account of wind direction when they are migrating and let the tailwinds carry them across the sea. This indicates that migratory birds only fly over large expanses of ocean if the tailwind and uplift conditions are favorable. This enables them to cover hundreds of kilometers above the open ocean.

www.mpg.de/17436480

LESS THAN PITCH-PERFECT

How good are professional singers at producing each note at exactly the right pitch? And how do they rate their own performance? This was the subject of a study by a team of researchers from the Max Planck Institute for Empirical Aesthetics in Frankfurt, New York University, and the University of Hamburg. A number of professional sopranos each recorded a vocal rendition of Happy Birthday in the studio. Afterwards, they evaluated their own recordings and those of their colleagues. Pitch accuracy – the ability to produce precisely pitched notes – was used as an objective measure of musical quality. Most of the participants were surprisingly inaccurate when judging their own performances, rating them too highly. However, the most proficient singers also turned out to have the most realistic opinion of their own singing. This indicates that the ability to evaluate one's own performance is a prerequisite for developing outstanding musical skills.

www.mpg.de/03202104en

ILLUSTRATION: ISTOCKPHOTO/DUNCAN1890

Striking the right note? A study revealed that mediocre professional singers often overestimate their own performance.

TAKING THE BRAIN FOR A WALK

On average, adults spend 80 to 90 percent of the day indoors – a very recent development in human evolution. This behavior is probably not particularly healthy. It has been proven that spending time outdoors has a beneficial effect on our health. Our brain structure also benefits from time spent outside, as a study performed by the Max Planck Institute for Human Development and the Hamburg-Eppendorf University Clinic now shows. This applies even if the periods spent outdoors are very brief – and regardless of whether we are in the city or the country. The results of the study show that the time which participants spent outdoors had a positive effect on the gray matter in a specific part of the cerebral cortex. This part of the cortex is involved in the planning and regulation of actions as well as behavioral control. Moreover, many psychiatric disorders are known to be associated with a reduction in the gray matter in this area of the brain.

www.mpg.de/17198632

PRECAUTIONARY MEASURES COME FIRST

Trees manage their resources differently than previously assumed. This is because they continue forming energy-rich carbon compounds even during periods of starvation, for example, during long dry spells; these compounds then serve as reserves for even worse times. To do this, the trees stop growing and, in extreme cases, may even digest their own energy-rich components. This way, the trees avoid using up all their reserves, since this would put them at risk of starving to death in the worst case, or render them incapable of mobilizing the energy they need to fight off pests. Until now, biological research assumed that plants only build reserves when sufficient photosynthetic products are available and their growth requirements are covered. This new knowledge can now be used to improve models that predict how forests will develop as climate change progresses.

www.mpg.de/03202105en

PHOTO: MARTIN SIEPMANN/IMAGEBROKER/FOTOFINDER.COM

Thirst means death from starvation: during periods of drought, trees like these spruces in Upper Bavaria cannot produce sufficient carbohydrates. They then have to draw on reserves stored in advance.

FORESTRY NEEDS NEW ROOTS

Climate change is devastating forests in Germany and other European regions. Our traditional understanding of which tree species can withstand heat and drought no longer holds true, which is why ecophysiologist Henrik Hartmann is calling for the creation of an interdisciplinary Institute for Forest Conversion. This new institute would provide scientific insights into how forests can be constituted to be able to withstand ongoing global warming.

Forests are not looking healthy. Several times over the past few years we have flown drones over forests around Jena to document the changes. What the footage reveals is shocking. Many of them are dotted with dead and dying trees. Trees have sparse crowns, with dry branches sticking out where lush green existed just a few years ago. The color of the treetops is also concerning; as early as August, the appearance of many trees resembles what you would normally expect to see in late September, when the leaves gradually take on the hues familiar in fall. These observations exemplify a more general development: climate change is threatening the long-term sustainability of agriculture and forestry in Germany and Central Europe. Many ecosystems are already under threat in their current form, and prospects for the coming decades are also bleak. The extreme summers of 2018 and 2019 left devastation in their wake, particularly in forests, several hundred thousand hectares of which were destroyed. In many cases, these were spruce monocultures ravaged by the bark beetle, but the spruce was not the only species affected. Many deciduous and pine trees, which had previously been considered to be relatively drought-resistant, also suffered severely. The die-off rates of various tree species have increased exponentially since 2017. The resilience of German forests to climate change has also been a matter of public debate, at

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VIEW POINT

HENRIK HARTMANN

ILLUSTRATION: SOPHIE KETTERER FOR MPG

Henrik Hartmann studied forestry and biology at the Canadian universities of New Brunswick and Quebec, where he also earned his PhD. He has been the Head of a Research Group at the Max Planck Institute for Biogeochemistry in Jena since 2014. The group conducts research into such questions as how trees react to drought stress and how they deal with resource scarcity more generally. It also investigates how trees control the storage of nutrients, particularly carbon and nitrogen. Hartmann is extremely concerned about the condition of German forests, which is why he is keen to bring together experts from the fields of forest science, forestry, and biology as well as from the social sciences with a view to equipping forests to deal with climate change.

least since the summer of 2018, and the topic of Waldsterben, or forest dieback, is discussed almost daily in newspapers and on the radio and TV. It is also often the subject of controversial public debate.

Long before the general public took an interest in forests, forestry researchers were studying the question of whether or to what extent some of our native tree species would be able to cope with the climatic conditions of the future. In 2004, for example, one group at the University of Freiburg led by Heinz Renneberg looked into whether beech would be a suitable species for future silviculture when climate change intensifies. The study found that the "species, which is sensitive to drought stress and flooding" is already suffering significantly from "reduced growth and competitive vigor," a trend "that will continue and probably worsen over the coming decades." The article triggered a whole series of responses from other scientists, who, as late as 2016, insisted that beech could continue to be one of the predominant species in Germany's forests even in the face of progressive climate change. This was in spite of the fact that it had become clear by then that when a beech tree sheds its leaves during a drought, it is not a protective mechanism against drought stress, but is due to the consequential damage the tree has suffered. So, rather than "allowing" its leaves to wilt to reduce the total surface area of the leaves and thus evaporation, the leaves wilt because their water supply has been cut off. The events of 2018 and 2019 also showed that the beech not only responds to climate change with reduced growth and competitive vigor – as predicted by Renneberg and his co-authors – but that it also suffers severe damage, often even dying off, which few would have thought possible just a few years ago. Similar concerns apply equally to other tree species, particularly in the face of progressive climate change. Maple, ash, pine and other species are similarly affected, and it is currently entirely impossible to predict the climatic conditions under which previously robust species, such as the oak, will reach their stress limits.

NEITHER FOREST MANAGERS NOR FOREST SCIENTISTS CAN CONTINUE AS THEY HAVE DONE FOR CENTURIES

In light of the ongoing climate change, neither the forestry industry nor forestry science can continue as they have done for centuries, because it is no longer possible to use past experience to plan for the future. As the example of the beech demonstrates, previous findings collected under different climatic conditions can only be projected onto the expected climatic developments to a limited extent. This retrospective approach also completely misses the mark in public discourse about the future viability of forestry, which is often profoundly influenced by self-appointed experts and armchair foresters. For example, there is no scientific basis for calling for a greater role for the much-exalted, species-rich, mixed deciduous forest as the resilient forest of the future – as the die-off rates of many deciduous species clearly demonstrate. A recently released analysis of forest inventory datasets from the U.S. and Canada shows, for example, that tree mortality rates in temperate forests rise with increasing species diversity, especially under extreme climatic conditions. Obviously, this finding cannot and should not be used as an argument in favor of the expansion of monocultures, but it does raise serious doubts about simplistic approaches, which may seem sound and obvious at first (who would intuitively call the benefits of diversity into question?), but which are based on emotions, rather than empirical science.

IT IS THE TALLER AND OLDER TREES IN PARTICULAR THAT SUFFER THE MOST UNDER DROUGHT CONDITIONS

The same applies to *Wenn Wälder wieder wachsen: Eine Waldvision für Klima, Mensch und Natur* (When forests grow again: envisioning forests for the climate, humankind and nature), a study commissioned by Greenpeace e. V. and published in 2018, which is touted as a guide to forest management for the coming decades. It states that trees should only be harvested “when they are older and thicker,” and that interventions in the forest should be “less frequent and less severe” with a view to almost tripling the number of thick trees compared to the numbers achieved under conventional forest management systems. The positively idyllic image of “a colorful array of tall and short, thick and thin trees standing side by side” that this study evokes is emotionally appealing, but it is no substitute for a scientific basis for the sustainability of older forests as suggested in the study, because the opposite has been proven to be true. It is the taller and older trees in particular that suffer the most under drought conditions, and we can even expect forests to become generally younger and smaller under future climatic conditions, as the taller and older trees suffer greater exposure to the stresses and upheavals associated with climate change and become subject to a greater die-off rate.

Clearly, the debate about the future of the forest must encompass a broad range of opinions and views, but we should not allow emotionally appealing but misleading and scientifically questionable reports to dominate dis-

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cussions. But unfortunately it is precisely this type of report that often has a significant impact on public perception.

A future-oriented forestry strategy must be based on empirical evidence and facts rather than on beliefs and wishful thinking. The requisite knowledge can only be obtained by conducting a systematic survey of what actually takes place in the forest. This data can then be used to correct and augment previous site-specific and phytosociological positions. For example, die-off rates can provide important information, particularly if the data can be used to identify precisely which tree species are acutely affected and where they are located. However, we still lack a comprehensive and detailed overview of how climatic trends are affecting die-off rates at different sites. Numerous surveys of forest conditions have been carried out, from the federal forest inventory to state surveys, to an annually recurrent survey carried out as part of the International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests (or ICP Forests for short). But none of them provides the spatial and temporal resolution that would be needed to establish causal relationships between developments at specific sites and climatic events. Survey data is also usually kept in archives that are not openly accessible, which hinders any decentralized analysis by the scientific community.

THERE IS NO LEGAL FRAMEWORK FOR THE AGGREGATION OF DATA WITHIN AN OPEN INFRASTRUCTURE

In recent years, remotely-sensed time series (such as satellite data) have been used more frequently to monitor forest vitality, because they provide a high temporal resolution (a few days to weeks). However, the spatial resolution does not usually enable an evaluation of forest damage at the individual tree level. There is, therefore, a temporal and spatial resolution gap between local and remote monitoring. As such, it is not possible to draw conclusions about climate-related forest damage at the regional level, which in turn makes it difficult to expand our knowledge at the site-specific phytosociological level. One way to close this gap would be to systematically merge the various data sets, using the data recorded in the forest to better evaluate remote sensing data and to contribute to a near real-time monitoring of forest vitality. However, the necessary legal framework does not exist that would provide for the systematic aggregation of data within an openly accessible infrastructure, which would then enable or even oblige the responsible institutions to provide access to their data. For this reason legislators ought to specifically promote the idea of data sharing and demand its implementation. Any turf wars between institutions must also be stopped, as these disputes often stand in the way of data sharing.

Furthermore, existing synergies between the various federal and state institutions and academic experts (chairs, research institutes, scientific networks, etc.) who have an interest in evaluating the data should be promoted through the coordination of their research agendas. Collaborations between the disciplines that are important for forest restructuring should also be intensified. Germany's scientific community has an enormous amount of expertise in these disciplines (which include vegetation modeling, forest ecology and ecophysiology, as well as economics and the social sciences), but there is also a lot of fragmentation. Bringing all of this expertise together in a (virtual) Institute for Forest Conversion would counteract this problem and make it possible to exploit the many existing synergies. Then, in addition to monitoring the forests in real time, research topics that are relevant in this context would have to be identified and a much greater emphasis placed on the use of modeling in forest planning. The empirical models that have been used up until now, which forecast future changes in forests on the basis of past trends, are of limited use when it comes to extrapolating from the data to make predictions into a climatically uncertain future. Mechanistic models, which comprise the fundamental processes that occur in trees, also need more data concerning the physiological properties and adaptive abilities of our native tree species. This data could be obtained through intensive forest monitoring programs, but also through experiments both in the forest and in the greenhouse.

AN INTERDISCIPLINARY INSTITUTE FOR PLANNING THE FOREST OF THE FUTURE

An interdisciplinary institute of this type would provide the best conditions for planning the future direction of forestry research and forest management. Interconnecting state research agencies, forestry practitioners, fundamental research, and forestry policy would provide a holistic understanding of the forest as a system, forming a basis for future-oriented forestry. To define society's demands on forests, but also the needs of the forests themselves, various interest groups, such as conservation initiatives or hunting associations, should also be involved in forest policy planning. Thus, such an approach to forest management and forest science of the future should be characterized by complexity and diversity – like the forest itself.

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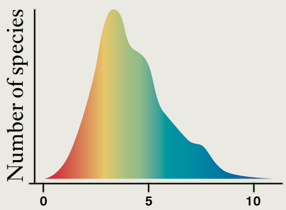
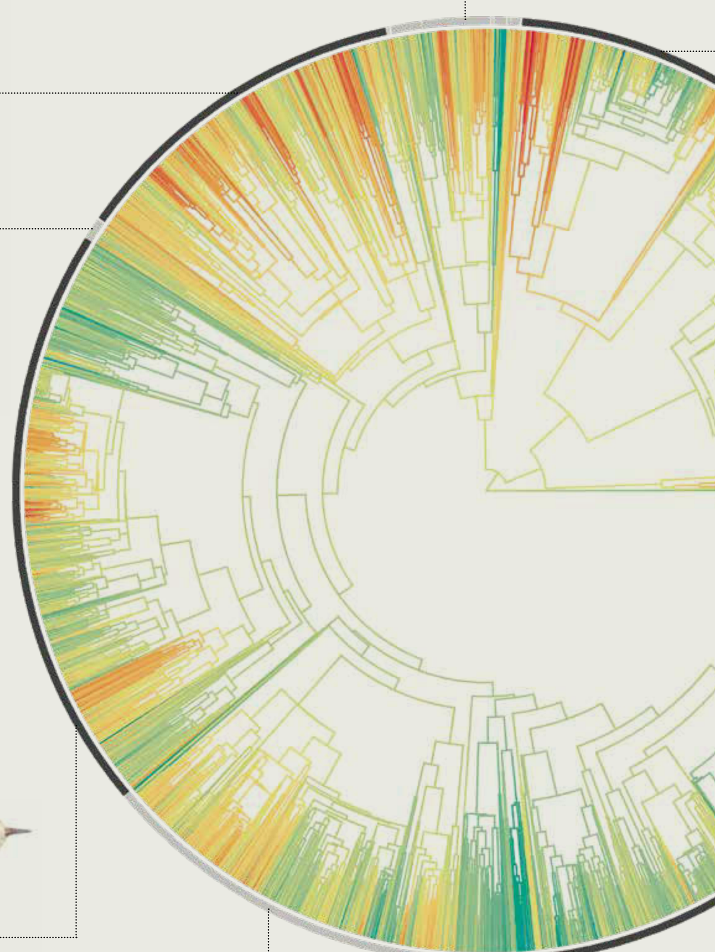
MYRIAD VOICES IN THE AVIAN CHOIR

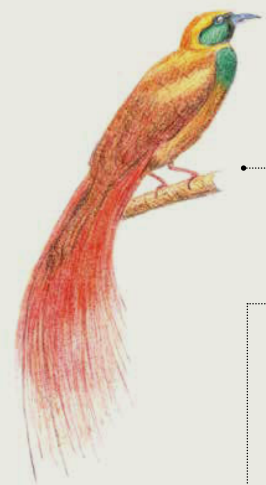
There are as many different bird songs as there are bird species. In this circular family tree of songbirds (Passeriformes), those species with low voices are highlighted in red, and those with high voices in blue. The distribution of the colors reveals that neighboring – i.e., closely related – species within the family tree often have similar voice pitches. The pitch at which a particular bird sings is therefore largely determined by its ancestors' vocal pitch. (Each of the birds depicted represents one of ten groups within the Passeriformes order.)



Maximum pitches of songbirds in kilohertz (kHz). (average: ca. 4 kHz)



Superb lyrebird
Australia
103 cm



Raggiana bird-of-paradise
Papua New Guinea
34 cm

Rail-babbler
Southeast Asia
29 cm

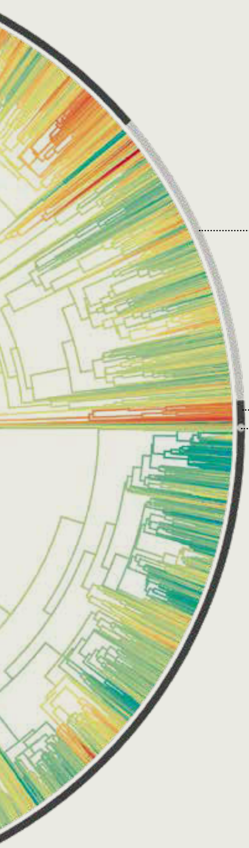
Rattling cisticola
Africa
14 cm

American robin
North America
25 cm

Cape May warbler
North America
13 cm

DIFFERENT ACOUSTICS

A blackbird in a forest can hear the song of another blackbird from over twice the distance as in the city, where the noise level is higher.



Red-billed scythebill
South America
25 cm

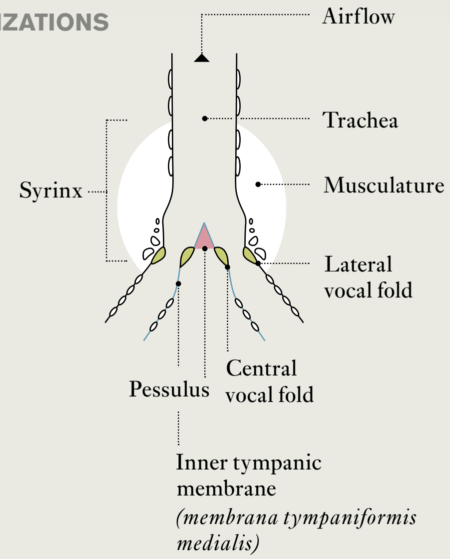
Long-wattled umbrellabird
South America
41 cm

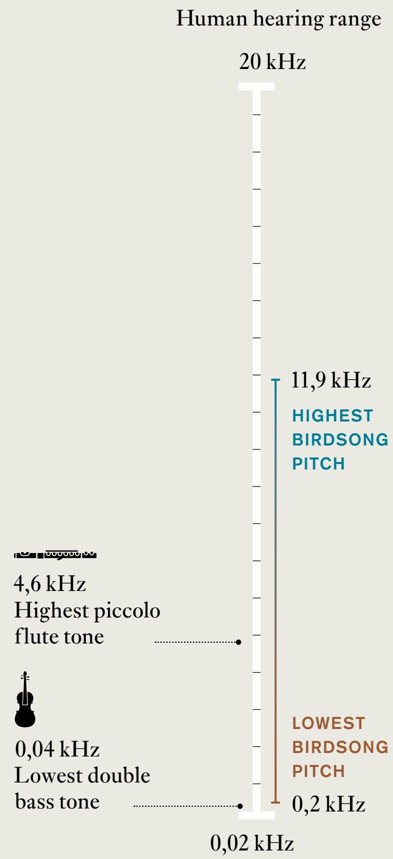
Grey-headed broadbill
Africa
17 cm

New Zealand rock wren
New Zealand
10 cm

POLYPHONIC VOCALIZATIONS

To produce their songs, songbirds use the so-called syrinx, which is located at the fork of the trachea. The syrinx can produce a different sound in each of the two bronchi, so birds can produce two sounds simultaneously or switch rapidly from one to the other.

