

01 | 2020

MAX PLANCK

Research

COSMOLOGY

The philosopher of the Big Bounce

GERONTOLOGY

The Methuselah cocktail

BEHAVIORAL ECONOMICS

Just be patient!



PLANTS
FOR POWER



PHOTO: OKAPIA

Plants are actually far too precious to simply let them go up in smoke, as is the case with this tobacco plant. After all, they absorb large quantities of carbon dioxide. That's why plant products have a more sustainable carbon dioxide balance than products produced from mineral oil, and they cause significantly less damage to the environment. They will therefore be essential in order to create a sustainable economy, either as fuel sources or as substances for medical use.

EDITORIAL

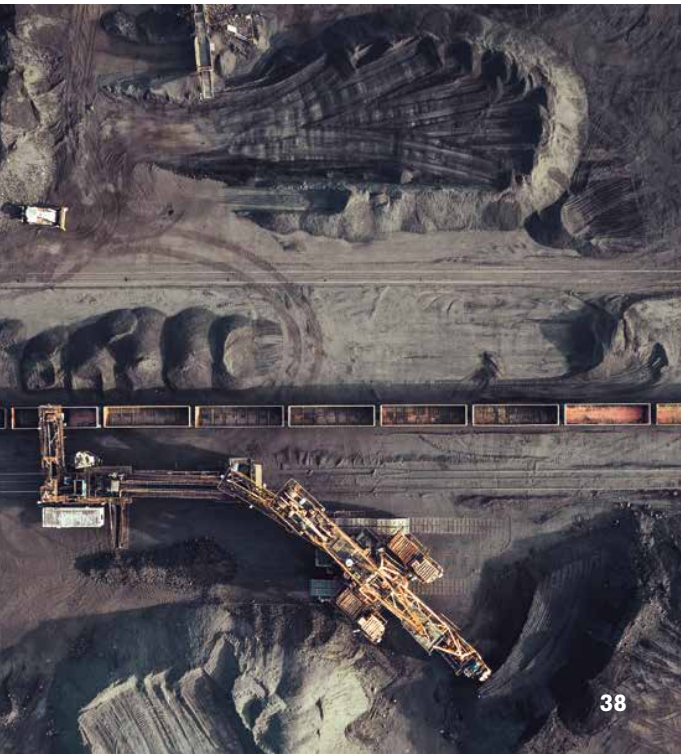
Dear readers,

“Nothing is constant except change,” said the ancient Greek philosopher Heraclitus, and a better way of describing our society today can hardly be imagined. The coronavirus pandemic proves that science is also subject to constant change – it continually poses unexpected and life-changing challenges. Communication is vital, and not just in these exceptional times. Forms of communication must be continually adapted to the upheavals in the media landscape and continuously respond to new challenges.

In such turbulent times, a science magazine cannot afford to stand still. To reflect this, we have changed some aspects of the Max Planck Research edition you are currently reading. Our aim is to place greater emphasis on topicality and social-relevance in the subjects we choose to cover and to present the results of our research within a broader context. We will also be bundling together the larger articles into a section entitled “Knowledge from”. Articles on research policy and science are brought together under “In brief”. The section “Visit to” will offer insights into the personality, biography, and motivation of selected scientists. And as you can see, along with these changes, we have adopted a fresher and more modern design.

Change is also the focus of this issue. After all, global crises – especially human-made climate change – are affecting our daily lives. It is no coincidence that in 2020 the topic of Germany’s annual “Year of Science” is bioeconomy. Max Planck Society researchers can contribute a great deal to this subject. They are showing us that a “green economy” offers more opportunities than just replacing fossil resources; it can open up entirely new ways of producing chemicals. But how do we successfully implement economic change? The articles in our current issue will provide some answers.

Enjoy reading!



38



48



56



72

38 | *IMPACTFUL*

We are more dependent on carbon as a raw material than we think.

48 | *IMAGINATIVE*

Anna Iljas calls the standard big bang model into question.

56 | *SUCCESSFUL*

A mix of medicines extends the lifespan of flies.

72 | *WIDE-RANGING*

Synthetic ivory can be produced in a range of different colors.

PHOTOS: SHUTTERSTOCK (TOP LEFT); FRANK VINKEN (TOP LEFT); WOLFRAM SCHEIBLE (BOTTOM RIGHT)

CONTENTS

03 | EDITORIAL

06 | ON LOCATION

in the Brazilian rainforest

08 | IN BRIEF

16 | VIEWPOINT

Between guilt, anxiety and hope

There is probably no other physical illness that has such a severe psychological impact as cancer. For a long time, researchers sought to find the cause of the disease in the personalities of the people affected. This was a fatal error.

FOCUS

Plants for power

22 | Fuel from straw and stubble

No energy crops will have to be planted for the second generation of biofuels. They will therefore no longer compete with food crops.

30 | Field factories

The production factories of the future will be in the fields. In future, scientists aim to use plants to generate substances that until now have been difficult to produce.

38 | An inventory of the fossil fuel age

The changing climate is forcing us to say goodbye to oil and coal. However, it won't be easy to detach ourselves from fossil materials.

46 | INFOGRAPHIC

The Neanderthal in us

48 | VISIT TO

Anna Ijjas

The philosopher of the Big Bounce

KNOWLEDGE FROM

56 | The Methuselah cocktail

Fruit flies and mice are providing scientists with amazing insights into the aging process.

62 | The mystery of the heavenly bursts

Radio telescopes constantly register pulses lasting just thousandths of a second. Where do these Fast Radio Bursts come from?