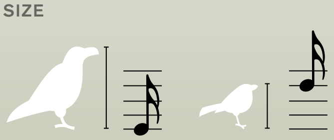




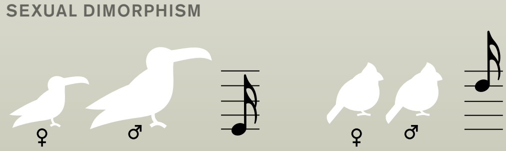
Golden-winged manakin
South America

Bare-necked Umbrella Bird
Central America

SIZE



SEXUAL DIMORPHISM



OTHER INFLUENCES

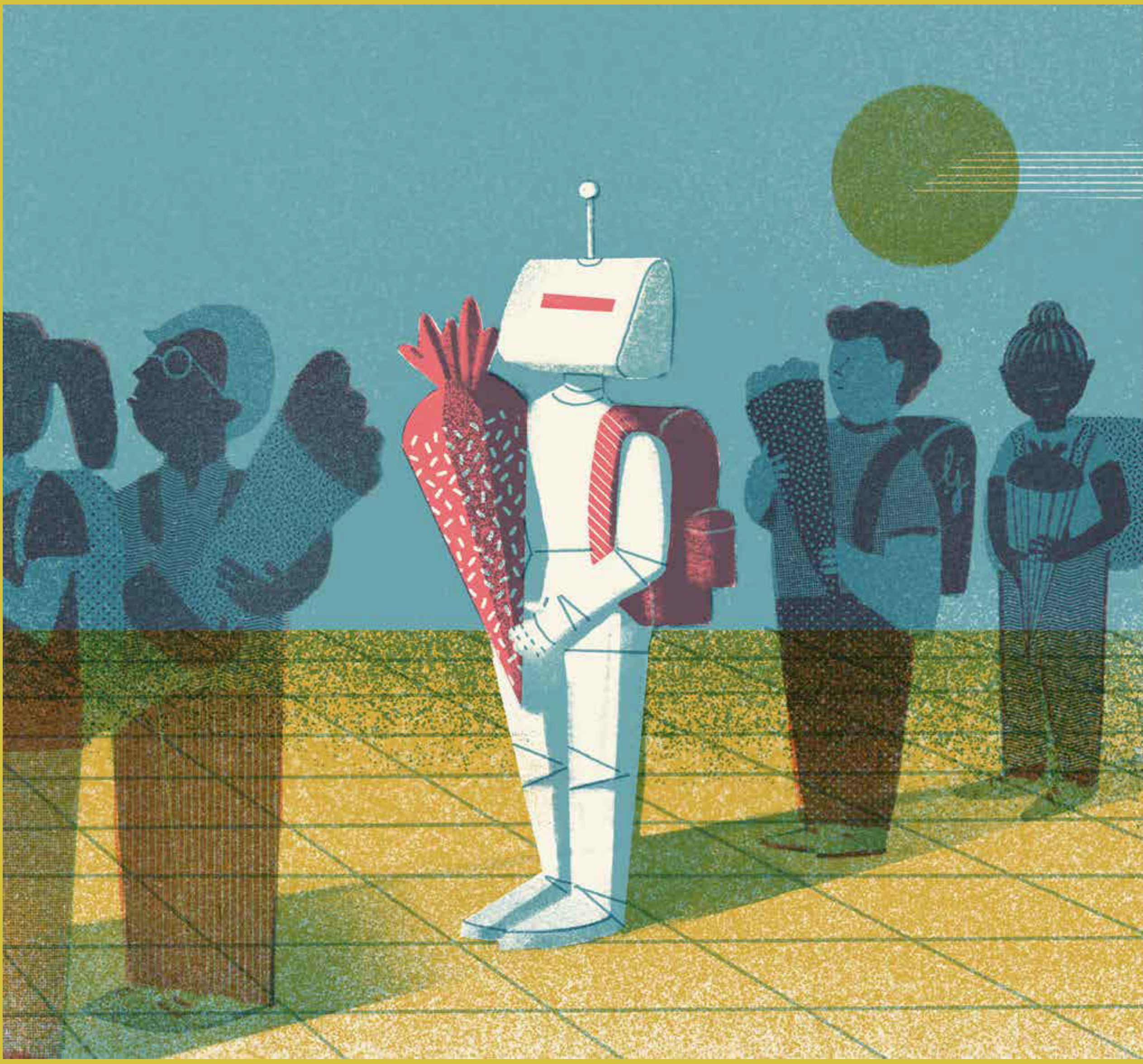
In addition to evolutionary history, the song pitch of a given bird species also depends to a large extent on its size, and therefore on that of its syrinx. The size difference between males and females also affects the maximum pitch.

GRAPHIC: GCO BASED ON MIKULA ET AL., ECOLOGY LETTERS 2020

FOCUS

ARTIFICIAL INTELLIGENCE IS LEARNING

ILLUSTRATION: LUISA JUNG FOR MPG



Learning like a human: in the future, systems using AI will not only recognize patterns in large volumes of data but also make it possible to understand the criteria they use to make their decisions.

NOT WITHOUT A REASON

TEXT: THOMAS BRANDSTETTER

Artificial intelligence (AI) has long been able to recognize patterns much better than humans can. However, in order to truly be worthy of its name, it would also need to understand causal relationships. And that is precisely what researchers at the Max Planck Institute for Intelligent Systems in Tuebingen are working on.

Cause and effect are everywhere. But that asymmetrical pairing isn't always as easy to spot as in the domino effect in which one piece knocks over the next. Human decisions often have highly complex causes – and sometimes even more complex consequences. Sometimes things mutually influence each other. For example, our CO_2 emissions warm the Earth and the thawing permafrost releases even more greenhouse gas. And when you look at an idyllic landscape photo, you can usually see shadows caused by the light of the Sun.

While we humans usually recognize causal relationships intuitively thanks to our brains, they still present considerable difficulties for intelligent machines. Machines may outperform us in finding patterns and correlations. However, the concept of cause and effect generally still eludes them. Researchers at the Department of Empirical Inference at the Max Planck Institute for Intelligent Systems see this shortcoming as a challenge. Led by Bernhard Schölkopf, they are trying to impart a sense of causality to learning machines in areas as diverse as the search for exoplanets, climate change, and the granting of loans.

Experiments bring understanding

One starting point for their work is the quality of the data available. Most Big Data sets arise from purely passive observation and contain no additional information about how they were created. For example, account transactions that include only the monetary amounts and the associated times say nothing about why the payments were made. "If a system can only passively collect data, that's generally not enough to detect a causal relationship," explains Julius von Kügelgen, who is working on his dissertation in the Department of Empirical Inference. "Unfortunately, however, 99 percent of the data available today is only passively collected – or at least treated that way when it's analyzed." One example of this is statistical data from which interrelationships such as the correlation between chocolate consumption per capita and the number of Nobel Prizes won by a country can be derived. In this case, the common cause principle applies. This ultimately attributes many such patterns to a causal relationship. Either one variable influences the other, or there is a third variable that causally influences both.

It's easy for a machine to determine the correlation. To do this, the algorithm simply needs to sift through relevant statistics and identify any patterns. However, in order to be able to understand the connection and find a possible explanation, additional information is needed. We humans are usually helped by our general understanding of how the world works. We have eaten chocolate and know that it has no effect on intelligence. And why should winning a Nobel Prize boost chocolate consumption? Our thoughts are thus quickly steered toward a third variable. For example, a strong economic system that leads to prosperity and chocolate on one hand and a good education system on the other. But because a computer algorithm lacks this general understanding, it is inevitably groping in the dark given the sheer amount of data. "What is more interesting is data already collected in experiments in which someone actively intervenes in a system and changes something," says von Kügelgen. For example, close observation quickly reveals a correlation between wet soil and rain. However, an experiment in which the soil is made wet with a garden hose and not by rain debunks the supposed causal relationship.

In his current research, von Kügelgen is dealing with even more difficult cases. He is driven by "what if" questions, specifically: would I have been granted the loan if my income had been higher? "Artificial intelligence is increasingly making decisions for humans. For example, when assessing creditworthiness," says von Kügelgen. "Our system can help people answer the question of what they should do in order to achieve a positive outcome." To do this, he and his colleague Amir Hossein Karimi construct parallel worlds. While these generally bear a strong resemblance to the real world, there are also differences, such as a higher income for a particular person. But because this difference is not real, there is, of course, no experimental data to help answer the "what if" question. Thus, in order to estimate what the parallel world might look like, researchers make assumptions about how the relevant variables that led to the algorithm rejecting the loan relate to each other.

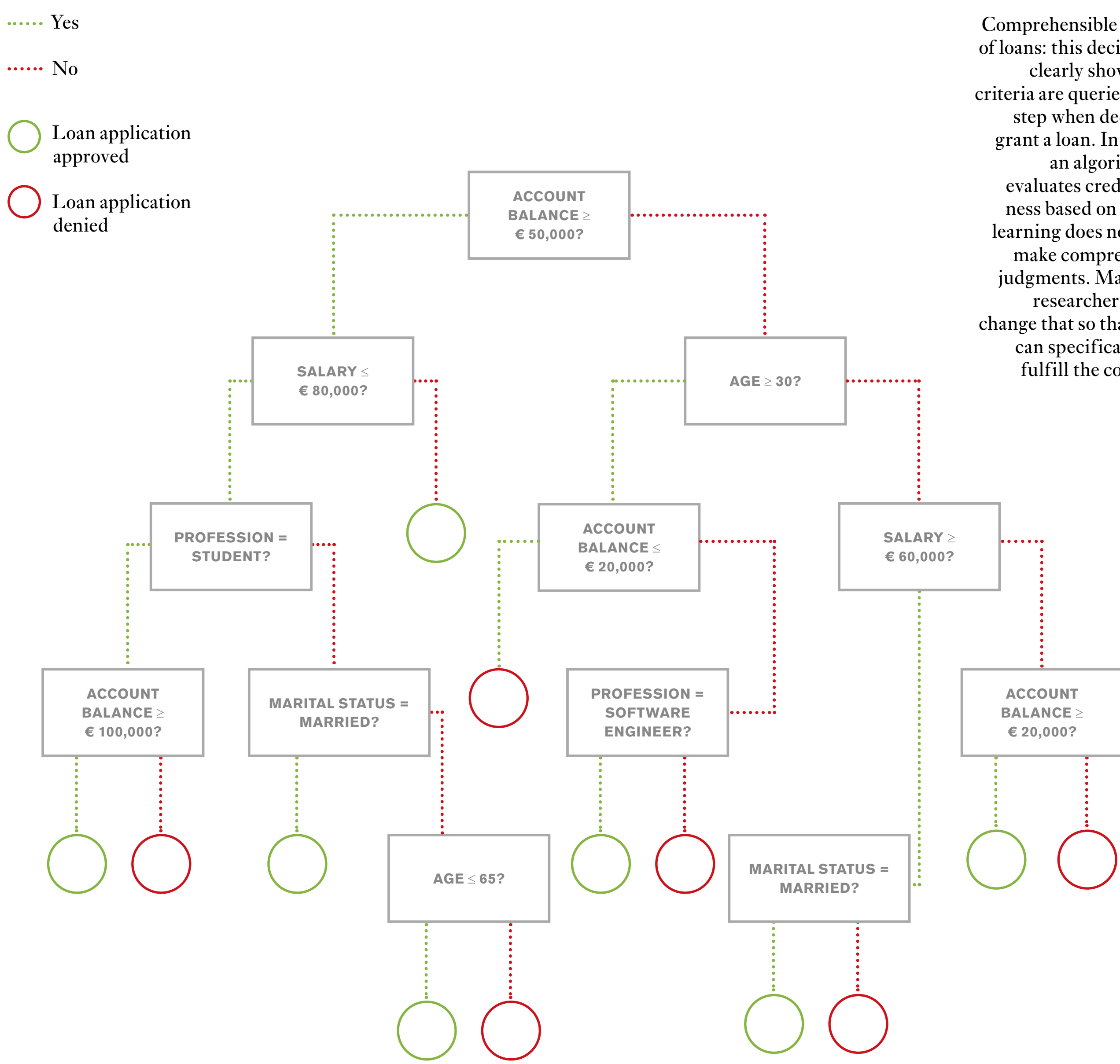
It is usually hard facts such as income, age, and education as well as the amount of the requested loan and its term that decide whether or not a loan should be granted.

SUMMARY

Machine learning algorithms are trained to recognize patterns within large amounts of data, for example in order to infer a disease from physiological parameters. However, they still do not understand cause and effect.

Researchers at the Max Planck Institute for Intelligent Systems want to teach computers to understand causality. Unlike children, algorithms cannot yet learn the corresponding models themselves; they have to be developed by humans for specific applications.

The Max Planck researchers are developing causal models for the comprehensible granting of loans, for the search for exoplanets, or for the climate policy control of an economic system.



Comprehensible granting of loans: this decision tree clearly shows which criteria are queried step by step when deciding to grant a loan. In contrast, an algorithm that evaluates creditworthiness based on machine learning does not always make comprehensible judgments. Max Planck researchers want to change that so that people can specifically try to fulfill the conditions.

GRAPHIC: GCO BASED ON AMIR-HOSSEIN KARIMI/MPI FOR INTELLIGENT SYSTEMS, TUEBINGEN, GERMANY

There are also additional variables that are difficult to measure but which nevertheless influence the decision-making process. Examples of this would be factors such as the cultural background or charisma of the applicant that have crept into the algorithm. These are summarized as statistical noise and must be evaluated. In the causal model thus created, it is then possible to run through the conditions under which a person would be granted the loan. For this purpose, one variable at a time (e.g., income) is changed, while all others remain the same. "After all, everyone should be able to improve their situation by making some personal effort," says von Kügelgen. "But to do that, you first have to know how best to meet certain requirements. And the algorithms used so far can't tell you that."

However, the underlying causal model that describes how the individual factors are interrelated must come from an expert. It won't work without a person who has knowledge of the matter at hand. In the foreseeable future, there seems to be no way around using the expertise of humans to understand causal relationships – even when it comes to machine learning (ML). And our cognitive abilities can naturally serve as a model for the development of intelligent machines. "Our brains have evolved to make us highly cooperative and socially interactive animals," says Martin Butz, who leads the Cognitive Modeling group at the University of Tuebingen. "This requires extremely flexible behavior in different situations." That's why we also have an internal model structure that tells us how things interact

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with each other in our environment, what the causal principle behind the interrelationships is, and what intentions drive our fellow humans. Humans would not be able to do this if we were purely reactive robots that merely recognize patterns and are driven by the prospect of rewards.

Artificial intelligence systems such as Alpha Zero, a program that taught itself to play chess in 2017, prove that with enough training time and computing power, even a reactive system can learn complex behavior. However, when compared with the real world with all its complexities, mastering the rules of a game with 32 figures on 64 fields is quite feasible. And although Alpha Zero may play better than a human, the program did not understand the game. It is therefore unable to explain to someone how to play chess. "In contrast, our brain is constantly trying to explain relationships," says Butz. Even young children intuitively understand the causal relationships of social situations. For example, developmental psychology experiments show them rushing to help an adult who is carrying a stack of books to open a door. They recognize both the intention of the other to open the door and the cause of the difficulty – the books – which is why the adult has no hands free. In order to react appropriately in such a situation, machines would first have to build their own kind of internal reality that is not simply overwritten whenever they are

For more transparency: Julius von Kügelgen (left) and Amir Hossein Karimi are developing models that make comprehensible lending decisions.

PHOTO: WOLFRAM SCHEIBLE FOR MPG

"Artificial intelligence is increasingly making decisions for humans."

AMIR HOSSEIN KARIMI

fed new data. Thus, in a way, the machines would have to form a consistent understanding of the world – in the same way that that understanding forms the basis of human perceptions. "We're still a long way from achieving that," says Butz. "On the other hand, there is also no evidence of any barrier that could prevent artificial systems from eventually reaching – or even surpassing – human cognition."

Not only social interaction and other temporal processes are characterized by cause and effect; even purely static representations – for example, photographs – have numerous causal relationships. They are in the mechanisms that make up the image, such as the perspective, the light used, and the distinction between the foreground and the background. Only someone who can recognize the connections and separate them from one another can achieve a robust understanding of the content of an image. For humans, it's easy. We can recognize a mug – even when we view it from an unusual perspective or in poor lighting conditions. And unlike machine-learning algorithms, no one had to show us 10 million pictures of mugs when we were children for us to learn what a mug is.

Similar, albeit much less intuitive, relationships also play a role in astronomy, such as in attempts to photograph exoplanets with large telescopes such as the Very Large Telescope (VLT) in Chile. As a rule, celestial bodies cannot be seen in the images that are created of them. Because the stars shine much brighter, the planets orbiting them are almost completely lost in the noise. "It's somewhat comparable to trying to photograph a firefly on a lighthouse several hundred kilometers away with its spotlight shining directly into the lens," explains Timothy Gebhard. To solve this problem, he is working in the Department of Empirical Inference to create an algorithm that takes advantage of causal relationships to elicit images of exoplanets from the images of the VLT.

In order to collect as much data as possible, astronomers focus their telescopes on a star which they suspect is in the vicinity of a planet. They then record a video over the course of several hours. At first, only a flickering around the star can be seen. This is caused mainly by turbulence in the Earth's atmosphere. Gebhard's task is to combine the thousands of images in the video in such a way that a single image in which the planet can be seen as clearly as possible is created. "Fortunately, in the field of physics, we have a good understanding of the causal relationships of the measurement process," says Gebhard. The telescope's sensor essentially counts individual particles of light. These can come either from the planet itself or from the star. Then comes the noise from the atmosphere and the measurement electronics. In addition, the planet travels in a circular orbit around its star as the video is recorded. Each pixel thus contains photons that can have different causes. "We try to use our causal knowledge of how the data is created to extract details from the recordings that are hidden within the noise," says Gebhard. Here too, the human brain ultimately helps the artificial system to recognize causalities.

"Thinking about cause and effect always ends up being the human's job," says Rüdiger Pryss, professor of medical informatics at the Institute for Clinical Epidemiology and Biometry at the University of Wuerzburg, Germany. In medicine, the goal is often to find patterns in patient data in order to divide patients into groups for which specific therapies can be found. However, if this is done using standard machine

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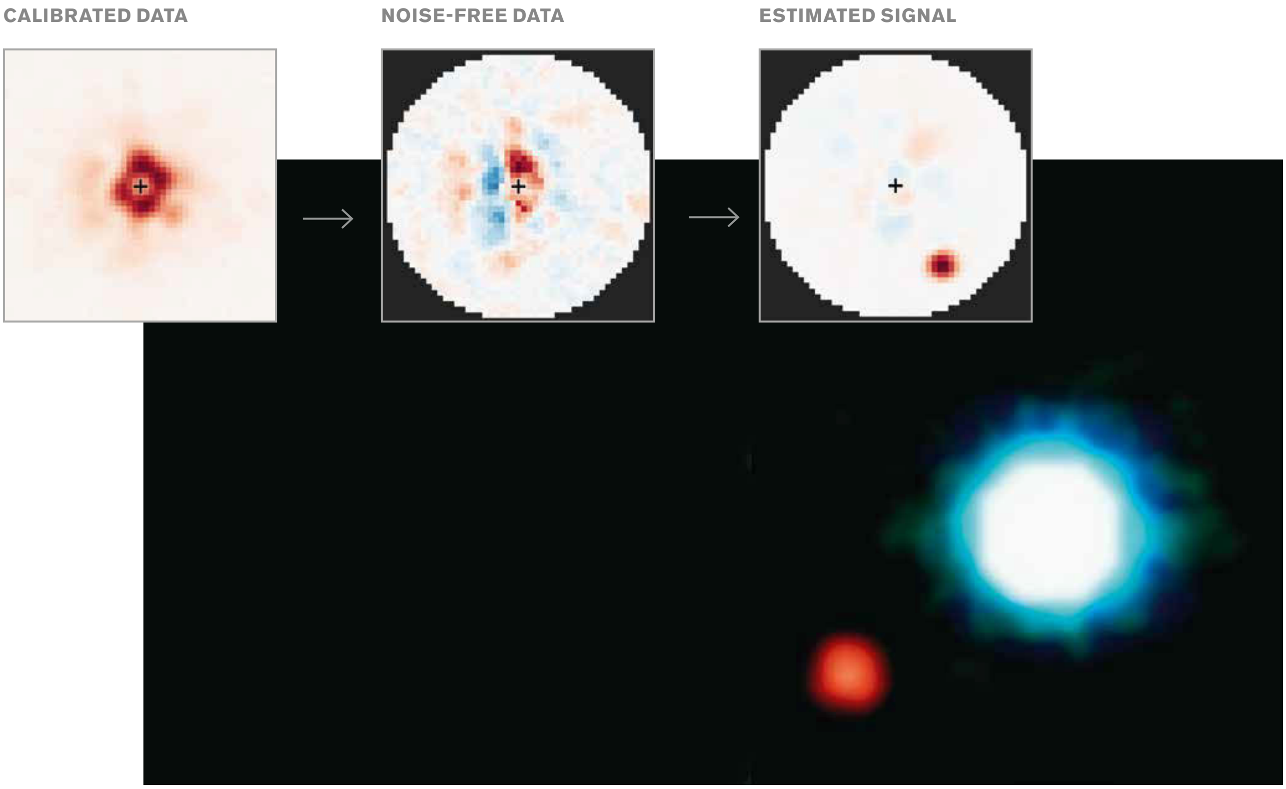


GRAPHIC: ESO; GCO BASED ON TIMOTHY GEBHARD/
MPI FOR INTELLIGENT SYSTEMS, TUEBINGEN, GERMANY

Flashlight in front of a lighthouse: in order to identify an exoplanet next to a star, an algorithm learns to remove its bright light from the data. As a result, previously hidden structures become visible in the data with reduced noise. When the algorithm combines many such images – while also taking into account that the planet is moving in the data because of the Earth's rotation – the signal from the planet clearly emerges.

learning methods, the question of why a patient ended up in a particular group often remains unanswered. The machines cannot explain the reasons for their decisions. Also the medical professional gets too few points of reference to understand them. However, especially in medicine, it is essential to involve humans at the right point in the process. Only humans can make sense of the results of the algorithms and must ultimately be responsible for the therapeutic approaches derived from them. Medical informatics specialist Rüdiger Pryss thus warns against wanting to tackle every problem with ML. "There are extremely powerful statistical methods that have been tried and tested for a long time, and they are often better suited to a specific application system," he explains. Some of these are so clear that they make the cause-and-effect problem less likely to arise. However, because of the current artificial intelligence hype, many users are allowing themselves to be persuaded to put their trust in machine learning.