66 | Just be patient!

According to behavioral economists, "Those who wait get more out of life." They are studying how they can encourage children and young adults to be more patient.

72 | Ivory from a test tube

The plan is to produce the synthetic material on a large scale, and not just for piano keys.

78 | POST FROM ...

Barbados, Caribbean

80 | COMMUNITY NEWS

82 | FIVE QUESTIONS

about protest voting

83 | PUBLISHER'S INFORMATION

*TAKING A TREE SAMPLE
IN THE BRAZILIAN
RAIN FOREST*

Tropical rainforests are home to about two thirds of all known animal and plant species. It is beyond debate that they are essential for the climate of the entire Earth. However, the fact that they can also tell us a great deal about the cultural aspects of past times has been largely ignored until now.

6

The giant, centuries-old tropical trees are living time capsules for those who know how to interpret them. During their lifespans, they absorb carbon from the air as well as water and minerals from the soil, incorporating them into their wood. Researchers at the Max Planck Institutes for the Science of Human History, Developmental Biology, and Biogeochemistry combine modern analytical methods such as dendrochronology, radiocarbon dating, stable isotope analysis, and gene analysis to reconstruct changes in the growth conditions of trees. In this image, a relevant sample is being taken from a several hundred-year-old Brazil nut tree in the Tefé National Park in Brazil.

The researchers' studies also make it possible to understand the effects of human activities on the forest ecosystem. Contrary to popular opinion, the peoples of the rain forest have been cultivating this region from 10,000 years ago. Far-reaching events such as wars and colonialism have left their marks on the tree archive just as deeply as the industrial extraction of rubber and precious woods for worldwide consumption have.



ON LOCATION



PHOTO: VICTOR L. CAETANO ANDRADE

PHOTO: SHUTTERSTOCK



Like most insects, bees are also suffering from the impact of pesticides and climate change.

INSECTS AND CLIMATE CHANGE

The impact of humans on the climate and ecosystems is becoming increasingly clear – a drastic decline in total insect biomass can be observed throughout Europe. While pollinating insect species are threatened with extinction, certain pests and vector insects are spreading to ever wider areas. To investigate the interactions between insects, the climate, and humans in greater detail, the Max Planck Institute for Chemical Ecology, the University of Lund, and the Swedish University of Agricultural Sciences are joining forces as part of the new Max Planck Center on next Generation Insect Chemical Ecology. Together, the partners are primarily focused on examining how higher average temperatures, greenhouse gases, and air pollution impact the olfactory system of insects and how insects adapt to these changes. The findings could make a significant contribution to solving global problems in the context of the climate crisis, global nutrition, and even the fight against diseases. After all, the rising temperatures also facilitate the spread of infections transmitted by insects, such as West Nile fever and malaria. Therefore, one aim of this collaboration in the Max Planck Center is to develop new methods of combating these diseases. The joint project was officially launched in January 2020 in Alnarp, Sweden.

www.mpg.de/14403006

AWARD-WINNING ★

ERIN SCHUMAN

8 Erin Schuman, Director at the Max Planck Institute for Brain Research, has been awarded the Louis-Jeantet Prize for Medicine 2020 for her work on local protein synthesis at synapses. These structures act as contact points between nerve cells in the brain and determine how effectively the cells can communicate with one another. Schuman found that many of the proteins that the synapses need for communication are produced locally in the vicinity of the synapses themselves, so that they are available at the right time and in the right place. This discovery paves the way for a better understanding of how synapses work and of the impact of disruptions in neuronal development. Bestowing grants of EUR 500,000, the Louis-Jeantet Prizes are some of Europe's most valuable awards for biomedical research. The money supports the prizewinners in their subsequent work.



PHOTO: MPI FOR BRAIN RESEARCH

SVANTE PÄÄBO

The Japan Prize 2020 has been awarded to Svante Pääbo, Director at the Max Planck Institute for Evolutionary Anthropology. Pääbo is considered the founder of paleogenetics, a discipline that is concerned with the analysis of genetic samples from fossils and prehistoric finds. He investigates which of the genetic changes in the course of evolutionary history have shaped modern humans by comparing the DNA sequences of modern-day humans with those of Neanderthals and other human ancestors. Pääbo's major scientific achievements include the complete decoding of the mitochondrial DNA of a Neanderthal in 2008 and of the Neanderthal genome sequence. The Japan Prize is often referred to as the Japanese Nobel Prize and is endowed with prize money of 50 million yen (about EUR 490,000).



PHOTO: KARSTEN MOBIUS



CUTTING- EDGE RESEARCH IN POLAND

Three additional centers will soon become part of the Dioscuri program in Poland, which was initiated by the Max Planck Society. Mathematician Pawel Dłotko, biologist Gracjan Michlewski, and physicist Bartłomiej Waclaw will lead the centers, where they will establish internationally competitive and innovative research groups. The aim of the Dioscuri program is to recruit researchers from prestigious international postings in Western Europe and the U.S. and to support them in setting up their own research group in their home country. The program thereby helps to overcome the performance gap that exists between Western and Eastern Europe. The first two Dioscuri Centers began their work in 2019.