A healthy skepticism about machine learning as a supposed panacea is therefore certainly in order. Nevertheless, it would obviously be negligent to completely forgo its benefits, especially when it comes to perhaps the most pressing problem of our time: climate change. In order to be able to take causal relationships into account here as well, Michel Besserve of the Department of Empirical Inference is developing an algorithm that can automatically predict the effects of interventions in the global economic system. It should help politicians to find the optimal strategy that minimizes greenhouse gas emissions yet costs as few jobs as possible. "The big challenge here is that our economic system has complex interactions between a large number of actors with differing interests," says Besserve. In the process, each actor adapts their actions to those of the others. Therefore, if we want to describe the economy as a causal model, cycles occur in which individual factors influence each other in a reciprocal manner. "Calculating the resulting equilibrium is much more difficult than if causality always points in one particular direction," says Besserve. The underlying causal model comes from the field of economics and describes the dependencies and interactions of up to 50 different sectors – from power generation and metal processing to goods transport to the meat industry, and rice cultivation. This allows the algorithm to calculate the changes in equilibria that occur when the system is interfered with at a particular point. This would allow policymakers to consider more variables in their future deliberations while avoiding unforeseen and undesirable effects of their interventions on the economy.

"Time is running out, and important decisions must be made now," says Besserve. "That's why we aim to make the new tool available as quickly as possible and thus help develop a sustainable economy." As soon as machines are able to deal with the concept of cause and effect, they could also help solve the major problems facing humanity.

www.mpg.de/podcasts/kuenstliche-intelligenz (in German)

KEY CONCEPTS OF ARTIFICIAL INTELLIGENCE

ALGORITHM
Any kind of calculation rule with which computer programs solve a problem step by step.

ARTIFICIAL INTELLIGENCE (AI)
The name given to a non-natural system such as a computer program that mimics human cognitive abilities. Strong AI is defined as a system that, like humans, is capable of learning independently of a specific task. Conversely, weak AI is an algorithm developed specifically for one task.

MACHINE LEARNING (ML)
This is currently by far the most successful and widely followed AI approach in which an algorithm learns to recognize patterns in unknown data with the help of large volumes of training data. Examples include the identification of faces in images or computer-aided diagnoses based on physiological data.

No longer a game: fully autonomous vehicles are already on the road on designated test routes. But according to surveys, only a slight majority of drivers trust them.

ILLUSTRATION: LUISA JUNG FOR MPG

WHEN MACHINES GET INVOLVED

TEXT: RALF GRÖTKER

We are increasingly encountering artificial intelligence (AI) in our everyday lives, from bots in call centers and robotic colleagues on assembly lines, to electronically controlled players in computer games. At the Max Planck Institute for Human Development in Berlin, Iyad Rahwan and his team are investigating how people behave when they interact with intelligent machines and what they expect from their artificial counterparts.

PHOTO: ARNE SATTLER FOR MPG

According to the Duden, "fake news" became an official term in the German language in 2017, about the same time Donald Trump took office as President of the United States. The emergence of fake news is closely linked to the development of AI. For example, artificial intelligence makes it possible to create fake news with a large reach and to spread it en masse via social networks. Does this change the trust we have in media content in general? Does fake news alter our behavior? These are typical research questions for Iyad Rahwan, who has been Director of the newly founded Center for Humans and Machines at the Max Planck Institute for Human Development in Berlin since the end of 2018. Together with his team, he sets out to answer such questions, not with surveys but rather through experiments that aim to find out what effect existing technologies have on people and gain an idea of how innovations that are currently in their infancy might affect us in the future. He sums up the research program of the center in a single sentence: what influence do digital technologies, social media, and artificial intelligence (AI) have on human behavior?

"Just imagine if someone in the early 2000s had an idea of how Facebook and Twitter would evolve and had conducted behavioral experiments in order to anticipate how advancing digital connectivity would affect the spread of misinformation," says Rahwan. "You could have simulated the whole situation we are facing today before it happened." And exactly what experiment does that? In the case of fake news, Rahwan suggests that one option could be to determine how well subjects can recognize when people have been edited out of existing photos. This is child's play with AI techniques and is possible for a large number of images. At the same time, he says experiments could be set up to get an indication of whether the use of AI techniques particularly encourages people to manipulate others through fake news. "Not only because the new technologies make manipulation easier but also because the person using the technology doesn't have to get their own hands dirty."

The methods Rahwan uses are improvised. There is no current scientific discipline that would be able to provide all of the necessary tools. "What we do is largely science fiction research. It's about getting test subjects to imagine situations they haven't yet experienced – and to then make decisions in those situations." The scientists he prefers to work with therefore come from behavioral research fields with an economic orientation – and who therefore have experience with simulations and laboratory experiments – as well as from psychology, computer science, anthropology, and sociology.

One research project that Rahwan is particularly proud of and which has also made him known far beyond professional circles is an experiment entitled Moral Machine. This has been conducted since June 2016 via a freely accessible online platform. Several million people from 233 countries and regions have participated so far. It is presented in science centers and museums worldwide and has been included in numerous textbooks. The experiment presents a dilemma: an auto-

Versatile: Iyad Rahwan studied computer science but is also interested in psychological and philosophical issues. He brings these topics together in the Humans and Machines research area at the Max Planck Institute for Human Development.

mated vehicle is approaching a group of pedestrians and is unable to brake in time. The artificial intelligence (AI) controlling the vehicle can decide only to either hit a wall (harming the car's occupants) or to run over the pedestrians. What should the AI do? Which option should its developers train it to prefer? In the experiment, different scenarios were presented to the subjects. Among other things, the scenarios differed with regard to the number of passengers and pedestrians as well as their ages. The results show that most subjects try to save as many lives as possible with their decisions and that they give preference to saving younger people over older people.

A kind of parable

Why do such findings matter? After all, the scenario presented in the test shows an absolute and extreme situation – and not one that developers of self-driven vehicles are primarily concerned with. In the German legal framework, at least, there is also no provision for autonomously controlled vehicles to weigh up whom they should protect in an emergency and whom they should allow to come to harm if there is no other alternative. As the regulation stipulates, in dangerous situations, the vehicle must simply come to a stop as quickly as possible. Period. "You can also think of the scenario as a kind of parable," says Rahwan as he defends the experiment. "Because, of course, self-driving cars have to be trained and programmed to make decisions. For example, do you let the car drive closer to the center of the road, where it can collide with oncoming vehicles? Or along the side of the road, where there is a risk of it striking a cyclist? Statistically speaking, such rules of conduct influence which groups of people come to harm and which do not." Of course, ethical issues cannot be resolved by people making decisions in a survey or online experiment. "But policymakers and those who formulate the regulations should at least be aware of how ordinary people feel about such issues – in part because they must be prepared to justify their decisions to a public that may disagree with them."

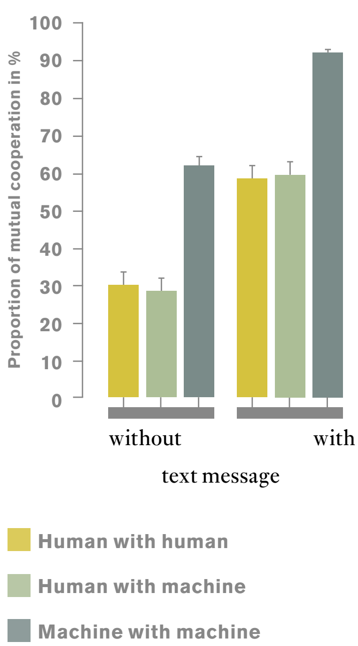
"Of course, self-driving cars have to be trained to make decisions."

IYAD RAHWAN

A prominent feature of Rahwan's research is that he is always reinventing his experiments. Most experiments involve a story that can be interpreted from many perspectives. At the same time, they deliver solid, quantitative results. How does he come up with such research designs? "The important thing is to allow yourself to keep an open mind and not always immediately think about whether or to what extent the appropriate methods can be used to study the question. You really have to seek out the most interesting question," says Rahwan. What also helps is being able to see the bigger picture. "I read a lot of popular science books. These often give me ideas for my own work. For example, my project on cooperation between humans and machines was inspired mostly by nonfiction books that dealt with cooperation between humans." According to Rahwan, popular science books not only help to make scientific content known to a wider audience. They also help scientists to work in an interdisciplinary way. "When I'm delving into an unfamiliar field, it's difficult for me to find exactly what I need among the countless articles from professional journals. In popular science books, which are designed for a broader readership, a kind of selection has already taken place."

In the project on cooperation between humans and machines, mentioned above, Rahwan tested how AIs can work together – with each other and with humans. "There's a lot of discussion about whether computers can replace humans. And most tests that investigate the potential of AI involve games like chess or Go, where there is always a winner and a loser. But the interactions that take place in reality look different." The researchers studied cooperation between machines and humans or with each other, using cooperation games from game theory. The best-known cooperation game is Prisoner's Dilemma, in which two players must decide whether to betray each other when questioned separately as witnesses. If one player betrays the other, that player gains the greatest advantage as long as the other remains silent. If they both stick together and say nothing, they still have a better outcome than if they betray each other.

COOPERATION BETWEEN HUMANS AND MACHINES



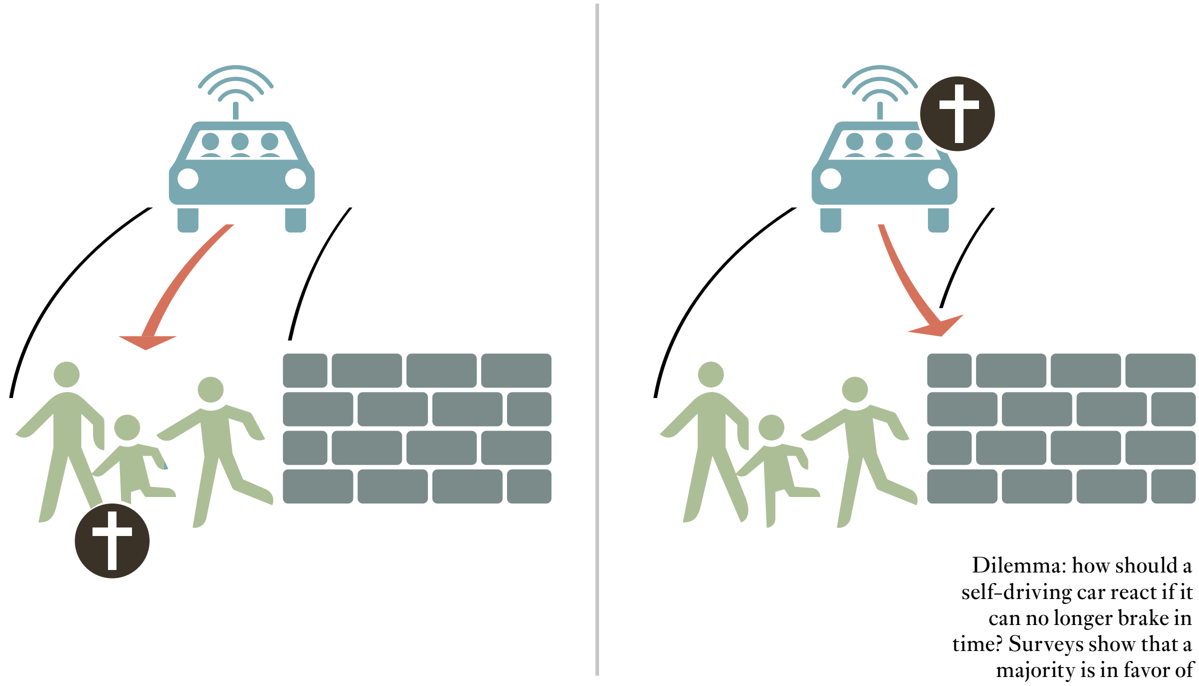
In one cooperation game, humans and machines initially cooperated poorly with each other. However, when the players were able to exchange text messages, the willingness to cooperate increased significantly.

GRAPHIC: GCO BASED ON CRANDALL, J.W., OUDAH, M., TENNOM ET AL. COOPERATING WITH MACHINES. NAT COMMUN 9, 233 (2018).

Human traits promote cooperation

Rahwan and his team tested the game on 25 different types of AI that use machine learning techniques. Initially, the results were rather frustrating. Most algorithms seemed more or less incapable of cooperation. And even the best performing algorithm was unable to successfully cooperate with humans. Things got interesting when the team gave both the human players and the winning algorithm from the first round of trials the opportunity to exchange a message. Specifically, both human and machine players were able to send a text message to the teammate at the beginning of each round, with phrases such as "Do what I say or I'll punish you", "I'm changing my strategy now", or "Give me another chance". To do this, they could choose from a predetermined pool of text messages. Scenarios were tested in which the human players were allowed to lie as well as ones in which they were not. The algorithms were basically unable to lie. None of the players knew the identity of their opponents. The amazing effect was that in the experiments without additional text messages, games in both the "human with human" scenario and "machine with human" scenario did not

GRAPHIC: GCO BASED ON MORALMACHINE.NET



Dilemma: how should a self-driving car react if it can no longer brake in time? Surveys show that a majority is in favor of saving as many lives as possible.

SUMMARY

Researchers led by Iyad Rahwan are investigating the influence of digital technologies on human behavior.

For example, in experiments with test subjects, they investigated the conditions under which humans and machines cooperate.

Another experiment focused on ethical guidelines for self-driving cars.

lead to particularly cooperative behavior. The "machine with machine" scenario performed slightly better. However, as soon as text messages were introduced as an additional element, the willingness to cooperate doubled in all three scenarios.

These results show three things. First: even without the ability to communicate, AIs are more cooperative than humans. Second: the cooperation performance of an AI can be increased if it is given human traits. When they can communicate, AIs clearly outperform all teams involving humans in terms of cooperativeness. Third: people react differently to an AI when it communicates. In fact, in the experiments with text chat, the human subjects were often no longer able to distinguish between the machine and a human counterpart. Is there a reason why algorithms perform more successfully than humans in the cooperation game? "One cause could be that machines stay true to themselves. If they have successfully completed several rounds of play in which they have not made use of the permitted option of non-cooperative, self-interested behavior, they will not break off cooperation in later rounds. Humans react differently in this situation – even if they almost always lose with this strategy," says Rahwan. Another reason could be that people often didn't follow through on the promises they had made in the text chat. This also leads to a decrease in mutual success in the game.

Are there things that a computer or AI will never be able to do? "Ultimately, I don't think there's anything AI can't do," says Rahwan. "But at least for the near future, I see limits wherever people interact with each other in ways that require a deeper psychological understanding. Machines are at a disadvantage here because they can learn from human behavior only through observation. They can't draw from their own life experiences and use these to interpret a situation."

www.mpg.de/podcasts/kuenstliche-intelligenz (in German)

ILLUSTRATION: LUISA JUNG FOR MPG

SOFTWARE TO SCAN THE PSYCHE

TEXT: ANDREAS LORENZ-MEYER

Just tired? Or depressed? Introverted or autistic? Imaginative or schizophrenic? The symptoms of psychiatric illnesses are not always clear. Therefore, Nikolaos Koutsouleris, a fellow at the Max Planck Institute of Psychiatry, also relies on artificial intelligence for early detection. Algorithms are designed to supplement the doctor's expertise by detecting patterns in patients' genetic and physiological data.

Just another day at the office. Suddenly a voice is heard: "You don't deserve this job!" The young woman turns to look, but no one is there. Her colleagues are all working at their desks. Did she just imagine that? Sometimes she gets the feeling the others are watching and controlling her and saying unkind things about her behind her back. She also feels they are secretly making insinuations and disparaging gestures about her performance. Although these thoughts are initially nebulous and easy to suppress, over time, they grow to ever more threatening proportions. Then, after ten months, the thoughts inside her head have become voices that seem to come from other people. They speak more and more often and harangue the 24-year-old. She stands up to them and argues with them. She is no longer able to concentrate properly, and she is making more and more mistakes at work. Is she going crazy? She finally seeks help. The diagnosis: schizophrenic psychosis. If the initial symptoms are as clear as in the case described here, an incipient psychosis can be easily detected. The onset of the disease can usually be prevented if only preliminary forms of delusions or hallucinations occur that the patient does not yet consider to be unshakeable reality. In other high-risk patients, however, the symptoms are more difficult to classify: they sleep badly, feel tired, are thin-skinned, unfocused and indifferent; they can barely cope with the everyday tasks of life and work, and they break off their social contacts. An incipient psychosis often remains undetected in such cases.

Nikolaos Koutsouleris wants to use artificial intelligence to better predict the risk of the future development of these types of psychiatric illnesses. Mathematical models aim to enable reliable prognoses to be made about who could become seriously ill and who can be

PHOTO: JARDUL/ISTOCK

The face is the mirror of the soul. But some people cannot correctly interpret this mirror image. Neuropsychological tests therefore form a part of the prognosis for psychiatric illnesses. A computer program factors in a person's ability to assign specific emotions to facial expressions when preparing the prognosis.

expected to be only mildly afflicted. The computer plays a supporting role in this. The objective here is not to replace the professionals, but rather to help doctors and psychotherapists detect correlations within the patient data that they might have missed. The most common form of schizophrenic psychosis is paranoid schizophrenia, which it affects 0.5 to 1 percent of the population. Patients experience hallucinations, delusions, and disrupted ego boundaries – in other words, the feeling of being controlled from the outside and the idea that thoughts can spread to acquaintances and to strangers. They believe that they are being persecuted or that others are stealing their thoughts. Those who are genetically predisposed are especially at risk. If both parents suffer from schizophrenia, their children have a 45 percent risk of developing the illness. However, the genes responsible for a person's schizophrenia have not yet been identified. Scientists are only aware of variants in the genetic makeup that increase the risk of a person developing psychotic disorders. These high-risk gene variants are compounded by environmental factors: stress and negative experiences such as the death of a loved one or the loss of a job can lead to the onset of psychosis.

SUMMARY

Some patients with a high risk of psychosis exhibit non-specific symptoms. The earlier a risk is identified, the better the chances for successful treatment.

In the future, artificial intelligence will improve early detection in those who are most likely to develop a psychiatric illness.

The NeuroMiner program can be used to create prognostic models that measure whether an individual at high risk will develop a psychotic disorder. The program evaluates psychiatric, medical and genetic parameters for this, while also factoring in the attending physicians' expertise.