www.mpg.de/14310896

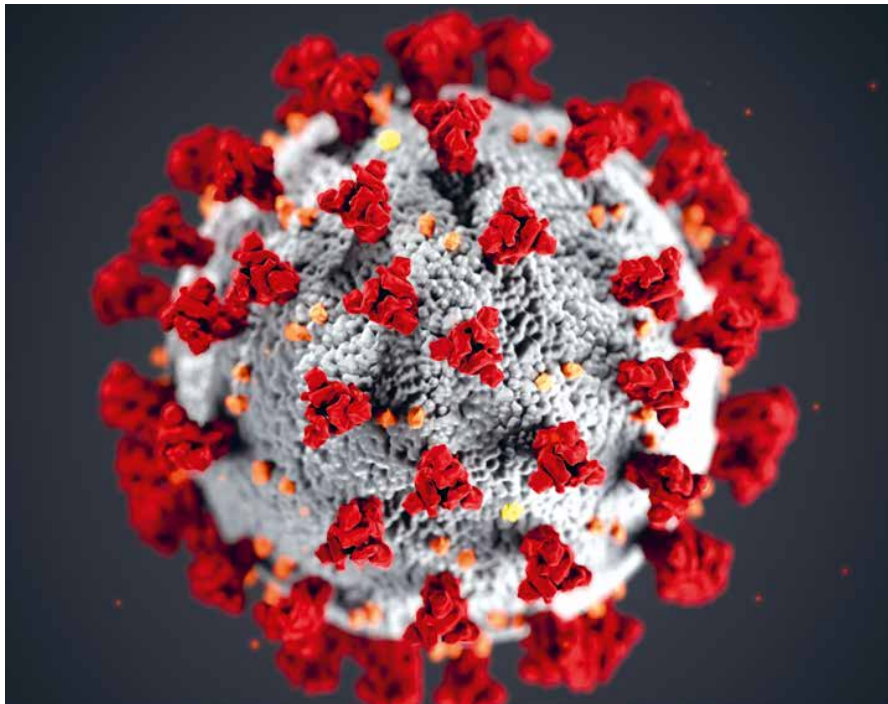


IMAGE: CDC/ALISSA ECKERT, MS; DAN HIGGINS, MAMS

IMMUNE BOOST AGAINST THE CORONAVIRUS

Researchers from the Max Planck Institute for Infection Biology have developed a candidate for a vaccine against tuberculosis that could also be effective against an infection with SARS-CoV-2. The substance is based on the BCG vaccine, which was discovered in the early 20th century as a means of combating tuberculosis. Studies in mice have shown that BCG can mitigate the impact of viral infections of the respiratory tract. Accordingly, mice suffering from influenza showed less damage to their lungs if they had previously been vaccinated with BCG. There are also indications that the vaccination activates the immune system against viral infections, thereby reducing the risk

of severe disease progression and lowering the mortality rate. Clinical studies have so far shown the tuberculosis vaccine recently developed by the Max Planck Institute to be well tolerated and more effective than standard vaccination with BCG. This raises hopes that the new vaccine will also be better able to alleviate the symptoms of an infection with SARS-CoV-2. Its effectiveness against SARS-CoV-2 – i.e., the Covid-19 coronavirus – will now be tested in a large-scale study at German hospitals, with participants drawn primarily from at-risk groups like health care workers and older people who are particularly vulnerable to the disease.

www.mpg.de/14610776

Scientists are searching for a vaccine against the coronavirus, shown here as a 3D model.

Cross section of a mouse's hippocampus. After erythropoietin is administered, the animals have more nerve cells in this brain region, which plays a key role in learning and memory.

A BRAIN DOPING AGENT PRODUCED BY YOUR OWN BODY

Erythropoietin, or EPO for short, is a notorious doping agent that not only boosts physical performance but also acts as a growth factor for nerve cells – reducing damage to the brain after a stroke, for example. Even patients with mental health disorders such as schizophrenia, depression, bipolar disorder, or multiple sclerosis have shown an improvement in cognitive performance with EPO. Now, researchers from the Max Planck Institute for Experimental Medicine in Goettingen have revealed how the substance works in the brain: they found that cognitive challenges in the nerve cells of the brain trigger a slight shortage of oxygen, leading to greater production of EPO along with its receptors. The growth factor subsequently boosts the activity of these nerve cells, induces the formation of new ones from neighboring precursor cells, and increases the interconnection of neurons. Taking EPO bolsters this natural effect, with test results showing that adult mice form 20 percent more nerve cells in the pyramidal layer of the hippocampus – a brain region crucial for learning and memory – after the growth factor is administered.

www.mpg.de/14569880



IMAGE: MPI FOR PSYCHIATRY

THE THOUGHTS OF OTHERS

In order to understand what other people are thinking and assess how they are behaving, humans need to be able to comprehend someone else's perspective. They develop this ability during childhood, but researchers have so far been at odds concerning the age at which it emerges. A recent study by the Max Planck Institute for Human Cognitive and Brain Sciences shows that children aren't truly able to understand what others are thinking or to anticipate their actions until they reach the age of four. As the researchers observed using eye-tracking technology, younger children can already predict the actions of a cartoon character – but if they're asked about it, they give the wrong answer. The researchers found the reason for this by taking measurements of brain activity: different brain structures are involved in the two decision-making processes – the nonverbal version expressed in their gaze and the verbal one expressed in their answer. It is not until the age of about four that the brain regions we use to actually understand what others are thinking reach sufficient maturity for us to express this perception verbally – although in early childhood, another brain function exists that does allow us to take another person's perspective.

www.mpg.de/14562450

A TALE OF SHEPHERDS AND HELICES

“Adoration of the Shepherds” by the Italian sculptor Giuseppe Torretti is a source of fascination not only for fans of the Baroque era, but also for chemists – because of lumpy efflorescence produced by corrosion on the restored marble relief. As researchers at the Max Planck Institute for Solid State Research have discovered, these phenomena are formed by a salt that crystallizes in the same triple helix structure as the protein collagen.

Now that restorers have access to accurate structural data for the salt (a hydrated form of calcium acetate), they can also identify that same corrosion product on other marble works and may be able to prevent the processes by which the efflorescence occurs. However, the inorganic helices could also be used as a template to cause other chemicals to adopt this structure.

www.mpg.de/14594656

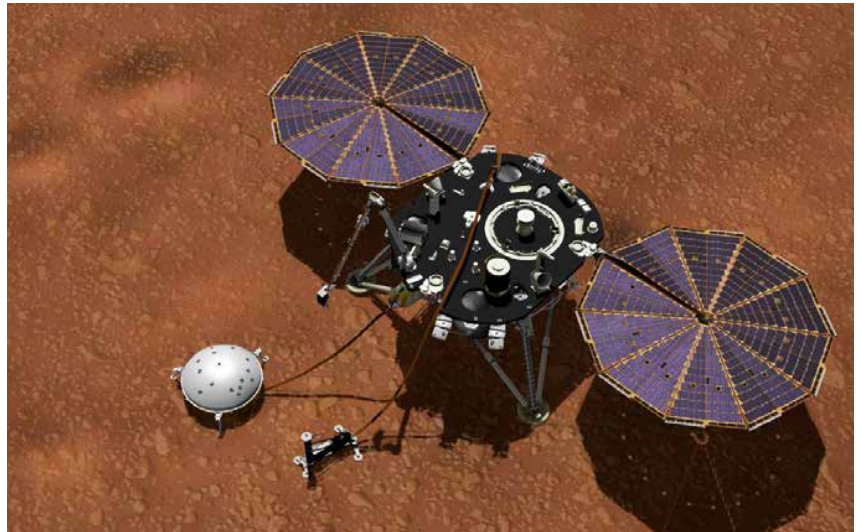


PHOTO: NASA/JPL-CALTECH

Space scout on the Red Planet: InSight – seen here in an illustration of the probe on the surface – delivers valuable insights into the inner workings of Mars.

MARS IS SEISMICALLY ACTIVE

The Red Planet is anything but tranquil. In the first ten months since starting its scientific operations in late February 2019, the seismometer of the InSight probe detected no fewer than 174 Martian quakes. On average, this corresponds to slightly more than one quake every two days. The data obtained by a team including researchers from the Max Planck Institute for Solar System Research provides the first comprehensive proof that Mars, like

Earth and the Moon, is seismically active. However, the tremors on our neighbor in outer space are nowhere near as powerful as those on Earth: none of the recorded quakes achieved a magnitude of more than 4. For 150 of them, the probe could only detect waves that propagate in Mars's crust, whereas the other 24 passed through the planet's rocky mantle and showed similar characteristics to quakes on Earth.

www.mpg.de/14506708

11



PHOTO: RATHGEN RESEARCH LABORATORY, STAÄTLICHE MUSEEN ZU BERLIN – PRUSSIAN CULTURAL HERITAGE FOUNDATION

After World War II, only fragments of “Adoration of the Shepherds” still existed. These are shown here as brownish sections in combination with a black and white photo of the intact relief.

COOPERATIVE PARROTS

Parrots are not only extraordinarily clever but also have a high level of empathy and a strong willingness to help. This is the outcome of behavioral studies of gray parrots by researchers at the Tenerife research station that is associated with the Max Planck Institute for Ornithology in Seewiesen. In their tests, the researchers issued metal tokens to a few birds in a group, who could exchange these tokens for food. The parrots who received a token generally behaved extremely selflessly, passing the token on to their neighbor with their beak if they hadn't received one. Consequently, parrots appear to recognize when a bird of the same species can benefit from their assistance and when they cannot. In further experiments, the researchers also observed that gray parrots are not envious when a bird of the same species receives a better payoff for the same performance or has to work less hard for the same payoff. Rather than an underdeveloped sense of fairness, this behavior may stem from strong pair-bonding behavior. Unlike chimpanzees, who will not put up with unequal treatment of this kind, gray parrots tend to live with a single partner for their whole lives. Animals that form long-lasting partnerships can probably be more tolerant of unequal treatment than non-monogamous species, because their generosity pays off in the long run.

www.mpg.de/1432811

In the behavioral experiments, the parrots receive metal tokens that they can then exchange for food.



PHOTO: COMPARATIVE COGNITION GROUP

IMAGE: SCIENCE PHOTO LIBRARY/MURTI, DR. GOPAL



Electron microscopy image of coronaviruses.

WASTE DISPOSAL FOR CORONAVIRUSES

When cells are subjected to stress, they intensify their disposal of cell components that are damaged or superfluous. Cells can also use this built-in waste disposal system to get rid of viruses. Now, a team from the Max Planck Institute of Psychiatry and the University Clinic in Bonn has discovered a protein for the elimination of waste substances that promotes the disposal of viruses and is regulated by existing commercially available antibiotics and drugs intended to combat intestinal worms. Together with scientists from the Charité hospital in Berlin, the researchers discovered that the active substances can inhibit the proliferation of the MERS coronavirus – a relative of the novel coronavirus, SARS-CoV-2. In humans, the MERS virus can cause severe pneumonia, which is fatal in more than a third of cases. As with SARS-CoV-2, there are still no drugs or vaccines available to combat the pathogen. It remains to be seen whether the active substances will boost the elimination of coronaviruses in humans. In the meantime, scientists at the Lead Discovery Center in Dortmund, a spin-off of the Max Planck Society, are investigating other substances that could stimulate cellular waste disposal systems and be put to therapeutic use.