The complex interaction of all these factors thus makes it difficult to offer a prognosis about whether and to what degree the illness could manifest itself. For example, if doctors knew that a patient was about to experience an acute psychotic episode, they could provide the person with targeted treatment. But this kind of reliable early detection does not yet exist.

Nikolaos Koutsouleris is working to change this. Fifteen years ago, he recruited and examined patients at the Ludwig Maximilian University in Munich for a study in the early detection of psychosis. "I was able to observe how mild symptoms in young patients who were in a high-risk state developed into severe illnesses and I could see the differences in their progress." But he also recognized that the traditional statistical prognosis methods did not help: "To this day, these methods don't work for calculating individual prognoses, because they cannot detect complex patterns. But this is exactly what would be needed for the early detection of mental illnesses – they can't be attributed to a specific gene or to specific damage to the brain." We still have insufficient knowledge about how the many different manifestations of psychosis are related to the spectrum of risk factors. "This is a Herculean task that can only be mastered using artificial intelligence," he explains.

Scientists were already using machine learning to diagnose neurodegenerative illnesses such as Parkinson's and Alzheimer's when Koutsouleris began his research. But at that time, no one had considered applying this technology in the field of psychiatry. However, Koutsouleris recognized the enormous potential artificial intelligence has for applying knowledge from basic research to psychiatric illnesses. At the same time, he also realized that he had to develop machine learning methods that would be easy for doctors to use, because current medical and psychology training programs do not yet include training in information technology.

NeuroMiner is a tool to help doctors and physicians

Koutsouleris was the perfect person to take on this project. As a specialist in psychiatry and psychotherapy at the University of Munich and as a computer programmer – he had taught himself several programming languages over the course of his doctoral research – he is at home in both worlds. Thus, in just over ten years, Koutsouleris has succeeded in developing NeuroMiner – a program that works with numerous algorithms. If it is uncertain which calculation method is the most appropriate, then the program simply applies several different methods. The results are compared and the best method is selected. The program also includes a meta-algorithm that combines different algorithms and then selects the combination that provides the most accurate prediction. Koutsouleris and his team are continuously developing the software further.

No programming experience is needed to work with NeuroMiner. "It can be used to analyze various data without any previous experience." First, the doctor feeds the program with data, e.g., from the genetic analyses and medical examinations of a psychosis patient. The doctor then selects an algorithm and trains it to detect the illness. NeuroMiner autonomously finds the settings for the selected algorithm that will ensure the optimum prediction of the psychoses. The general applicability of the learned settings is also tested. Can the algorithm make a reasonable prediction based on the input data? Does the "learned" decision function agree with the professional literature on the illness?

The training phase is then complete. The algorithm can now be used to calculate the risk of other patients developing a psychosis. Users can also share their models

Psychiatry and IT – Nikolaos Koutsouleris is at home in both worlds. This is how he was able to develop machine learning methods for the prognosis of psychiatric illnesses. His goal: a digital mental health assistant.

PHOTO: AXEL GRIESCH FOR MPG

with colleagues and let them test their reliability. If the model also performs well in these cases, it is ready for clinical trials. NeuroMiner does not permit users to jump back and forth between steps, so as to ensure that they do not tailor their models too closely to the training data and therefore obtain inaccurate predictions.

New algorithm

Early this year, Koutsouleris published an algorithm that raises the use of artificial intelligence in psychiatry to a new level. It can be used to make reliable predictions for patients aged 15 to 40 in various high-risk states of paranoid schizophrenia or for people with depression. "Many affected patients in the high-risk state are already experiencing high levels of psychological strain and suffering distress. They experience "mental storms" or have difficulty distinguishing mere concepts from reality," Koutsouleris explains. If such high-risk criteria as mild psychotic symptoms or a family history of psychosis occur together with reduced performance, the risk of psychosis increases to between 14 and 20 percent. The algorithm can predict with an accuracy of 83 to 85 percent whether individuals will develop a psychosis within two years.

The algorithm follows several steps: doctors first interview their patients and perform neuropsychological tests. For example, the patients are tested on how well they can correctly recognize emotional facial expressions. The program uses these results to calculate the probability of the development of a psychosis. It also indicates if sufficient data are available for a conclusive prognosis. If not, the physicians enter their own evaluation data in the next step. The algorithm thus combines the expertise of humans and machines. If the prognosis is still not sufficiently certain at this point, genetic risk factors from a hereditary analysis are considered. The program identifies all mutations associated with the development of psychoses and weights them based on their relevance. The brain can also be

"Doctors and patients will trust the algorithm's results only when they understand how it works."

NIKOLAOS KOUTSOULERIS

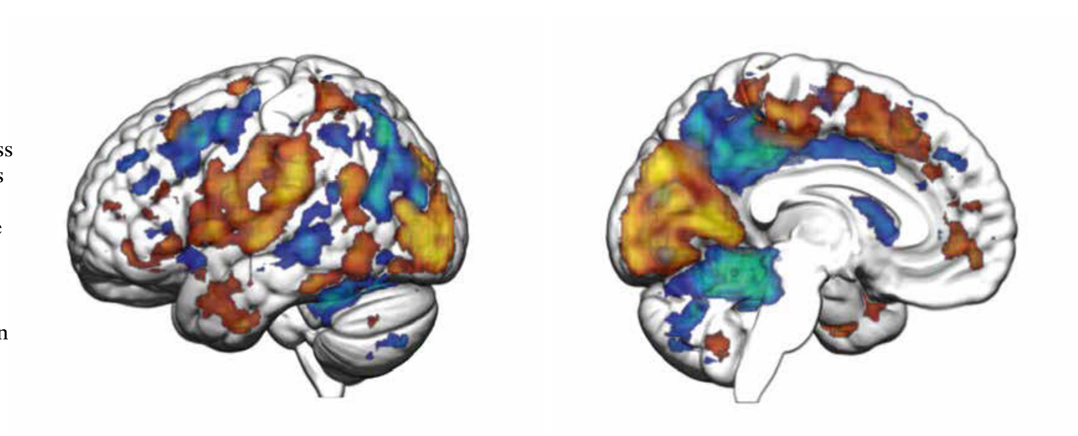
examined using magnetic resonance imaging. “All of these factors have to be accounted for in 40 percent of patients; especially for those who from the start have been attested as having a high risk for developing a psychosis. As a result, the algorithm reduces the number of cases in which a psychosis would otherwise have been incorrectly predicted,” says Koutsouleris.

Reliability and transparency

However, reliability as well as transparency are crucial for artificial intelligence to become an accepted diagnostic tool in the field of psychiatry. “This is critical for clinical applications! Doctors and patients will trust the algorithm’s results only when they understand how it works.” Although the patterns that the prediction algorithm has learned can already be traced, the researchers still cannot explain exactly how the program obtains its results. Koutsouleris and his team have therefore written software that calculates the weighting of the different parameters. This enables all of NeuroMiner’s calculation steps to be followed.

Artificial intelligence could thus result in a paradigm shift in the care of people with mental illnesses: away from simply managing chronic illnesses and toward preventive medicine that seeks not only to treat defects or symptoms, but also to strengthen the patient’s resilience. Outpatient clinics for early detection are still relatively inefficient, as they take too long to predict the risk of an illness. Artificial intelligence should greatly accelerate this process. Preventive psychiatry could soon provide a reliable prognosis of a patient’s risk of developing an illness and offer treatment tailored for that specific patient. For example, a personal “digital mental health assistant” would give a patient access to e.g., a network of individualized support services.

The progression of the disorder described at the beginning could thus take a different turn with the aid of artificial intelligence. Shortly after the occurrence of the first diffuse symptoms, the primary care physician refers the patient to a high-risk outpatient clinic. There, the results of brain scans and genetic tests are analyzed on the computer and an 85 percent risk of developing an illness is determined. Doctors then recommend indivi-



A prognosis pattern learned by the computer: the algorithm predicts an increased risk of illness for patients who have less brain volume in the red areas and more in the blue regions: the more pronounced the pattern, the higher the risk. If the volume distribution is reversed, the risk of illness is low.

Several predictive models are now available that have been tested on independent samples. A clinical trial will now show whether their use results in more successful therapies. “The next few years will see many new projects testing the use of artificial intelligence in psychiatric clinical practice – such as for predicting psychiatric illnesses in high-risk and depressed patients, or to predict the probability of the success of magnetic stimulation treatment for schizophrenia.”

dualized treatment with behavioral therapy, lifestyle changes and low-dose antidepressants. From then on, the patient’s risk of developing the illness is regularly checked in the outpatient clinic. The patient also uses an app to independently measure certain warning signals in real time. This provides a warning if symptoms and behavior patterns worsen and a progression of the illness can be anticipated.

www.mpg.de/podcasts/kuenstliche-intelligenz (in German)

FROM HEAVENLY BODIES TO HUMAN BRAINS

What holds matter together? What binds the universe? What is the nature of human thought? Charlotte Grosse Wiesmann of the Max Planck Institute for Human Cognitive and Brain Sciences has always been interested in the big questions. Grosse Wiesmann, who originally studied physics, now investigates which developments in the brain enable children to empathize with others.

TEXT: CATARINA PIETSCHMANN

It's one of those blisteringly hot July days in Berlin's Prenzlauer Berg district, when all you want is to find some shade. Through the open windows of the old apartment building tinkle the sounds of chimes. They come from the nearby heritage brewery. A carafe of water containing lemon slices and mint is on the table. Charlotte Grosse Wiesmann pours two glasses of water and sits back in her chair. Her workplace is, in fact, the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, a little more than an hour away from Berlin on the intercity train. She would normally spend the travel time constructively by reading or writing scientific papers. But because of COVID-19, Grosse Wiesmann, a neuropsychologist, is currently working from home. And it's been that way, with brief interruptions, since March 2020. The hygiene regulations at the Institute are very strict, particularly for researchers like her who work with young children. Much to their frustration, her staff members had to suspend their research projects for an extended period of time. The 35-year-old's team, which includes a philosopher, a biomedical scientist, two psychologists, and a mathematician, have only recently been able to get going again. Naturally, masks and, for the kids, negative lollipop tests are mandatory.

Charlotte Grosse Wiesmann heads the Minerva Fast Track Research Group "Milestones of Early Cognitive Development" at the Institute. The group investigates why and at what age young children are able to empathize with others – at what point do they understand that other people have a conception of the world that may differ from their own? This mental ability – referred to by scientists as having a "theory of mind" – is essential for living among other people. Anyone who has a deficit in this area, for instance people with autism or schizophrenia, will experience problems in their interpersonal relationships. A theory of mind is something unique to humans. Other animals, even primates, are thought to be capable of it to only a limited extent. Perhaps this shouldn't surprise us, since the ability to empathize with others appears to be related to another typically human skill: expressing oneself through language.

"When we construe what someone else might be thinking, we say things like, 'He thinks that ...'. I wanted to discover whether children learn to empathize with others at the same age when they also learn to

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VISIT TO

CHARLOTTE GROSSE WIESMANN

PHOTO: DAVID AUSSERHOFER FOR MPG

Values deep insight: Charlotte Grosse Wiesmann investigates milestones in the development of children's brains, testing the behavior of children and recording their brain activity.

employ such sentence constructions," says Grosse Wiesmann. To get the children's attention for her behavioral tests, she stages playful scenes. One such scene, for example, involves a toy mouse who puts a jelly bear in a bag and then takes a nap. "While the mouse is napping, the child and the researcher take out the jelly bear and put it in a box. Then we ask the child where the mouse should look for it when it wakes up," says Grosse Wiesmann. Two to three-year-olds invariably point to the box, while four-year-olds say, in the bag. "In other words, they understand that the mouse thinks the jelly bear is still where it hid it." Younger children can't yet accomplish this change of perspective.

What is different in older children? Has something changed in their brain? To discover this, the researchers record, among other things, the activity within the brains of their test subjects while they watch cartoons. This is done using electroencephalography (EEG), a technique that measures the electrical activity of the brain by means of voltage fluctuations on the scalp. "The younger children will mostly sit on their mother's lap during this process, and we briefly distract them to put EEG electrode caps on them," explains Grosse Wiesmann. In addition, we frequently use magnetic resonance imaging (MRI), which visualizes to within a millimeter the structures of the maturing young brain. How, though, does she get children to lie in the narrow space in the scanner? "They don't yet experience claustrophobia. In the case of the one-and-a-half-year-olds, we usually time the scan to coincide with their midday nap. Hence, the parents arrive around the same time as the normal midday nap and go through the standard sleep routines – reading to the child or singing – and when the child is asleep, they lay him or her on the MRI table." We tell the five-year-olds that the MRI is a spaceship in which they can watch a movie. "Once they put on the headphones and video goggles, they quickly forget about their surroundings," she says. While Mickey Mouse or the sassy squirrel Scrat from *Ice Age* are having their adventures, the researchers view the monitor on which the child's brain structures appear slice by slice. "Starting at about four years of age, we find a stronger connection across a bow-shaped nerve fiber bundle – the "fasciculus arcuatus" – which, starting at this point in development, connects two important areas of the brain. One of these is located in the posterior temporal lobe and assists us in thinking about other people. The other lies within the frontal lobe of the cerebral cortex and is presumably responsible for distinguishing between different perspectival levels, and thus differentiating one's own viewpoint from another's." Only when this "information superhighway" is in place are children able to consider someone else's perspective. The connection develops at about the same time as the ability to articulate conjectures about what others are thinking. "Interestingly, the new neural connection supports this ability irrespective of how well other mental abilities – intelligence, language comprehension, or impulse control – have yet developed," Grosse Wiesmann emphasizes. She suspects that having a well developed fasciculus arcuatus explains why some people are particularly good at empathizing with others. "Great apes aren't that good at it, and, conversely, this may simply be the result of a weaker connection."

Charlotte Grosse Wiesmann performed research in particle physics before she found her way to her current subject, the brain

The human brain is a small universe unto itself. Charlotte Grosse Wiesmann only discovered her path to it after conducting research in a completely different world – that of quantum physics. Her father, himself a physicist, isn't entirely blameless regarding the early awakening of her interest in physics. He brought back a telescope from a trip to the U.S., through which they looked at the stars in the evenings. This was followed by physics projects at school and participation in the German youth science competition "Jugend forscht." For this, she meticulously recorded the orbits of Jupiter's moons over time and then, using this data, verified

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PHOTO: MPI FOR HUMAN COGNITIVE AND BRAIN SCIENCES

Hand puppets as lab equipment: Charlotte Grosse Wiesmann employs playful methods to investigate the relationship between the ability to empathize with others and language development.

Crucial connection: from around the age of four, the fasciculus arcuatus (green) links two areas of the brain: a region in the posterior temporal lobe (brown), which helps us as adults to think about the thoughts of others, and an area in the anterior cerebrum (red), which is thought to help us distinguish between our own and other people's perspectives.

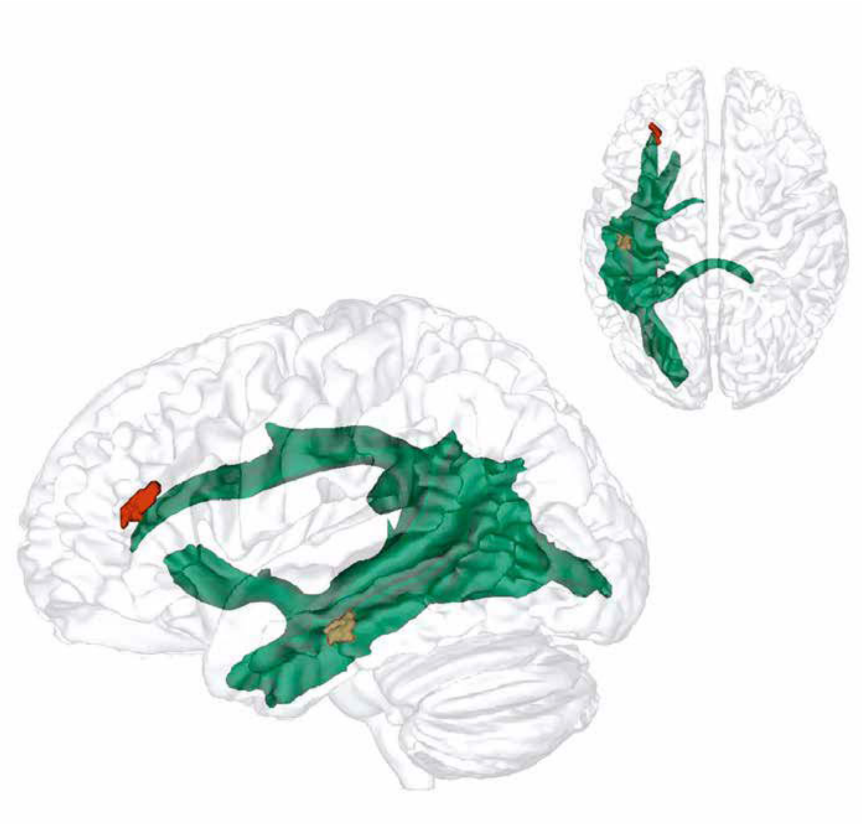

IMAGE: MPI FOR HUMAN COGNITIVE AND BRAIN SCIENCES

Kepler's laws describing the orbits of smaller bodies around a central body. It was the fundamental questions of theoretical physics – gravitation and elementary partical physics – that interested her, and she enrolled at the University of Hamburg to study physics – as well as philosophy. "At school, I had always been torn between the humanities and conceptual scientific questions. And I thought I had found a way to combine studying both subjects," she says. When she transferred to the Humboldt University in Berlin to complete her primary studies, she realized it would be impossible to pursue two degrees at the same time. The physics classes were held in Adlershof on the outskirts of the city, while the philosophy seminars were held almost simultaneously in Berlin-Mitte.

It couldn't be helped; she would have to concentrate on one course of study. She chose theoretical physics, in particular, the question of how the theory of gravity can be reconciled with particle physics. The German Academic Scholarship Foundation enabled her to spend a year abroad in Paris, at the renowned Ecole Normale Supérieure. But conceptual work – working out the big picture – wasn't how Grosse Wiesmann had imagined it would be. Frustrated, she abandoned her doctorate in mathematical physics after half a year. "All I seemed to be doing was calculating integrals. It was all very technical, and it seemed like getting my head round all the theories of fundamental physics would take forever, before I could even begin to work creatively myself."

But there were so many other exciting questions to explore. How do humans behave and function? How do they think? The philosophy of mind. Brain research! After a brief time out, she looked around for research groups working in these fields and came across neuropsychologist Angela Friederici, Director at the Max Planck Institute in Leipzig. "I contacted her and asked her: how does language affect thought? That's how we started talking, and pretty soon we'd found a project for my doctorate."

At academic conferences, she repeatedly bumped into Victoria Southgate from the Center of Early Childhood Cognition at the University of Copenhagen. "Her theory of development seemed related to my own ideas. Going to her for my postdoc seemed like the logical thing to do." Southgate, a psychologist, offered her a job, but Grosse Wiesmann wanted to conduct her own research project, and she successfully applied for a Marie Curie Fellowship from the EU. To spend the year in Copenhagen, she even postponed starting the Minerva Working Group for which Angela Friederici had already proposed her.

Copenhagen! It's an expensive place to live, where affordable housing is in short supply. Eventually she found accommodation in a shared apartment. She had a whole eight square meters of living space to call her own. But the fascinating research and career opportunities made it all worthwhile. What Grosse Wiesmann couldn't have imagined was that Copenhagen would change her private life as well. She had only been living in the city for a few weeks when she found herself stranded on the way to the airport one day: "We had to get off the train, and everyone was crowding around a Metro employee trying to get information. I couldn't understand a word, because at the time I didn't speak any Danish," she says. That didn't go unnoticed. A Dane on his way to the U.S. stepped in and translated for her. Together they searched the Internet for ways to reach the airport as quickly as possible, because Grosse Wiesmann was running late. The two hit it off and her helper, a historian who specialized in restoring and building furniture, suggested they meet when he got back. "He wanted to show me around Copenhagen – on a tour of the city's best bakeries," she recalls with a smile. Cinnamon pastries and Wienerbrød, a fluffy puff pastry filled with vanilla cream and/or assorted fruit preserves. Mmmmh, simply irresistible! The rest, as they say, is history. They moved in together while still in Copenhagen. That same Dane has now built most of the furniture in her Berlin apartment, and they are expecting their first child together in October – a girl.