www.mpg.de/14453988



PHOTO: WIM HOEK / SHUTTERSTOCK

13

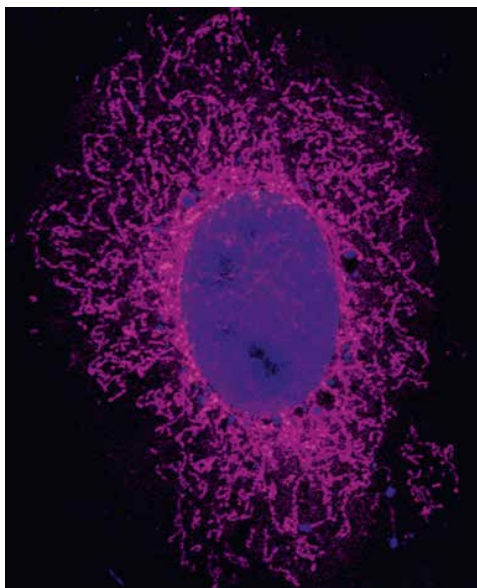
Female blackcap. The species exhibits a wide range of migration behaviors: depending on their origin, the birds fly different distances to their wintering areas, and some of them don't migrate at all.

BIRDS MIGRATE REGARDLESS OF CLIMATIC CONDITIONS

Cuckoos from Kamchatka migrate to Angola to spend the winter there—a distance of about 14,000 kilometers. Where and how far the birds fly is determined primarily by the climate, but this has changed dramatically time and again over the last 50,000 years. Researchers at the Max Planck – Yale Center for Biodiversity Movement and Global Change have used computers to model the worldwide development of bird migration during this period. The simulations show that birds migrated back and forth between summer and wintering grounds even during the last ice age. However, according to the model, the ways in which migratory birds react to climate change varies from region to region. In Europe, Asia, and Africa, for example, there were about as many migratory bird species during the last ice age as there are today, and

the flight distances remained relatively constant on average. The same cannot be said for North and South America, where there were 20 percent fewer migratory bird species during the last ice age. It appears that many of these were resident species during the ice age and only began to migrate afterwards. The migratory routes were also 40 percent shorter than they are today. Thus, bird migration has continued even during major changes in climate. But researchers still don't know how it is being affected by anthropogenic climate change. This is progressing at a faster rate than previous climate change events, and birds' living conditions are also deteriorating in many ways, such as through the loss of habitat and food sources. The computer model can now help to predict the impact of these changes on bird migration.

www.mpg.de/14502196



The ARHGAP11B protein (magenta) in a basal brain stem cell (cell nucleus: blue).

CANCER-LIKE METABOLISM PROMOTES BRAIN GROWTH

The size of the human brain has increased profoundly over the course of evolution. Scientists at the Max Planck Institute of Molecular Cell Biology and Genetics in Dresden have discovered that basal brain stem cells can proliferate thanks to a gene by the name of ARHGAP11B, which triggers the formation of more neurons. Now, the researchers have also established how the gene works: it interacts with another protein in order to close a pore in the mitochondrial membrane, preventing calcium leakage from these organelles. This results in a high calcium concentra-

tion, allowing the mitochondria to generate energy via the metabolic pathway of glutaminolysis and to induce the brain stem cells to proliferate more strongly. A high rate of glutaminolysis is characteristic of highly proliferating cells, notably tumor cells. It would therefore appear that one reason for the pronounced expansion of the human brain over the course of evolution was a change that allowed human metabolism to switch to cancer-like metabolism within the brain for a limited period of time.

www.mpg.de/14324498

A FLEET OF MICROSWIMMERS

A microswimmer from the Max Planck Institute for Intelligent Systems in Stuttgart has outstripped its natural role models. A team from the Institute has developed a micro-robot that swims much faster than bacteria or algae. The tiny floating body is shaped like a hollow hemisphere with a small hole in the bottom. As soon as this is immersed

in liquid, an air bubble forms inside the hollow space. Researchers then use ultrasound to cause the bubble to pulsate, producing thrust that propels the microswimmer forward. In the future, these acoustically powered minisubmarines could be used in minimally invasive medical treatments, for example.

www.mpg.de/14420595 (in German)

FEEDBACK, DONE RIGHT

Feedback is regarded as a crucial component of a successful business culture. Used correctly, it can enhance performance and teamwork. In an experiment, researchers from the Max Planck Institute for Human Development investigated how different types of feedback influence future conduct. The best effect on teamwork was seen when participants received feedback reflecting the performance of the group as a whole. In contrast, ranking feedback – that is, information that classified an individual's personal performance relative to the other participants – led the subjects to increasingly view themselves as competitors. In the extreme, this led participants to aim their actions solely at outdoing others, even if this was ultimately harmful to the group and therefore also to themselves.

www.mpg.de/14436490



SMOKING WITHOUT SMOKE

Not even smoking bans can protect people from passive smoking in public places. Indeed, the air in these spaces still becomes contaminated with pollutants from cigarette smoke (such as nicotine and fine particulate matter) when current or past occupants have previously been smoking elsewhere – because the substances are exuded by their clothing, skin, and hair. Now, for the first time, researchers from the Max Planck Institute for Chemistry and Yale University have been able to confirm the existence of indirect passive smoking using measurements. They recorded the concentration of 35 volatile organic compounds (VOCs)

contained in cigarette smoke in a movie theater auditorium over a period of several days. The results showed that audience members who sit in a movie theater for an hour inhale quantities of contaminants that are equivalent to the secondhand smoke from up to ten cigarettes. The degree of exposure to the individual pollutants depends on their volatility, among other things. In the case of the carcinogen benzene, for example, the exposure was equivalent to the smoke from eight cigarettes. In rooms that are less well-ventilated than a movie theater auditorium, the exposure is likely to be even higher.

www.mpg.de/14558058

A STRANGER WITH AN ELEVEN-KILOMETER RADIUS

Neutron stars are compact, extremely dense remnants of supernova explosions. Occasionally, two of these exotic stellar spheres merge – as was the case in GW170817, an event that astronomers observed in gravitational waves and the entire electromagnetic spectrum in August 2017. From the data on GW170817 and from theoretical considerations, the researchers led by Collin Capano from the Max Planck Institute for Gravitational Physics determined the radius of typical neutron stars, such as those that collided in GW170817. For this, the scientists chose scena-

rios that firstly corresponded to the gravitational waves of GW170817 and secondly generated a short-lived, hypermassive neutron star as a result of the merger. Thirdly, in order to be considered, the models needed to agree with known constraints on the maximum mass, which the astrophysicists had determined from electromagnetic observations of the source of GW170817. The result was that a typical neutron star with 1.4 times the mass of our Sun has a radius of about eleven kilometers.

www.mpg.de/14575466



IMAGE: ESO / L. CALÇADA

A ball of wonder: neutron stars have a mass greater than the Sun, but matter is packed inside them at an unimaginably high density – as they typically have a radius of just eleven kilometers.

THE FIRST SALMONELLA BACTERIA

The beginning of agriculture represented a milestone in the history of humankind. It has long been hypothesized that close contact with animals has led to the emergence of many new diseases – known as zoonoses – in humans. Now, a team of scientists from the Max Planck Institute for the Science of Human History has studied bacteria from the 6,500-year-old skeletons of farmers, thereby shedding new light on the development of zoonoses. The research-

ers reconstructed eight ancient genomes of the pathogen *Salmonella enterica*. Their analysis revealed that these were progenitors of the Paratyphi C strain of bacteria, which now exclusively infects humans but occurs only rarely. The historical salmonellae, however, probably infected humans and animals alike, which suggests that the agricultural way of life actually facilitated the emergence of new diseases.

www.mpg.de/14506431

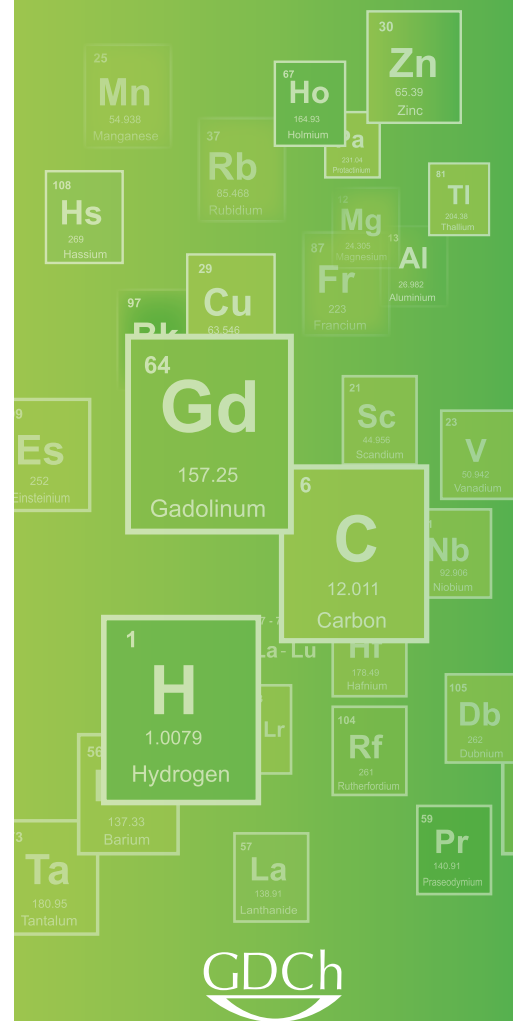
Y O U R
C A R E E R
P O R T A L

for chemistry
& life sciences

From chemists to chemists –
make full use of the GDCh
network:

- ➔ Job market – online and in the *Nachrichten aus der Chemie*
- ➔ CheMento – The mentoring program for young chemists
- ➔ Publications about career paths
- ➔ Workshops
- ➔ Job fairs and lectures

ADVERT



GDCh

GESELLSCHAFT DEUTSCHER CHEMIKER

www.gdch.de/karriere

BETWEEN GUILT, ANXIETY AND HOPE

Receiving a cancer diagnosis is always a shock. There is probably no other physical illness that has such a severe psychological impact on the person concerned. For a long time, researchers sought to find the cause of the disease in the personalities of the patients themselves. This was a fatal mistake, as our author shows on the basis of how the issue was treated in the past.

Perhaps you've also experienced a situation in which a good friend suddenly announces, "I have cancer." At first, you don't know what to say. You want to cheer your friend up and be optimistic. And so, even before you've thought about it, you find yourself saying: "You'll be alright, you'll make it. You're such a positive person." But what if your friend doesn't "make it"? What did you really just say? That, if your friend dies, it will be because he didn't put up a good enough fight, didn't nurture enough hope, or that he didn't have a sufficiently positive attitude towards his illness?