That means that in two years' time she will have her own little "test subject" at home – very practical. Will she take advantage of that? "Of course!" she says with a laugh. "It's a great way to try out new behavioral tests." Until that time, her focus will be on advancing her scientific career. However, she is more preoccupied with her staff's research at the moment; due to the COVID-19 pandemic, her four doctoral students have been able to collect almost no data in the last year and a half. "They are under tremendous pressure. Half of their time has already run out, and unfortunately I can't offer them an extension." Staff posts at the Institute, like the Minerva grant, are limited to three years. For her own part, she can apply afterwards for a standard position as a junior research group leader, either within the Max Planck Society or elsewhere. In the long term, Grosse Wiesmann is aiming for a professorship, preferably in the field of brain development in young children. "Of course, it would also be interesting to explore the research on adults in this field. Or the research on great apes. But the core question – how the human brain develops – is one I will stick with," she says.

At the moment, her research is occupying all her time, so her husband will be taking most of the couple's parental leave. Even though her scientific field is completely unrelated to that of Angela Friederici, she appreciates having her support during her "Minerva time." "Having her as a mentor is fantastic; I still need to figure out how so many things function in the world of research." There's only one thing she does miss: having the time to get involved politically and socially, as she did when she was active in the "Netzwerk Europa" alumni program. One of the trips for the program took her to Bosnia-Herzegovina ten years after the war in Yugoslavia, where she got to see how cultural initiatives are helping to overcome conflicts between the former factions of the civil war. "We handed out disposable cameras to the various ethnic groups, asked them to take photos of their daily lives, and then organized an exhibition." More recently, Charlotte Grosse Wiesmann volunteered to tutor Syrian refugees and organized panel discussions on migration issues. But right now, all she has time for is to play her flute or go for a run. Due to her pregnancy, she has switched from jogging to Nordic walking. Soon, however, even that will no longer be possible, and a great many other aspects of her life will also change.

What she misses right now is the time to get involved politically and socially, to support refugees or to organize panel discussions

PHOTO: MPI OF MOLECULAR PLANT PHYSIOLOGY / SEVENS[+]MALTRY

DOUBLE TAKE

MAX PLANCK INSTITUTE OF MOLECULAR PLANT PHYSIOLOGY

Only when the timing is right and a plant flowers at the correct time can it properly form seeds and ensure its continued existence. Thale cress *(Arabidopsis thaliana)* often grows in fields and along roadsides. It opens its inconspicuous white flowers in the spring (left-hand picture). In order to find the ideal time to bloom, the plant measures the length of the day using special sensors in the leaves. If the light period is long enough, messenger substances migrate from the leaves to the tips of the shoots, where they transmit the signal to flower. As soon as the molecular message has arrived, flowers begin to develop from the dome-shaped tissue of the shoot tips – the shoot apical meristem – in which the plant stem cells are located (right).

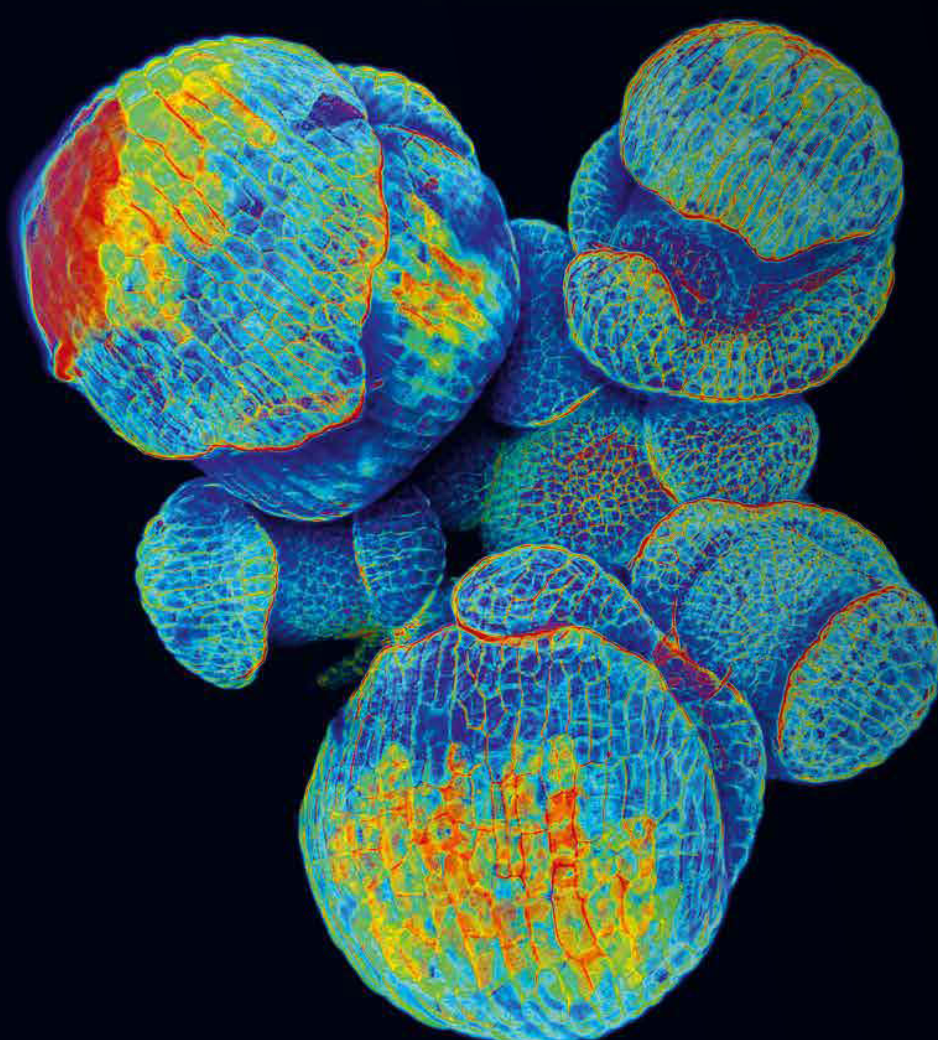

IMAGE: MPI OF MOLECULAR PLANT PHYSIOLOGY / A. SAMPATHKUMAR

DROPLETS IN THE CELLULAR SOUP

TEXT: TIM SCHRÖDER

For decades, few people were interested in the puncta that biologists observed when they examined cells under the microscope. Cliff Brangwynne and Anthony Hyman from the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden were among the first researchers to study these mysterious phenomena in more detail.

Nowadays, the structure of cells is something that children learn about in school. Cells are generally depicted as small bubbles or rectangles with a nucleus and several organelles floating around inside – including the "Golgi apparatus," in which proteins are modified, and the mitochondria, which are the cells' power plants. If the drawings in schoolbooks are to be believed, a cell contains little else.

In reality, however, the cells are full to the brim. It's estimated that there are around five billion protein molecules inside every cell – and these molecules aren't simply floating around. On the contrary, they join together in a fascinating way to form puncta, which appear from time to time and then merge with one another. Sometimes, dozens of these structures form within minutes and then disappear just as quickly. Researchers have been aware of puncta for as long as microscopes have existed. But for a long time, few people were particularly interested in these small, poorly defined blobs. All of that changed when the cellular biologist Anthony Hyman and his colleague Cliff Brangwynne made an astonishing discovery during a physiology course in 2008. The group was examining eggs from the roundworm *Caenorhabditis elegans* under the microscope when Cliff Brangwynne noticed a number of strikingly large structures inside the cells that behaved like oil droplets in water. This was enough to pique the researchers' curiosity!

Since then, a fascination with puncta has spread throughout the scientific community. Today, we know that these structures are actually accumulations of proteins and other large molecules such as nucleic acids – and that they are not formed by chance. On the contrary, their growth and dissolution is actively controlled by the cells themselves. Anthony Hyman, Director at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden, refers to these protein structures as "condensates." They are formed when proteins come together in the cellular fluid (cytosol) and form a denser mass. In other words, the proteins transition to a new "phase."

Many scientists now believe that these protein condensates play a vital role in biochemical processes within the cells, whether it be in cell division, in reading the genetic code and producing proteins, or in the development of diseases. "In most cases, we still don't know exactly what drives the formation of condensates or what function the various structures perform," says Hyman. As an example, if you re-

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IMAGE: MOHAMAD ALMEDAWAR/MPI OF MOLECULAR CELL BIOLOGY AND GENETICS

KNOWLEDGE FROM

BIOLOGY & MEDICINE

A fluorescent, saccharolytic enzyme stains endothelial cells violet. If the cells are suffering from a lack of oxygen, certain proteins assemble into aggregates (green spots). These proteins come together with the saccharolytic enzyme in the white spots.

placed the five billion protein molecules with people and kept the density the same, all of those people would be contained within a volume roughly corresponding to the that of Lake Como. The fascinating thing is that the proteins can rearrange themselves within the space of a few seconds and thereby form condensates.

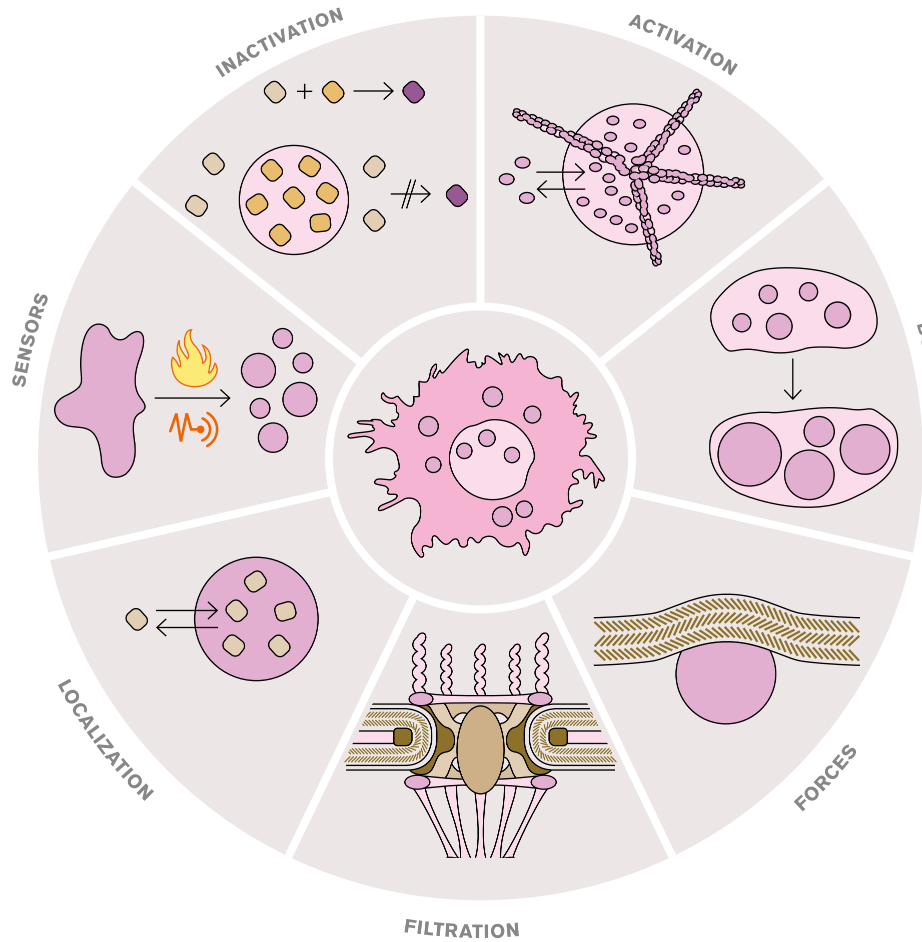
Frightful aggregates

Anthony Hyman and his team are exploring when and how proteins come together in the cells – for example, by investigating the temperatures or salt levels at which the protein condensates form. These are important insights because many diseases probably occur when the natural rhythm of condensate formation and dissolution gets out of sync. One example is the so-called "tau" protein. Inside cells, this protein regulates the assembly of "microtubules" – long, threadlike molecules that form part of the cytoskeleton. If the tau protein adopts an incorrect three-dimensional structure, it produces the deposits – i.e. "plaques" – typically associated with Alzheimer's disease. Another example is amyotrophic lateral sclerosis (ALS), a disease characterized by the death of nerve cells that control the muscles. If these cells fail to do their job, the body can no longer move muscles even though they are otherwise intact. Hyman and his team studied the "fused in sarcoma" (FUS) protein, whose mutated forms are associated with the development of ALS. The FUS protein is normally found in the cell nucleus. In cells that are exposed to environmental stress, however, it leaves the nucleus and forms droplets in the cytosol. When Hyman's group produced droplets using FUS proteins with mutations similar to those in ALS, they made an alarming discovery: after a few hours, the droplets had solidified into "frightful aggregates," as Hyman puts it. Clearly, the mutated proteins had triggered a phase transition from a liquid into a solid, crystal-like state that could also be a cause of the disease.

Nowadays, researchers have a good understanding of the principles underpinning phenomena such as the phase transitions from solid to liquid and the formation of condensates. Physicists have studied these phenomena and described them in detail.

Hari Raj Singh (left) and Sina Wittmann in the laboratory at the Max Planck Institute of Molecular Cell Biology and Genetics. Together with their colleagues, they want to find out how biocondensates form in cells – and what functions they perform.

PHOTO: MPI OF MOLECULAR CELL BIOLOGY AND GENETICS



GRAPHIC: GCO BASED ON CELL. 2019 JAN 24; 176(3)

Scientists still haven't discovered all of the functions that condensates perform in cells. Discussions focus on (clockwise from top): the activation of reactions; the storage of surplus molecules (buffering); the generation of mechanical forces; the modification of membrane pore size (filtration); and the localization of molecules at a specific site. If the condensates only form under certain conditions, they could also be used as sensors. Furthermore, they could prevent reactions between molecules by keeping them separate from one another (inactivation).

Key factors include the concentration of the substances, the electric charges of the proteins involved, and the fact that certain protein sections are more hydrophilic or hydrophobic. That being said, researchers still haven't figured out how cells start and stop the process of phase separation and condensation – or how they control it. In principle, the protein concentration in the cells must be high in order for condensates to form. Anthony Hyman therefore asked himself not only why the puncta form in certain diseases, but also how the process of aggregation is initiated or inhibited in healthy cells. "Why isn't the cell like a scrambled egg, with the proteins clumped together? After all, the proteins in the cytosol are at such a high concentration that they should actually be precipitating out of the solution."

Hyman may now have identified a key molecule in this process, namely adenosine triphosphate (ATP) – the molecule that supplies living cells with almost all of their energy. His ears pricked up when his team added ATP to protein condensates and found that the condensates disappeared. Apparently, ATP prevents the proteins from aggregating, even at the high concentrations inside a cell.

Better solubility in water

ATP appears to be acting like "hydrotropic" substances, which are not solvents themselves but are used in the chemical industry to increase the solubility of organic compounds in water. This molecule occurs in large quantities in cells, and it is conceivable that it only has a hydrotropic effect at certain concentrations. In that case, a change in concentration would affect the solubility of protein condensates. "It's possible that ATP originally developed as a biological hydrotrope in order to keep biomolecules soluble at a high concentration, and that life only began to use it as an energy source at a later stage," explains Hyman. This hypothesis is difficult to prove experimentally, however, because it's almost impossible to modify the hydrotropic properties of ATP without affecting its role as an energy source. "But if this hypothesis is correct, it would explain why protein aggregates often form in age-related diseases – because ATP production decreases with age."

Protein condensates may also play an important role in cell division. Before a cell divides, the chromosomes arrange themselves in the middle of the cell. Within a few minutes, the cell then forms a rigging-like structure known as a "spindle" – and this apparatus acts like a series of tow ropes, pulling the chromosomes into the two daughter cells. This spindle is also formed by protein condensation and emerges when individual tubulin molecules stack up alongside one another in the cytosol to form long chains known as microtubules. But how exactly are these microtubules formed? Hyman and his team conducted an experiment in which they produced condensates of the microtubule-binding tau protein and added tubulin, which migrated into the tau droplets. As the tubulin was now at a significantly higher concentration inside the tau droplets, it triggered the formation of microtubules. Hyman and his colleagues therefore suspect that cells use phase separation as a way of initiating microtubule growth and cell division.

As yet, Hyman is unable to say how important the condensates will turn out to be in cell physiology as a whole. Though previously thought of as nothing more than blobs inside a cell, these condensates are now known to be structures that form according to specific molecular rules – and experts are steadily gaining a better understanding of how these rules work. "There's now a great deal of evidence to suggest that these are actually biochemical micro-factories." Despite these findings, some researchers still believe the condensates to be irrelevant, while others see them as one of the most important discoveries in modern biology. "It remains to be seen which view is correct – or whether the truth lies somewhere in-between," says Hyman.

Anthony Hyman is considered one of the discoverers of phase separation in cells. When studying eggs of the roundworm *C. elegans,* it occurred to him that the accumulations of RNA molecules inside the cells were behaving like droplets of oil in water.

PHOTO: SVEN DÖRING

SUMMARY

Proteins can form bubble-shaped aggregations inside a cell. These condensates can develop and dissolve again within seconds or minutes.

Condensates are likely to be involved in fundamental processes, such as cell division and protein production.

Scientists suspect that diseases such as Parkinson's or Alzheimer's are caused by the uncontrolled formation of protein condensates in cells.

Uncounted heads: statistics analyzing population development often lag behind reality. Cell phone data – from social networks, for example – offers a quick way of recording changes.

PHOTO: ISTOCK/DMYTRO VARAVIN

DIGITAL DEMOGRAPHY

TEXT: JAN SCHWENKENBECHER

More than one-third of the world's population uses Facebook at least once a month. In the process, Facebook collects a lot of data from its users, which represents a valuable but barely tapped source for scientific research. Emilio Zagheni and his team at the Max Planck Institute for Demographic Research in Rostock are using social media data in an attempt to track and predict international migration.

For three days, authorities observed the tropical wave that was making its way westward through the Atlantic as it gathered strength, and by the evening of September the 16th 2017 it had grown to such an extent that they declared it a hurricane and dubbed it "Maria". Day by day, Hurricane Maria continued to grow, finally reaching its maximum force three days later, at three o'clock in the morning. By that time, the storm was producing wind speeds of 280 kilometers per hour combined with an air pressure of 908 millibars. It was the tenth strongest tropical hurricane in recorded history. Maria slammed into the coast of Puerto Rico a few hours later, uprooting trees, ripping the roofs off houses, and flinging cars through the air. The electricity and fresh water supply collapsed and just eleven of 69 hospitals were still able to function. Maria became one of the most lethal natural disasters in U.S. history. The authorities initially claimed that it had caused 45 fatalities. However, they continued to correct this figure, and finally arrived at 2,975 victims about a year later. Thousands of Puerto Ricans – for several months, no one really knew exactly how many – fled the island nation, a U.S. territory, to seek refuge on the U.S. mainland. The U.S. Census Bureau only released the migration data it collects as a matter of routine over a year later.

Emilio Zagheni drew on all available sources and became aware of the underlying figures earlier on. He provided additional perspectives too. "Whilst the official data is good and extremely accurate," Zagheni explains, "it is based on annual snapshots and many things can happen between any two of these. Any information about what people have been doing in the meantime is lost. Some of them only stayed in continental U.S. for a few weeks or months. Others moved on to other states." Zagheni is a Director at the Max Planck Institute for Demographic Research. He graduated in statistics and demography, and tries to combine the two in his research. The working area he heads is known as "Digital and Computational Demography." What does he do there? In this area, digital data is studied and utilized to answer demographic questions. And which digital data in particular? Anything that he can get his hands on, but mainly data from Facebook, Instagram, Twitter, and LinkedIn. The case of Hurricane Maria shows how this approach works.

Better data, more targeted help

Zagheni and some of his colleagues had begun collecting aggregate and anonymous Facebook data for the U.S. in January 2017, some nine and a half months before Hurricane Maria made landfall. He would take a kind of snapshot every few months, which enabled him to see how many users were active in each of the 50 states and what their age and gender were. In the case of residents outside of continental U.S., the data also revealed from which countries or U.S. territories a particular user had come. Puerto Rico was one of these territories. Looking at the data, Zagheni and his colleagues found that the number of Puerto Ricans living on continental U.S. increased by 17 percent in the weeks after Hurricane Maria, which equates to around 185,200 people or 5.6 percent of the total population of Puerto Rico.

Most of them sought refuge in Florida, which is the closest U.S. state to Puerto Rico. But between 8,000 and 15,000 Puerto Ricans, most of them young men, also made their way to Pennsylvania, New York, Connecticut, and Massachusetts, which are far more distant. That information is important, because, as Zagheni explains, "To be able to help people, you first have to understand migration patterns and know who is going where and why. And so this kind of data is important, for example, to enable the authorities to send the right amount of resources and support to various places where it is needed."

Hurricane Maria is just one of the many cases in which Zagheni has used Facebook data to explore human migration. He accesses the data via the ads platform, which was specifically created for advertisers. Businesses that wish to place an advert via the app can specify which Facebook users should be able to see it, for example, men living in Berlin, aged between 30 and 40. Exactly how Facebook concludes that particular users have certain demographic characteristics and interests is not fully explained by the social media giant. However, Zagheni and his colleagues do not just have to have faith in the black box that is Facebook. As the old saying goes, "faith is good, but facts are better;" so Zagheni and his team checked how accurate the data was for basic demographic data. In a recently published working paper, they demonstrated that Facebook's data regarding gender, age, and place of residence is between 86 and 93 percent accurate. Facebook's data offers researchers advantages not only in regard to Hurricane Maria because, for one thing, it contains much more granular details than traditional data from official sources. It can, for example, be downloaded on a monthly or even daily basis if required. It is also more readily available than government data and can be accessed much more rapidly. Another benefit is its

PHOTO: SHUTTERSTOCK/ALESSANDRO PIETRI

Ongoing disaster: some streets in San Juan, the capital of Puerto Rico, were still flooded weeks after Hurricane Maria had passed over.

A tenacious throng: long lines formed at the airport shortly after the disaster, where some people waited for days for a flight.

PHOTO: JOE RAEDLE/GETTY IMAGES

comparability because when it comes to traditional data sets it is often the case that different countries collect data using different definitions and at varying levels of detail and accuracy.

If, says Zagheni, one were to make inquiries in Poland and in Germany about how many people emigrated from Poland to Germany in 2007, the figures would be very different. “The Poles would say it was about 14,000, whereas the Germans cite 150,000,” one of the reasons for the discrepancy being because “the German authorities classify anyone who comes from Poland and registers at the town hall as an immigrant, regardless of how long he or she stays in Germany. The Polish authorities, on the other hand, only classify people as emigrants it they intend to relocate permanently to another country.” In terms of Facebook data, everyone is the same and therefore comparable. But there is also a big disadvantage: Facebook users are not representative of the entire population. In a nutshell, a lot of over-60s and a huge number of under-20s do not even use Facebook. While the figures for other social networks may be different, none of them is actually representative of the population as a whole so, from a research perspective, it is becoming increasingly difficult to make absolute statements. Observing trends, on the other hand, enables researchers to filter out inherent distortions that remain constant.

Mobility data from the career portal

But migration is not the only field of research for which Zagheni and his team rely on digital data; another aspect concerns the aging of the population. “We’re currently analyzing the extent to which technology could be of use to senior citizens and how access to technology is changing for different groups,” Zagheni explains. How digitally literate are senior citizens and how could the situation be improved? Researchers are also studying the impact of technological change, for example: “Access to technology might differ between men and women in some countries,” as Zagheni explains. “Gauging this differential access – by looking at how many men and how many women use social media – would enable us to draw conclusions about the degree of women’s empowerment in a particular country.” Nor does the relevant data always have to come from Facebook. Sarah Johnson, a doctoral researcher in Zagheni’s research group, for example, is currently using data from LinkedIn, an online site where users can cite their professional expertise and companies can recruit new personnel. LinkedIn includes a special function for attracting employees, which Johnson is using to study the migration of highly educated professionals. “The platform provides us with highly valuable aggregate-level

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information," she says: "For example, we can see how many people are willing to move from one place to another." Every LinkedIn user has the option of specifying this feature in their profile. Johnson has been collecting this type of aggregate-level data at regular intervals since last summer and is currently evaluating it. "We want to understand which types of users actually relocate and what characterizes that particular group," she says: "That might enable us to make a more accurate assessment of the conditions under which someone would really relocate for a job and when they are less likely to do so."

If Johnson succeeds in identifying specific factors that influence migration, they could be incorporated into existing migration models to make them more accurate. Researchers would then be able to make more accurate predictions of migration movements. Another doctoral researcher in Zagheni's team, Carolina Coimbra Vieira, is also working on this question. "People often simply assume that migrants relocate to a neighboring country whenever they move abroad," says Coimbra Vieira. "But mere proximity is just one of many factors that play a role, such as the language spoken or the economic conditions in the destination country." She is also researching another potential factor, namely the cultural proximity between the two countries. Yet, how can one measure cultural proximity? "Using food," says Coimbra Vieira.

Sugar cane schnapps and cheese crackers

Being a Brazilian, Vieira tested the idea using Brazil as her representative sample: she first identified the ten most typical Brazilian dishes, from churrasco to cachaça and pão de queijo to feijoada. She then analyzed how many Facebook users in Brazil and in 29 other countries were interested in Brazilian food on the assumption that the more people who share the interest, the closer their respective cultures are. "On the one hand, what we observed was that the cultural proximity to neighboring countries, such as Paraguay and Bolivia, is fairly high," says Coimbra Vieira. "Yet geographical proximity was not the only factor that determined cultural proximity. An especially large number of Facebook users in both Portugal and Angola were also interested in Brazilian food." Both are Lusophone countries and also have close historic ties to Brazil. Coimbra Vieira and her colleagues are currently testing the model for 16 other countries beyond Brazil and the initial results are promising. "Again, what we see is that the degree of cultural proximity or distance is a predictor of migration," says Coimbra Vieira.

Data protection is a key issue in all of the research being conducted by Zagheni's working group. "We use highly aggregated data sets in which no group contains less than 1,000 people," Zagheni explains. "That makes it impossible to draw conclusions about specific individuals." But that is not the only aspect of data protection. "We also need to think about group privacy," he says. If, for example, the data shows that a certain group of people is migrating from one region to another, you could endanger the group by publishing the data. For example, it could be a group of war refugees who are fleeing from government persecution.

There is another aspect to data privacy: "You have to take a different approach to data protection depending on the group of people involved. People vary

GRAPHIC: GCO BASED ON M. ALEXANDER, K. POLIMIS, E. ZAGHENI, THE IMPACT OF HURRICANE MARIA ON OUT-MIGRATION FROM PUERTO RICO: EVIDENCE FROM FACEBOOK DATA, POPULATION AND DEVELOPMENT REVIEW 45, 3 (2019); WIKIPEDIA

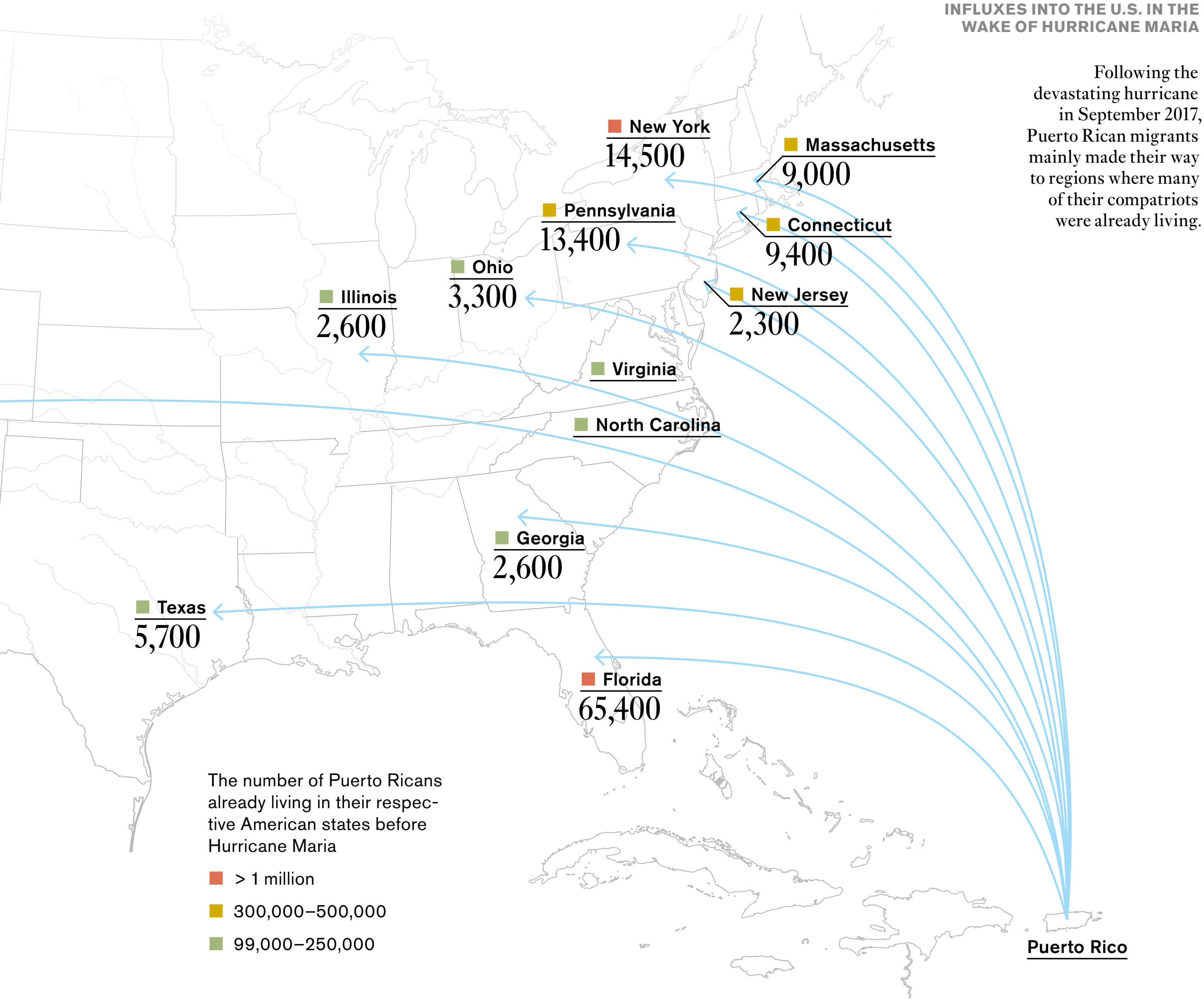
SUMMARY

When it comes to such things as tracking people's movements after a natural disaster, social network data is more quickly accessible and more detailed than government data and, although it is not representative, it does provide a good source for monitoring and predicting migration trends.

In doing so, the researchers pay careful attention to the safety of vulnerable groups.

INFLUXES INTO THE U.S. IN THE WAKE OF HURRICANE MARIA

Following the devastating hurricane in September 2017, Puerto Rican migrants mainly made their way to regions where many of their compatriots were already living.



in terms of how well informed they are. Not everyone understands how their data could be exploited, and that level of awareness differs between various demographic groups: young or elderly, a lower or higher level of education, migrants or nationals." There are also cases in which researchers draw a line and refuse to pursue a particular question although it would be technically and legally feasible to do so. There are public groups with thousands of members on social media sites such as WhatsApp, whose chat history could easily be downloaded by any member of the group and used for research purposes. But because most of people don't know about this possibility, Zagheni and his colleagues choose not to do so.

Zagheni's research group already has enough unanswered research questions for which they will need to find new approaches, perhaps by combining multiple data sources such as Facebook records with data tables from the U.S. Census Bureau, or by collecting their own data in the future. If, for example, there was an interest in which books or music those 30- to 40-year-old Berliners who are interested in Brazilian food read and listen to, then Zagheni and his colleagues could simply place an advert aimed at this target group on Facebook and invite them to take part in a survey. In this way, they suddenly have access to entirely new digital data sources.

FUEL FROM THE STEELWORKS

TEXT: PETER HERGERSBERG

With the steel industry accounting for some six percent of global CO_2 emissions, the Carbon2Chem project is taking an unusual approach to reducing the industry's climate footprint: scientists from organizations including the Max Planck Institute for Chemical Energy Conversion and the company thyssenkrupp AG are studying how this greenhouse gas can be used as a raw material for chemical products that – until now – have been produced from oil.

Almost everyone sees carbon dioxide as a problem, but it could actually provide a solution in certain situations. No matter which area of society or the economy you look at, most people are trying to find a way to get rid of the stuff – and few people have found the perfect way of doing so. The steel industry is one such example. Although it may one day be able to convert iron ore into iron using hydrogen or perhaps even electricity instead of by burning coal, this process is fraught with challenges, and the scale of these obstacles is often played down. Moreover, even if these challenges can be overcome, other steps in the steel production process still involve the emission of considerable quantities of CO_2. The problem is even worse when it comes to waste incineration plants or cement works, where it's almost impossible to reduce CO_2 emissions. To prevent the greenhouse gas from entering the atmosphere and further exacerbating climate change, these facilities have just two options: either to capture the carbon and compress it into underground reservoirs or find someone who can do something with it. One potential buyer is the chemical industry, which could use CO_2 as a raw material for the production of plastics, dyes or fuels. Until now, the industry's primary raw material has been oil – which not only exacerbates climate change, but is also only available in limited quantities.

As part of the Carbon2Chem project, scientists are researching how waste gas containing CO_2 can be used for chemical production via a process that specialists refer to as carbon capture and use (CCU). Given that the steel industry is one potential user, thyssenkrupp AG is one of the key partners in the project – after all, the company could not only apply the technology itself but could also offer it to other steel producers. The key participants also include teams from the Max Planck Institute for Chemical Energy Conversion in Muelheim and the Fraunhofer Institute for Environmental, Safety, and Energy Technology (UMSICHT) in Oberhausen. In addition, other industrial companies and research facilities have also joined the project, which since 2016 has received more than EUR 140 million in funding from the Federal Ministry of Education and Research. "With Carbon2Chem, we want to show that CO_2 is also suitable for synthesizing chemicals such as methanol under actual industrial conditions," explains Robert Schlögl, Director at the Max Planck Institute for Chemical Energy Conversion and one of the initiators of the Carbon2Chem project.

The project partners have set their sights on methanol, firstly because chemists have a great deal of experience when it comes to producing this alcohol from CO_2. Secondly, the chemical industry uses methanol as a precursor for a number of plastics and other products, consuming 70 million metric tons per year worldwide. That isn't all that much when you consider that steel companies around the world emit over two billion metric tons of CO_2 each year, which would be enough to produce around 1.4 billion metric tons of methanol. But 70 million metric tons is a start – and demand could potentially increase, including in areas other than chemical production. Methanol is also suitable for use as a fuel in parts of the transport sector that will continue to be reliant on liquid fuels for the foreseeable future, such as aviation. In addition to meth-

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A smoking source of raw materials: at the thyssenkrupp plant in Duisburg, the Carbon2Chem team is researching how CO_2 emissions from steel production can be put to sensible use.

PHOTO: PICTURE ALLIANCE/JOCHEN TACK

anol, the Carbon2Chem partners use CO_2 to synthesize urea – another substance that is required in large quantities in the chemical industry.

As the project aims to adapt the processes for industrial applications, some of the researchers work at a "technical center" on the premises of thyssenkrupp in Duisburg. At first glance, the site looks very industrial. It is skirted by two pipelines, as thick as sewer pipes, that are supported on pillars. These pipelines carry gases released during steel production – and above all exhaust gas from the blast furnaces. Among other applications, thyssenkrupp uses the heat from these gases to generate electrical power. From the moment you peer through the gate of the Carbon2Chem site, one installation in particular catches your eye: standing as tall as a six-story building, a towering mass of steel pipes and boilers is encased in bright yellow scaffolding. It all looks more like a chemical production facility than chemical research, which is more commonly associated with flasks and test tubes.

Clearly, the research being conducted here has already outgrown its laboratory. Built in the first phase of the project, this system has a key role when it comes to using steelworks or other prolific emitters of CO_2 as a source of raw materials for chemical products. For example, it is responsible for purifying the steel mill gases that are channeled from the pipeline. This is necessary because the emissions that emerge from the chimneys during iron smelting, as well as those from cement production or waste incineration, contain a heady mixture of substances in varying proportions. Although this is a nightmare scenario for chemists who are keen to operate industrial processes in as controlled a manner as possible, steel mill process gases contain CO_2, carbon monoxide and hydrogen. In other words, they contain all the components of "syngas," which the chemical industry has so far produced from natural gas or coal, specifically for use in methanol production. At the same time, blast furnace gas does not contain a sufficient quantity of hydrogen, which must therefore be added. Where this hydrogen is going to come from is a question for Carbon2Chem.

Nina Kolbe is in charge of the Carbon2Chem subproject "CO_2 Sources and Infrastructure" at thyssenkrupp. She helps us get to grips with this complex maze of pipework, showing us where the individual components of the gas mixture are extracted and where they are subsequently mixed again in the required ratio. There are modules whose purpose is to remove sulfur-containing substances or ammonia, for example, as well as modules that can scrub out CO_2 if required. All of this technology allows the researchers to control how thoroughly a component is removed from the waste gas. "We purify the gas as thoroughly as necessary and as inexpensively as possible," says Kolbe. In a laboratory next door, staff working under Holger Ruland, head of the Carbon2Chem working group in Robert Schlögl's Department, carry out checks to determine whether the gas is pure enough. The lab is packed with instrumentation and electronics used to analyze the properties of the gas, but the key piece of equipment is a proton-transfer-reaction mass spectrometer. This instrument is able to analyze complex gas mixtures during operation and can detect a specific gas at a concentration of just a few particles per million.

SUMMARY

Using CO_2 from waste gases from the steel industry – as well as from waste incineration plants and cement works – to produce methanol and other essential chemicals could reduce the carbon footprint of these sectors.

In the Carbon2Chem project, researchers have found that the established process for methanol synthesis can also be carried out using industrial waste gases.

Whether the concept enjoys widespread use will depend on factors such as whether enough affordable hydrogen can be generated using renewable energies.

Ruland's team also address questions such as how methanol can be synthesized as efficiently as possible using steel mill top gases and why this process sometimes falters. This work is being carried out at the project's second location, the Carbon2Chem laboratory at Fraunhofer UMSICHT, about half an hour's drive from the technical center in Duisburg. In the facility, which is big enough to house a basketball court, Ruland points to a box that wouldn't quite fill half of a small freight container. "That's Schmusy." This tailor-made apparatus is connected to the ceiling by finger-thick steel pipes and appears to contain a large number of valves, pipes, regulators and other electronic control elements. "Schmusy allows us to produce dirty syngas," he says, explaining that the device's name is a portmanteau of the German words for "dirty" and "synthesis gas."

Unlike in steel mill gases or other waste gases from industrial plants, Schmusy allows the researchers to accurately control the addition of contaminants. Accordingly, they can determine which components of the top gases, for example, interfere with the established industrial process for methanol synthesis – and in which quantities. "Most problems are caused by the usual suspects," says Ruland. These include for example, all of the sulfur-containing substances and large quantities of oxygen, which are already known to cause problems because they poison the catalyst. This catalyst, which is made of copper, zinc and aluminum oxide, is responsible for activating the highly inert CO_2 and the hydrogen so that they can combine to form methanol and water.