For many years, researchers in the fields of psychosomatics, psycho-oncology and psychoneuroimmunology have been studying how much influence the psyche has on the physical body. To date, research findings have shown that there are complex and by no means clear relationships between the body and emotions when it comes to the way diseases develop and how they are successfully overcome. Even so, whenever people generally talk about cancer, they often claim that it is caused by suppressed feelings, for example, that stress and anxiety have a negative impact on the healing process, or that a positive attitude helps. Assumptions like these can help actively deal with cancer – but they can also be seen as shifting blame onto the person who is ill and thus creating an additional heavy burden. The extent to which scientific research and social attitudes can influence each other and shape how cancer sufferers are treated is shown in the psychosomatic models used in the past regarding cancer development.

→

VIEW POINT

BETTINA HITZER

Bettina Hitzer holds a doctorate in history and from 2014 to January 2020, she led the Minerva Research Group at the Max Planck Institute for Human Development. In 2017, she habilitated at the Freie Universität Berlin, where she works as a Senior Lecturer. In 2016, she was awarded the Walter de Gruyter Prize for her wide-ranging research work by the Berlin-Brandenburg Academy of Sciences. Bettina Hitzer lives with her family in Berlin.



ILLUSTRATION: SOPHIE KETTERER

THE STUDIES FOCUS ON WHAT ATTITUDE THE FEMALE PATIENT HAS TOWARDS HER SEXUALITY

In ancient times, melancholy was associated with the development of cancer. However, in the 19th century, such assumptions were increasingly viewed as obsolete. Cancer came to be understood as a disease that originates at the cellular level at the latest after Rudolf Virchow developed his cellular pathology theory in 1858 – for it suddenly appeared impossible that feelings might influence cells, which could now be seen under the microscope. Even so, practicing physicians (who soon also included female physicians) had clearly not abandoned the idea that such a connection might exist. Medical handbooks repeatedly warned doctors against telling patients that they had cancer, since the diagnosis could cause them to lose all hope and plunge into despair. They claimed that such an approach was also medically damaging, since the anxiety that this engendered allegedly reduced the already low chance of recovery.

The physical effects of anxiety also attracted attention among specialists in psychosomatic medicine, a discipline that attracted renewed interest at the start of the 20th century in connection with the new field of psychoanalysis. Anxiety was declared the number one cause of disease. However, most psychosomatics experts assumed that diseases are only caused by anxiety if they stem from functional disorders that later become chronic. Even as late as 1947, Viktor von Weizsäcker, one of the founding fathers of German psychosomatic medicine, expressed the view shared by most of his specialist colleagues when he claimed that when it came to cancer, a psychosomatic explanation foundered “on the rocks of material processes.” However, attitudes began to change soon after the Second World War. This was due to a complex series of factors.

During the 1930s and 1940s, experimental cancer research pursued new hypotheses and increasingly focused on physiological processes. Researchers no longer attempted to discover a single, specific cause of cancer, but instead began to regard it as a multi-factorial phenomenon. It now appeared more likely that the psyche might also be involved, particularly since up to then, laboratory research and conventional therapies (operation and radiation) had hardly increased the chances of recovery.

In the U.S., psychosomatic medicine had become so well established by the end of the 1930s that it laid claim to recognition as a full-fledged medical discipline. It had close links with the field of psychiatry and made use of psychometric methods at an early stage on its way to attaining scientific acceptance. These included personality tests such as the Rorschach test, named after the Swiss psychiatrist who invented it, which at the end of the 1930s began its meteoric rise to become one of the most frequently used psychological test procedures for decades to come. People who take this test are asked to state which animals and plants or objects come to mind when they are presented with a series of inkblot images. During the early 1950s, this test was also administered to cancer

WERE THERE
NOT NOTICEABLE
PARALLELS
BETWEEN
CONFORMIST,
BOURGEOIS
CITIZENS AND
THE CANCER
PERSONALITY?

patients. The aim was to find out whether specific personality traits or conflicts might play a role in causing cancer.

Initially, these studies focused almost entirely on patients with breast or cervical cancer. The reason given for choosing these two forms of the disease was that they were the most frequent cancers occurring among American women. Yet why were no studies performed on men with stomach and lung cancer, which at that time were the most prevalent forms of cancer among men? It is quite clear that here, the study's design was influenced by contemporaneous debates regarding the role of women in society. Indeed, the results of the studies mainly focused on two aspects of personality: the relationship between a patient and her mother, together with her own maternal nature, and her feelings about her sexuality. At the time, precisely these two aspects of femininity were extremely controversial and attitudes towards them were changing.

Against the background of the attachment theory developed during the early post-war years, mothers who were unfeeling, unable to form attachments or who showed ambivalent behavior towards their child, were viewed in a negative light in the U.S. This applied to the discussion surrounding schizophrenia as well as to psychosomatic cancer research. Here, cancer was frequently also regarded as a type of organic psychosis, i.e. a pathological development that takes on a physical form in conjunction with schizophrenia. It was assumed that an unfeeling mother had a major impact on how her daughters dealt with emotions. The daughters did not learn how to perceive and express unpleasant emotions that were not socially acceptable. They "functioned", but the price for doing so was suppression and self-alienation, as well as latent depression, and later on in life they were unable to cope with the experience of loss.

This personality assessment was initially regarded as (one) specific cause of breast and cervical cancer. However, towards the end of the 1950s, women with other forms of cancer and male cancer patients were also included in personality studies. The notion of a personality structure that caused all forms of cancer, or which made a person more prone to developing the disease, began to take shape. It gained even more traction after researchers presented the results of laboratory studies that appeared to confirm the existence of a cancer personality.