All in all, methanol synthesis has so far proven to be relatively impervious to most of the contaminants found in the waste gases in question. "Many doubted that the standard catalyst would work with CO_2 from the waste gases, because it should be deactivated by the large quantities of water that are produced in the process," says Ruland. The fact that this does not happen is good news when it comes to implementing the Carbon2Chem concept in industry, because searching for a new catalyst can be quite a laborious process. Nevertheless, the chemists' work is still not done. Indeed, the researchers working with Holger Ruland and Robert Schlögl not only want to understand the process in detail, but also to improve upon it if possible and to adapt it to other waste gases from iron smelting. In this context, the chemists have spotted a problem that has practical implications. "In experiments conducted over a period of several thousand hours, the catalyst's activity sometimes peters out and then at some point comes back," says Schlögl. The researchers already have their suspicions as to what might be causing this phenomenon: too much oxygen. "It may be that the measures we've taken to remove the varying levels of oxygen are insufficient," Schlögl says. However, it's still unclear whether these uncontrolled interruptions would even be noticeable in an industrial facility. "In a system that contains 25 metric tons of catalyst, it's not a problem if one kilogram doesn't behave exactly as it should," says Schlögl.

Researchers from Fraunhofer UMSICHT are keen to establish whether this temperamental behavior is also relevant on an industrial scale – and whether other challenges may emerge under these conditions. The team is attempting to answer these questions with the help of a small demo system that produces two liters of methanol per hour. Their next step will involve a demo system at the Duisburg technical center that produces several thousand metric tons per year. "With this, we hope to prove that the process is also stable on a large scale and over a long period of time," says Holger Ruland.

At that point, the process of methanol synthesis from steel mill gases will also be fed with hydrogen produced at the technical center. After all, the process is only beneficial in terms of climate protection if the hydrogen is green – in other words, if it was obtained from water using electricity from renewable sources. The problem is that, at present, wind and solar power rarely produce more power than is needed. Producing green hydrogen on a large scale would require a massive expansion of renewable energy sources, especially since many areas of the economy and industry – not least iron smelting – are pinning

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Searching for causes of disruption: in the Carbon2Chem laboratory at the Fraunhofer UMSICHT research institute, a team of Max Planck researchers are analyzing, among other things, which constituents of blast furnace gas have an adverse impact on methanol synthesis. For this, the researchers use a specially designed system to mix up dirty syngas from various components, which are supplied from gas cylinders in the yellow cabinet (right).

PHOTO: THOMAS HOBIRK/MPI FOR CHEMICAL ENERGY CONVERSION

PHOTO: THOMAS HOBIRK/MPI FOR CHEMICAL ENERGY CONVERSION

Synthesizing methanol: Christian Froese, a researcher from the Max Planck Institute for Chemical Energy Conversion, monitors a methanol synthesis process in the Carbon2Chem lab in Oberhausen. The vacuum tubes in the foreground are part of a mass spectrometer.

their hopes on hydrogen as part of their efforts to transition to climate-friendly practices. And even if there are theoretically enough facilities to meet demand, there will always be fluctuations in supply. This means that the electrolysis process, which is used to split water into hydrogen and oxygen, must be able to operate flexibly and may even have to be stopped altogether on windless nights. So far, these unpredictable conditions have been a source of concern for the operators of electrolyzers, who fear that the systems will not be able to cope and will quickly fail. Whether their concerns are justified has also been the subject of research by scientists from thyssenkrupp AG and the hydrogen and fuel cell center ZBT in Duisburg.

This research is being conducted on back at the technical center in Duisburg – in a facility that stands about as high as the gas-purification installation and just a few steps away from it. Special safety measures are required in order to enter the facility because it operates at high voltage and uses a caustic alkaline solution – but we're at least allowed to peep through the door. Enclosed by scaffolding, the electrolyzer takes up relatively little space inside the vast facility. Inside the device, you can see a series of chest-high plates lined up behind one another, and it's between these plates that the hydrogen is produced. The electrolyzer was developed by a thyssenkrupp subsidiary, which is already distributing it commercially, and has proven to be more flexible than initially assumed. Indeed, the system operates flawlessly even with an unsteady power supply. This is another outcome that paves the way for applications of the Carbon2Chem concept.

From a technical perspective, there is little standing in the way of the CCU project and its aim of using waste gases from the steel industry as a source of raw materials for areas of chemical production. Nevertheless, it remains to be seen whether the two sectors will ultimately put the concept into practice. This is a question of long-term security of investment – and, of course, of the cost. "Are customers ready to pay a surcharge for green steel or green methanol?" asks Nina Kolbe. For those buying a car, for example, the climate protection contribution would perhaps come to a few hundred euros. Given the correct political and economic framework, these goods could still be competitive despite their higher production costs. Although the future price of CO_2 is a factor, it's not the most important thing to consider: "One key question is whether we have enough affordable hydrogen – and enough electricity from renewable sources to produce it," emphasizes Holger Ruland. And this sentiment is echoed by other specialists working with CCU technologies.

A global market for renewable energies

Robert Schlögl believes that hydrogen would be significantly cheaper if electrolyzers were no longer manufactured in a workshop but rather using modern production technology. Still, this does nothing to change the fact that Germany is likely to face a shortage of green electricity in the future. This shortfall could be remedied by countries with a greater supply of sunshine and wind, such as Namibia. Indeed, the German government has just signed a hydrogen partnership with the southern African country, where a feasibility study and pilot project will be carried out to determine whether Namibia is capable of becoming a hydrogen exporter.

This would also constitute an important step toward establishing a global market for renewable energies, such as that which currently exists for fossil fuels. Schlögl helped to develop the German government's hydrogen strategy, and he believes that global trade in hydrogen, for example, is the best way to ensure that products from Germany remain competitive on the world stage – a better way, in fact, than EU tariffs on climate-damaging imports: "That would mean everyone has to pay higher prices." Of course, this assumes that a global demand exists, because the world is turning away from fossil fuels. Schlögl is very optimistic in this regard: "No one can continue to ignore the reports of the Intergovernmental Panel on Climate Change and the obvious signs of climate change."

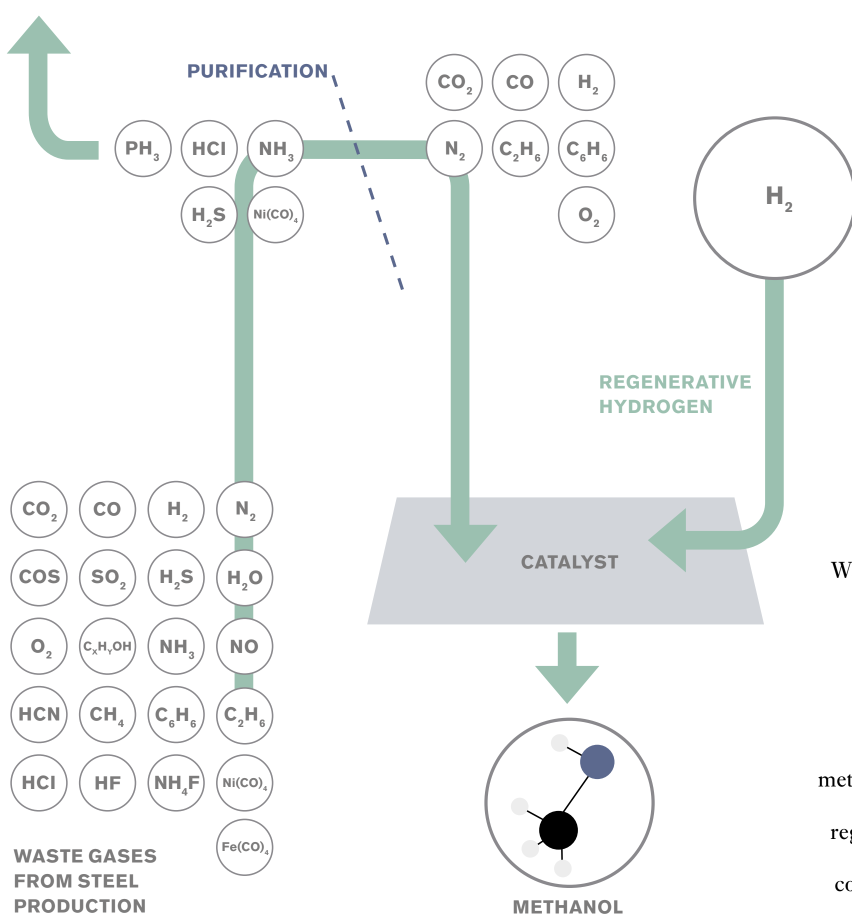
But these insights alone are not enough. It's also vital that emerging economies in particular are able to afford the measures needed to transform their industries in an environmentally friendly manner. Moreover, Carbon2Chem and other CCU technologies may not yet be effective enough, especially in terms of climate protection. "Any system that begins by using fossil resources and ultimately releases CO_2 is problematic if we want to achieve climate-neutrality," says Stefan Lechtenböhmer, who is carrying out research at the Wuppertal Institute into how industrial and energy systems can be redesigned in a climate-friendly manner. In the short and medium term, CCU could certainly aid the transition to a climate-neutral economy, particularly if the CO_2 is converted into durable products. "In any case, you've then used the CO_2 twice, as it were. Depending on the product, you've also stored it for a number of decades." However, the economist points out that, in the long term, carbon should only be used in locations where no alternatives exist. Still, hydrogen can be used to produce steel almost entirely without carbon. "Because the investment cycles in the steel industry are long, we should start embracing this solution as well. Otherwise, we might run into problems if we want to achieve net zero by 2045."

Nevertheless, Lechtenböhmer believes that a project like Carbon2Chem is vital, so that we have various courses of action to choose from in the future. Of course, this is a position that Nina Kolbe shares – including with regard to whether the steel industry should produce iron using hydrogen instead of coal, thereby avoiding CO_2, or whether it should opt to make use of the greenhouse gas instead: "There's a lot going on in industry around the world in terms of climate protection," she says. "We should pursue both approaches in order to reduce CO_2 emissions as quickly and cost-effectively as possible."

GLOSSARY

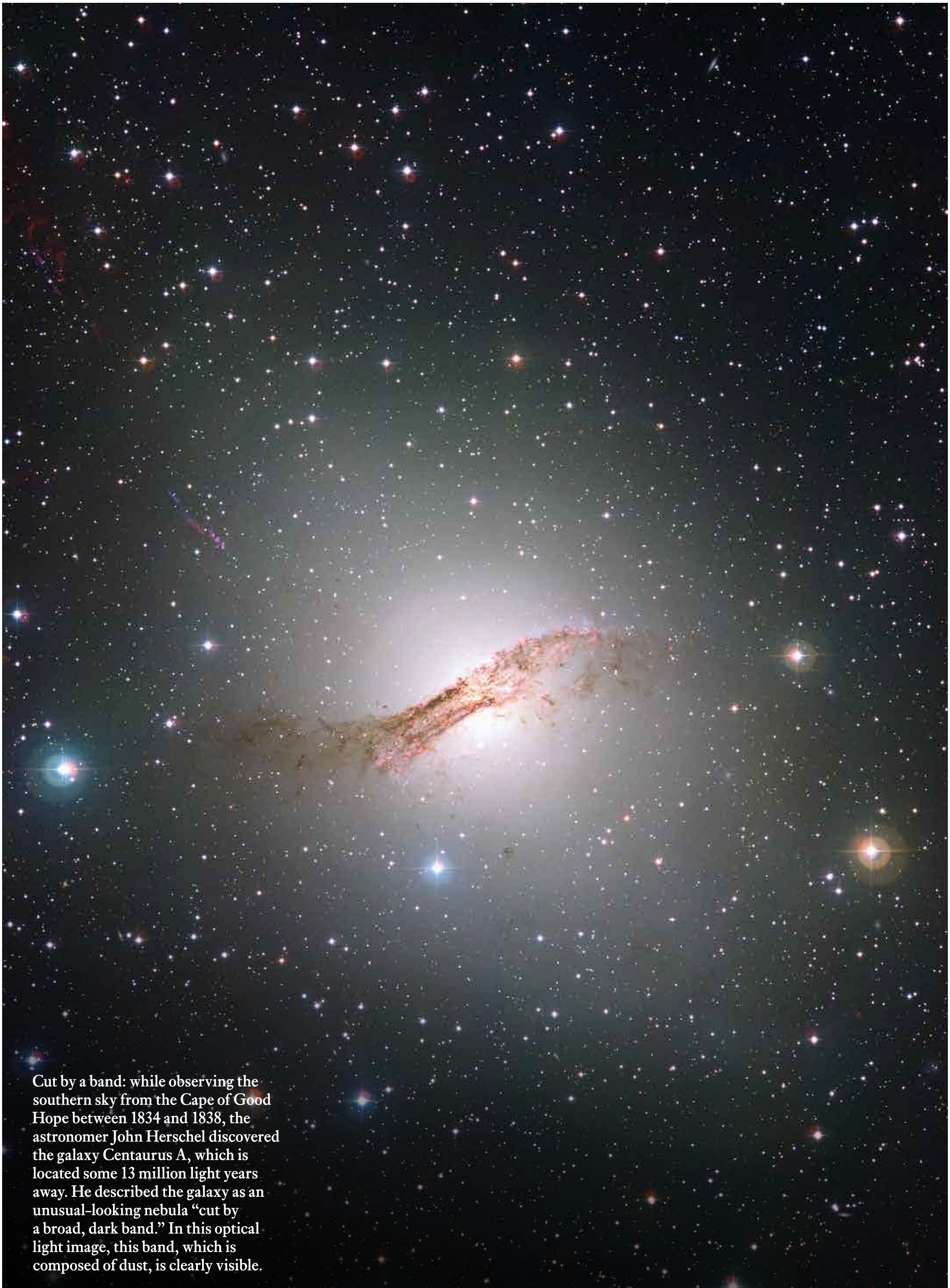
CARBON CAPTURE AND USE (CCU)
uses CO_2 from industrial waste gases for chemical production.

BLAST FURNACE GAS
is produced in the blast furnace process, where coke is used to reduce iron ore to pig iron, and makes up the greater part of the CO_2-containing waste gases at the steelworks. In addition, coke oven gas is produced during the conversion of coal into coke, and converter gas is produced during the conversion of iron into steel.



Waste gases from steel production contain many different substances (bottom left). The gases are purified in order to remove components that interfere with methanol synthesis (top left). A catalyst uses regenerative hydrogen to convert the CO_2 contained in the gases into methanol.

GRAPHIC: GCO BASED ON THE ORIGINAL BY HOLGER RULAND/MPI FOR CHEMICAL ENERGY CONVERSION



Cut by a band: while observing the southern sky from the Cape of Good Hope between 1834 and 1838, the astronomer John Herschel discovered the galaxy Centaurus A, which is located some 13 million light years away. He described the galaxy as an unusual-looking nebula "cut by a broad, dark band." In this optical light image, this band, which is composed of dust, is clearly visible.

PHOTO: ESO

ZOOMING INTO THE HEART OF CENTAURUS A

TEXT: HELMUT HORNUNG

Centaurus is one of the most famous constellations in the southern sky. Take a closer look at the constellation through binoculars and you'll see a pale nebula known as Centaurus A – it is in fact a distant galaxy in which a supermassive black hole resides. Michael Janssen from the Max Planck Institute for Radio Astronomy in Bonn and Radboud University Nijmegen led an Event Horizon Telescope team that has now come closer than ever before to understanding the nature of this gravity trap.

The chronicle of Centaurus A begins in the nineteenth century at the Cape of Good Hope. There, at the southern tip of Africa, astronomer John Herschel constructed an observatory. He observed the night sky there from 1834 to 1838 and a few years later published a catalog of astronomical objects. In this, he describes, among other things, an unusual-looking nebula "cut by a broad, dark band."

Designated NGC 5128, Herschel's discovery was listed in *A New General Catalogue of Nebulae and Clusters of Stars*. However, it was not until the 1950s that, thanks to increasingly precise observations, astronomers discovered that NGC 5128 was a galaxy entirely separate from our own. It is approximately 13 million light-years from Earth.

Research into Centaurus A began gaining momentum with a paper published by John Bolton and two co-authors in the scientific journal Nature in 1949. Shortly after World War II, the British-Australian astronomer and his team had begun matching cosmic radio sources with objects that had long been observed in visible light. The scientists were utilizing a completely new observational window on space: radio astronomy. At that time, this technology had only been around for less than two decades.

In the early 1930s, Karl Jansky was tasked by Bell Telephone Laboratories in New Jersey with investigating the source of radio transmission disturbances. In the summer of 1931, he constructed a 30-meter-long massive contraption made of wood and wire to eavesdrop on the radio spectrum and apprehended the culprit – thunderstorms!

Jansky could have been content to leave it right there, had he not also noticed a strange, steady hiss. It seemed to originate from a particular source that moved across the sky daily every 23 hours, 56 minutes and 4 seconds, precisely the period of the Earth's rotation relative to the stars. In the spring of 1933, it became clear that this hiss could only be coming from the depths of the universe.

Two years later Karl Jansky wrote that "these radiations are received any time the antenna system is directed towards some part of the Milky Way system." He was referring to the glowing band that, at our latitudes, can be seen stretching across the sky on summer nights. This is a section of the Milky Way, our galaxy, which is shaped like a slightly bent frisbee and is home to hundreds of billions of stars – one of which is our Sun with its eight planets.

Focusing in on the Milky Way

Jansky's discovery was ignored by the scientific community, however. Only one person appreciated the potential of the new method: Grote Reber. Reber, an amateur radio operator, invested $ 2,000 in materials to construct a fully movable dish nearly ten meters tall. He positioned it in the backyard of his home in Wheaton, Illinois, and directed it at the Milky Way every spare minute he had. In 1943, Reber published the data of his sky survey.

Gradually, this observational technique began to establish itself. A few years later, a group led by John Bolton employed a specialized radio telescope located on the coast of Australia. Constructed as a "sea cliff interferometer", it simultaneously recorded two signals – one emitted directly from the source in the sky and the other reflected from the surface of the Pacific Ocean. Superimposing the two signals – a technique known as interferometry – made it possible to mimic a radio telescope several hundred meters in diameter.

This allowed the group to successfully identify previously detected radio sources, such as Centaurus A, Virgo A, and Taurus A, with their optical counterparts: respectively, the galaxies NGC 5128 and M87 in the constellation Virgo, and the Crab Nebula, which is a supernova remnant in Taurus. Bolton's group reported these findings in the paper in *Nature* mentioned above.

The results represent a technical triumph, since the resolution of a telescope is dependent on the wavelength of radiation it detects. The longer the wavelength, the fewer details the telescope can record. Radio waves are nothing more than light waves with a very long wavelength. The Earth's atmosphere is transparent to submillimeter and millimeter radiation (just beyond the infrared), all the way through to radio waves with a wavelength of centimeters to several meters.

SUMMARY

Radio astronomers have observed Centaurus A for many decades.

The Event Horizon Telescope has now succeeded in giving us an unprecedented view into the center of this active galaxy, almost to the base of its enormous jet.

The observations help elucidate the mechanism that causes such jets to emerge close to black holes.

Due to the low resolution of radio antennas, they always need to be large; the dish of the Effelsberg Radio Telescope, for instance, is 100 meters in diameter. One clever way to trick nature is through interferometry. John Bolton was one of the first to exploit this trick. The Event Horizon Telescope (EHT) is also based on this principle. It consists of eight interconnected telescopes distributed around the globe at greater or lesser distances from each other. They all simultaneously observe the same object in the sky. Once the recorded signals are superimposed, the telescopes effectively function as a single telescope with a diameter equal to the greatest distance between the participating observatories.

In the case of the Event Horizon Telescope, this adds up to a virtual telescope with a diameter the size of the Earth itself. The EHT array detects radio waves with a wavelength of 1.3 millimeters and can resolve objects 20 millionths of an arc second apart. With it, you could theoretically read a newspaper from Munich (ignoring the curvature of the Earth) that someone was reading on a bench in New York's Central Park.

On April 10th 2019, the Event Horizon Telescope Collaboration released the now iconic first image of the shadow of a black hole. The data for this image were collected in 2017 from the center of the giant elliptical galaxy M87. At that time, the EHT Collaboration also recorded data from Centaurus A. After lengthy analysis, they released an image in July 2021 showing the heart of this galaxy, where a black hole is lurking that is 55 million times the mass of the Sun. From it – as is typical of most active galaxies – a jet of matter issues that symmetrically extends several hundred thousand light-years into space.

Rendering details smaller than a light-day

The black hole itself remains hidden. "But now, for the first time, we can study an extragalactic radio jet on scales smaller than the distance light travels in a day," says team leader Michael Janssen, who conducts research at the Max Planck Institute for Radio Astronomy in Bonn and Radboud University in Nijmegen. "We see first-hand how such a massive jet is born."

Supermassive black holes located at the centers of active galaxies like Centau-

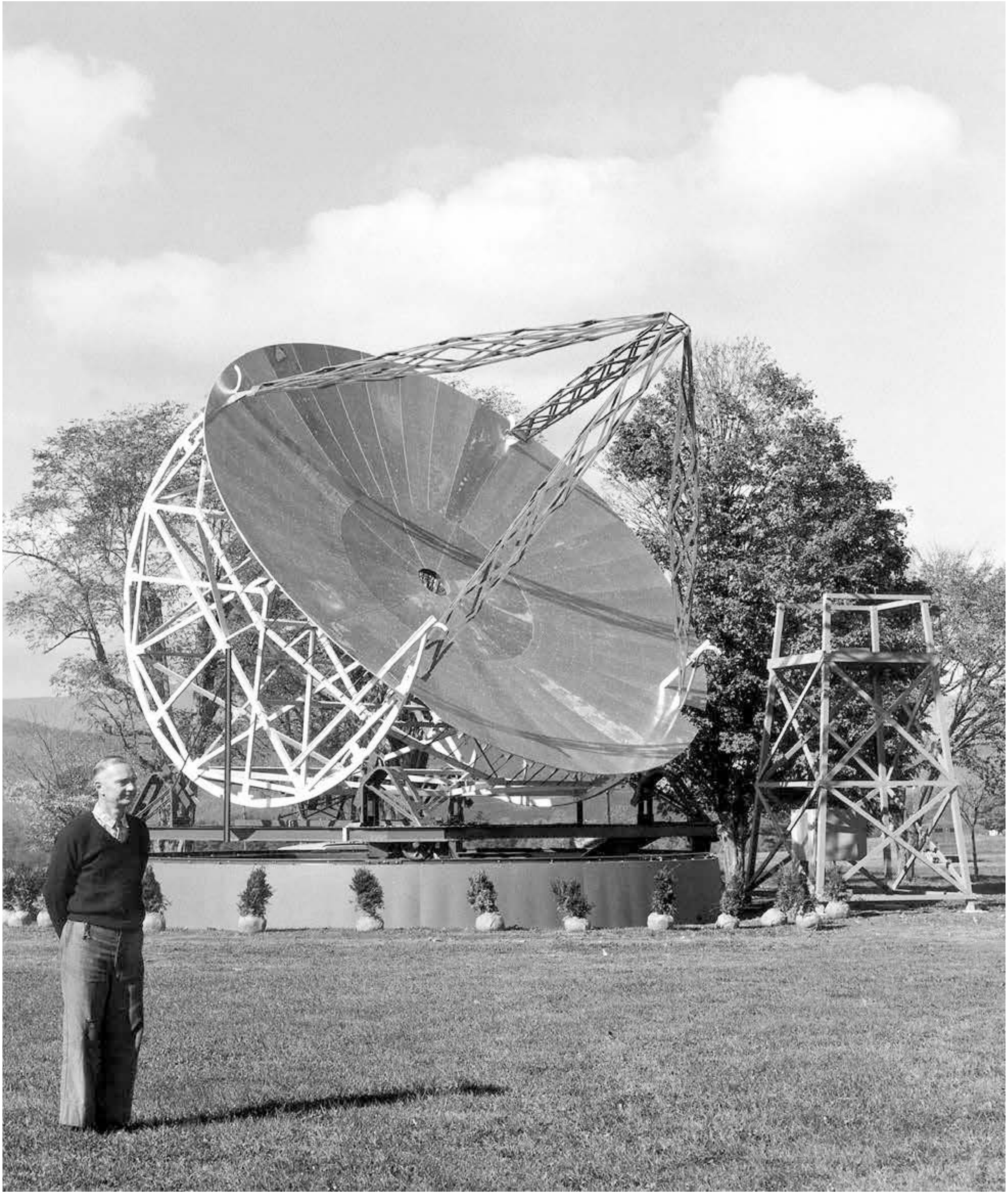
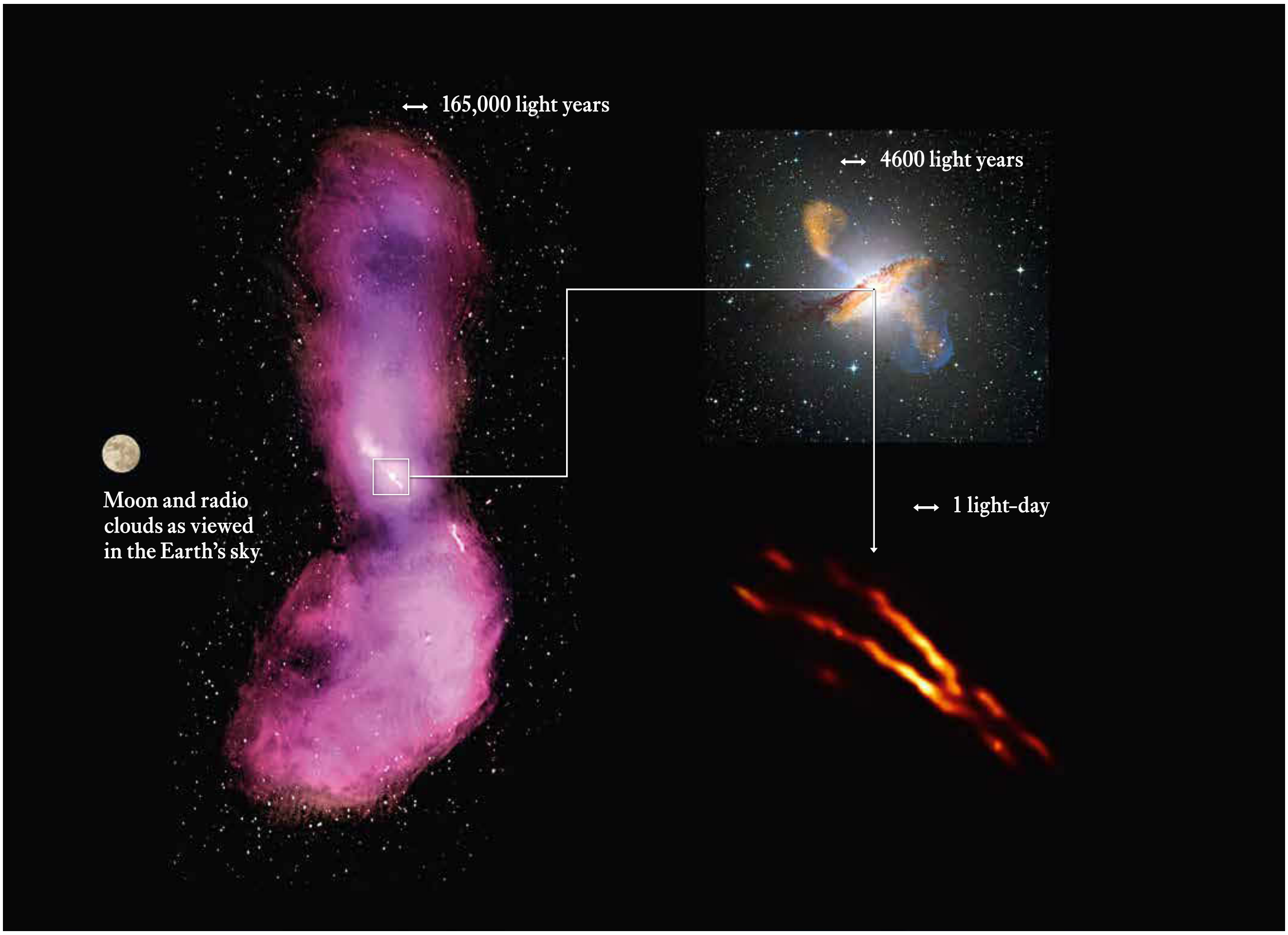


PHOTO: SCIENCE HISTORY IMAGES / ALAMY

Pioneer: in the 1930s, Grote Reber built a dish in the garden of his home in Wheaton, Illinois that was similar in form to contemporary radio telescopes. In 1943, Reber published the data from his full sky survey – opening a new observational window on space.



IMAGES: R. BORS; CSIRO/ATNF/I. FEAIN ET AL., R. MORGANTI ET AL., N. JUNKES ET AL.; ESO/WFI; MPIFR/ESO/APEX/A. WEISS ET AL.; NASA/CXC/CFA/R. KRAFT ET AL.; EHT/C. JANSSEN ET AL.

Zooming in: in the radio-wave spectrum, the extended symmetric gas clouds of the Centaurus A jet extend over an arc in the sky as wide as 16 full-moon diameters (left). The composite image depicting submillimeter, X-ray, and visible light images reveals only the galaxy itself (top right). The view into the heart of Centaurus A using the Event Horizon Telescope is many orders of magnitude more accurate, while the image of the jet has the highest detail resolution (bottom right).

rus A exert an almost irresistible pull on their surroundings. These black holes consume gas and dust causing them to release huge amounts of energy. Most of the matter near the edge of a black hole falls into this cosmic abyss. However, some of the surrounding particles escape just before they can be captured. This creates the jets we see, but the underlying mechanism behind these remains a mystery.

Researchers are attempting to explain exactly how matter behaves near a black hole using a variety of models. But what process is responsible for launching the jets from their galactic centers? And how do they come to extend many thousands of light years out into space, far surpassing their host galaxies in size? It is hoped the EHT will help answer these questions.

For example, the new image shows that the Centaurus A jet is brighter at the edges than in the center. Scientists are familiar with this phenomenon from other jets, but it has never been observed so clearly. “Thanks to this striking feature, we can now rule out all those theoretical models of jets that do not result in such edge brightening,” explains Matthias Kadler, an astrophysicist at the University of Wuerzburg. In addition, the EHT measurements have identified to a high degree of accuracy the position of the black hole from which the jet originates.

In the future, observations at even shorter wavelengths and higher detail resolution will make it possible to depict the black hole at the heart of Centaurus A – in the same way the black hole in the giant galaxy M87 was imaged. The researchers are now turning their attention to studying the magnetic fields. “I feel sure that we’ll soon master the improved methods needed to analyze the data,” declares Anton Zensus, Director at the Max Planck Institute for Radio Astronomy.

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No worries! Even in traffic, Australians prefer to take a laid-back approach.

Max Planck researchers are currently collaborating with partners in over 120 countries. In the following article they talk about their personal experiences and impressions. Alban Mariette from the Max Planck Institute of Molecular Plant Physiology in Potsdam is researching how plants construct their cell walls. He is currently spending two years in Australia as part of the Melbourne-Potsdam PhD Program (MelPoPP). Here, he shares details of his experiences during the lockdown period and about his work-life balance as a PhD student. He also waxes lyrical about the awesome Australian scenery.

Entirely lacking muscles and bones, plants nevertheless take on complex forms, producing their own stems, stalks, cones and trunks, as well as flowers and leaves. These tissues draw their strength and structure from the walls that surround each cell, which primarily consist of complex polysaccharides. For my doctoral thesis, I am researching the role played by certain proteins – the so-called nucleotide-sugar transporters – in cell wall synthesis. I use fluorescent biomarkers to make the proteins visible so that I can examine them under the microscope.

My studies are focused on thale cress *(Arabidopsis thaliana)*, an unassuming little plant with tiny white flowers, which also happens to be one of the most popular model organisms in plant research. To discover the precise function of the transporter proteins, I am studying thale cress plants that have been genetically modified to make them incapable of producing the proteins in question.

I am conducting my PhD research at the Max Planck Institute of Molecular Plant Physiology in Potsdam, as well as at the University of Melbourne. In 2016, these two institutions and the University of Potsdam collaborated to establish the Melbourne-Potsdam PhD Program. This gave me the opportunity to do research on two continents. I originally planned to spend one year in Australia, but everything was delayed because of the COVID-19 pandemic and so one year morphed into two.

Melbourne is one of the few Australian cities that were subjected to a strict lockdown between March and June 2020. Residents were only allowed out of the house for one hour a day and had to stay within a five-kilometer radius. Both of my experiments and those of my colleagues were put completely on hold during this period. Just a handful of us were allowed into the Institute for two hours every three days to water the plants. The rules were gradually relaxed in June, when we PhD students were permitted to take turns working 20 hours a week in the lab. (I easily rack up 50 hours in a normal work week). Fortunately, I

POST FROM

MELBOURNE, AUSTRALIA

was able to extend my employment contract at the Max Planck Institute in Potsdam for another year and am now planning to complete my PhD there next summer. Melbourne is an incredibly multicultural, green city with a very European lifestyle, so I soon felt at home there. The university's Parkville campus, where the School of Biosciences is situated, is really close to the city center, so I can get to know the Melbourne coffee scene on my daily walks. Much of my working day is spent in the lab, the hothouse or peering through a microscope. To strike a proper balance, I like to go to the gym and have joined an tango Argentino class. I particularly like the Australians' laid-back attitude: one of the things you'll hear most often around here is, "No worries, mate!"

My "Aussie" friends also love traveling, but despite the temptation to join them, my PhD workload makes it difficult to do so. But I did manage to make time for a trip along the famously scenic Great Ocean Road, which begins not far from Melbourne and snakes its way through some breathtaking scenery, past the Twelve Apostles – giant boulders that guard the mythical Southern Ocean.

Nor will I ever forget another great trip: I spent Christmas 2019 (during the Australian summer) with a group of doctoral researchers and postdocs in eastern Victoria. For some of us it was our first Christmas in southern climes, totally bereft of snow.

Unfortunately, the region was ravaged by catastrophic bush fires while we were there and we had just enough time to get to know this charming coastal region before it was devastated by the flames. When we got back to Melbourne, some of us started wearing masks to protect ourselves from the disastrous air pollution caused by the fires. That was still a very unusual thing to do back then and we felt pretty strange. Who would have thought that just a short time later, masks would become part of everyday life all around the world!

PHOTO: PRIVATE

Alban Mariette

26, is a plant and cell biologist who originally studied at the Université de Rennes 1 and the Université Paris-Sud. He began studying for his PhD at the Max Planck Institute of Molecular Plant Physiology in Potsdam in September 2018. He is studying plant cell wall synthesis as a member of Arun Sampathkumar's research group in Potsdam and at Berit Ebert's laboratory in Melbourne.

FIVE QUESTIONS

ABOUT GENETICALLY MODIFIED MOSQUITOES

FOR ELENA LEVASHINA

Ms. Levashina, in May the British biotech company Oxitec released genetically modified mosquitoes in the U.S. for the first time. Males of the species *Aedes aegypti* have had a gene inserted into their genome that prevents their female offspring from developing. In this way, the population should shrink as the number of females decreases from generation to generation, the population is intended to shrink, thus reducing the risk of being infected with Aedes-borne diseases such as dengue fever or the Zika virus. In Florida, concerned citizens protested the field trial. Do you think the experiment is safe?

ELENA LEVASHINA I think this mechanism is very safe. The inserted gene only stops the development of half of the offspring. So we are not talking about mosquitoes with altered characteristics. In Florida, the intent is to shrink this mosquito population or make it disappear completely, and with it the inserted gene. Moreover, only transgenic males are released; they do not suck blood. This means that it is impossible for anybody to be bitten by a genetically modified mosquito. In my opinion, there are also no ecological consequences to fear. *Aedes aegypti* is an invasive species in Florida, so a few years ago it didn't even exist there. Currently, it makes up about four percent of the mosquito population there. So it wouldn't be a loss if the species were to vanish from the ecosystem again. In addition, islands like the Florida Keys are very well suited to such a field trial, because they limit the spread of mosquitoes in any case.

What could happen in the worst case?

Basically, nothing more than failing to reach the goal and not decreasing the number of mosquitoes. This is because the inserted gene has a kind of safety switch: it can be switched off with tetracycline For example, it would be theoretically conceivable that mosquitoes in the vicinity of farms that use the antibiotic tetracycline in animal husbandry would not be affected by the gene modification. However, since that antibiotic is hardly in use today, this is very unlikely to happen and has certainly been tested in advance.

Resistance to insecticides occurs time and again. Is that to be expected here as well?

The researchers deliberately inserted the gene into a region of the mosquito genome that is essential for survival. A mutation in this region is lethal in virtually every case and would therefore not spread. In addition, the time span for a mutation to appear and spread is extremely short. Laboratory experiments show that populations collapse after only a few generations – in the field, that means within one reproductive season.

With insecticides, mosquito nets and vaccinations against at least some of the mosquito-borne diseases, there are already several strategies in place to fight infectious diseases. Why do we need another one?

It is always good not to put all eggs into the same basket. Past history has shown that a single weapon can always become blunt – for example, pesticides to which mosquitoes become resistant. We should get to the point where we know exactly which method to use for each location and infectious mosquito species. With targeted use, we can minimize the risk of resistance development and reduce the impact on the environment.

What should be considered before attempting any future release trials?

The protests in Florida show that we have to take people's fears seriously. The best way to counteract those fears is to demonstrate transparency – in the trials, when publishing the data, and in engaging early in public debates and education. Those who know the benefits and risks of the technology can make up their own minds.

Interview: Harald Rösch

Dr. Elena Levashina is a Group Leader at the Max Planck Institute for Infection Biology.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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- Rome
- Florence

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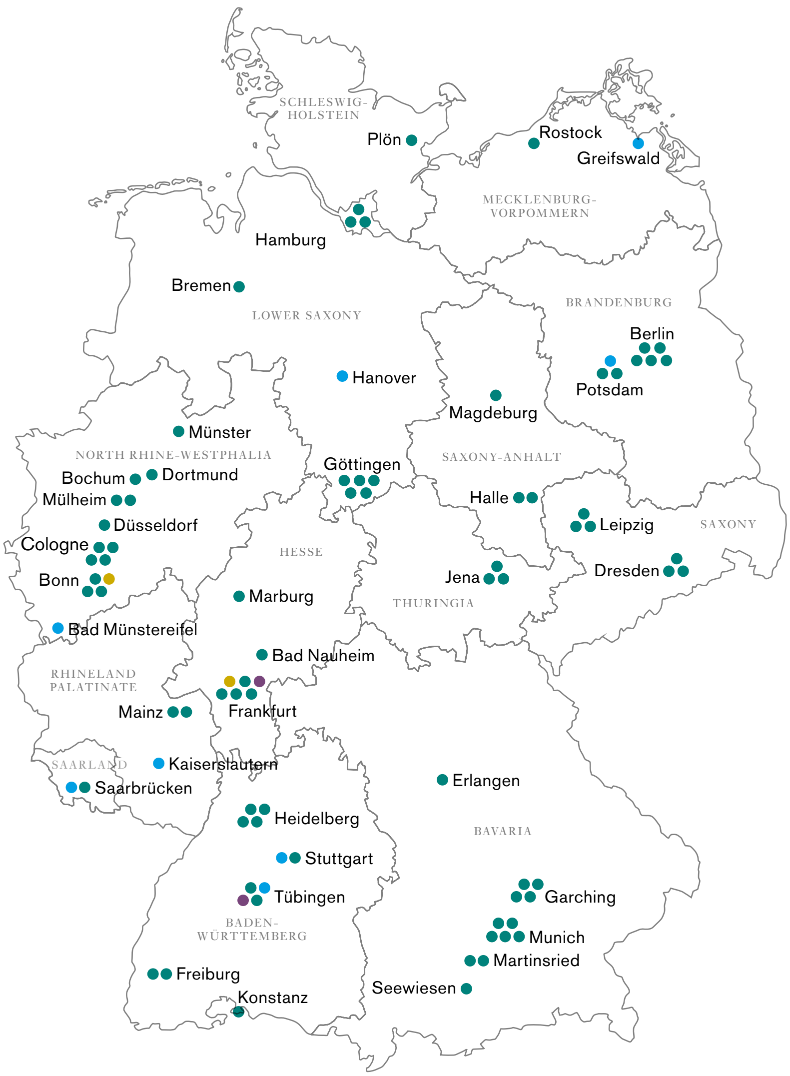
- Luxembourg



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