This development came about after the concept of stress gained enormous acceptance during the mid-20th century. The term was originally used in physiology, but now also came to be regarded as a psychological phenomenon. Now, it was possible to conduct experiments on animals to examine whether rats who were emotionally neglected due to early separation from their mothers or subjected to maltreatment with electric shocks



20

SELF-HELP
BOOKS
RECOMMEND
SEEING THE
DIAGNOSIS
AS BEING A
TURNING POINT
AND THE
CHANCE
FOR A NEW
BEGINNING

were more likely to develop tumors than their less stressed counterparts. What's more, psychosomatic research could be combined with research into carcinogenic substances. Were rats or mice who were well cared-for less prone to illness from the carcinogenic effects of tar than anxious test animals who were kept in isolation? Some test series appeared to justify such assumptions, and were cited as further scientific evidence for the results of the psychosomatic cancer research.

During the late 1960s, these results – which were condensed and simplified to create the concept of a cancer personality – attracted a surprising amount of media attention. They were taken up by members of the student movement and politicized. In West Germany, the cancer personality model was used as an example when discussing whether certain feelings and types of relationships were pathological – at both an individual level and within society as a whole. Were there not noticeable parallels between conformist, bourgeois citizens and the cancer personality, i.e. the friendly facade behind which negative feelings were hidden and suppressed, the self-alienation perpetuated in the name of respectability, conflict avoidance and the submission to authority that it entailed?

It was questions like these that interested Fritz Angst (fear), son of a Zurich industrialist, who under the pseudonym Fritz Zorn (anger) published the autobiography “Mars”, one of the trendsetting books of the late 1970s and early 1980s. He regarded his own cancer as being the result of the many tears he had been unable to shed as a consequence of his bourgeois upbringing, where expressing one's feelings was frowned upon. To this extent, he claimed – and this was a new development – that cancer also had a positive side, that it was a wake-up call that had made him aware of the sickness in his soul. For him, the cancer diagnosis opened up the opportunity to make radical changes to his life, and to live in the right, “authentic” way, even if he only had a short time left to do so.

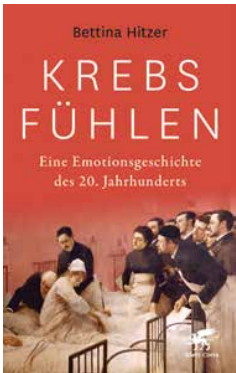
Fritz Angst-Zorn died in November 1976, just before his book was published. His ideas about what cancer stood for were shared by many. The number of self-help books that regarded a cancer diagnosis as being a turning point in life and the start of a new, more honest way of living sky-rocketed. A different attitude towards oneself also supposedly promised a better chance of recovery.

However, there were also those who disagreed with such psychosomatic explanations of cancer. The pointed criticism of the American intellectual Susan Sontag attracted broad attention. As a former breast cancer patient, Sontag denounced such psychosomatic interpretations of illness, since in her view, they placed the blame upon the shoulders of the patient. However, by the time her essay *Illness as Metaphor* was published in 1978, the

concept of the cancer personality was already the subject of controversy within the psychosomatic medical field. One criticism, for example, was that no serious information about the original personality structure could possibly be provided by studies whose subjects had not only experienced the shock of a cancer diagnosis, but were also severely ill and under the influence of painkillers.

Despite methodological innovations, no satisfactory arguments could be presented in response to many of the objections, and as a result, an increasing number of psychosomatic specialists decided to abandon the search for personality factors that might cause disease. Instead, medical practitioners turned their attention to the psychological side- and after-effects of cancer. These questions became more urgent during the 1970s, when chemotherapy became an established form of treatment.

Unlike an operation or radiation therapy, this treatment lasted for weeks or even months. Even those medical practitioners who had previously not taken psychosomatic medicine seriously began to realize that psychosocial support was needed in order to enable patients to endure the hardly tolerable side-effects and continue with the therapy. This led to the creation of psycho-oncology, which aimed to improve the wellbeing and quality of life of patients and as a result to potentially increase their chances of recovery. However, belief in the concept of a “cancer personality” is still widespread among the general public and it often carries – unbeknown to them – the “cultural baggage” described in this article.



THE BOOK

Bettina Hitzer

Krebs fühlen
Eine Emotionsgeschichte des
20. Jahrhunderts
Klett-Cotta, Stuttgart 2020
540 pages, EUR 28.00

**Awarded the Leipzig Book
Fair Prize**

In the medical research field, psychoneuroimmunology – which was established during the 1970s – questions the role of the psyche in a new way. The purpose is to find out how the interplay between the psyche, nervous system and immune system(s) works. It seems plausible that such interrelationships can influence the progress – and possibly also the development – of cancerous diseases. This approach is congruent with general cancer research, which is currently working intensively to find out how the body’s own immune system can be activated in a targeted way for the treatment of cancerous diseases, or be given additional support through the introduction of specific antibodies. The first medications of this type have already been approved. Even so, it remains entirely unclear whether this method will be successful in the long term. However, this is not a question that can be answered by looking back at history. Rather, history shows how public discussion and attitudes towards the body and role models influence research, and how in turn, the concepts of disease that are created in the medical field not only produce treatments, but also have an important impact on the way in which sick people are perceived and treated in society.

FOCUS

PLANTS FOR POWER

22 | Fuel from straw and stubble

30 | Field factories

38 | An inventory of the fossil fuel age

Both food and fuel: while grains of barley and other cereals are regularly processed into food, the leftover straw or stubble can also be used to produce second-generation biofuels.

PHOTO: ISTOCK



FUEL FROM STRAW AND STUBBLE

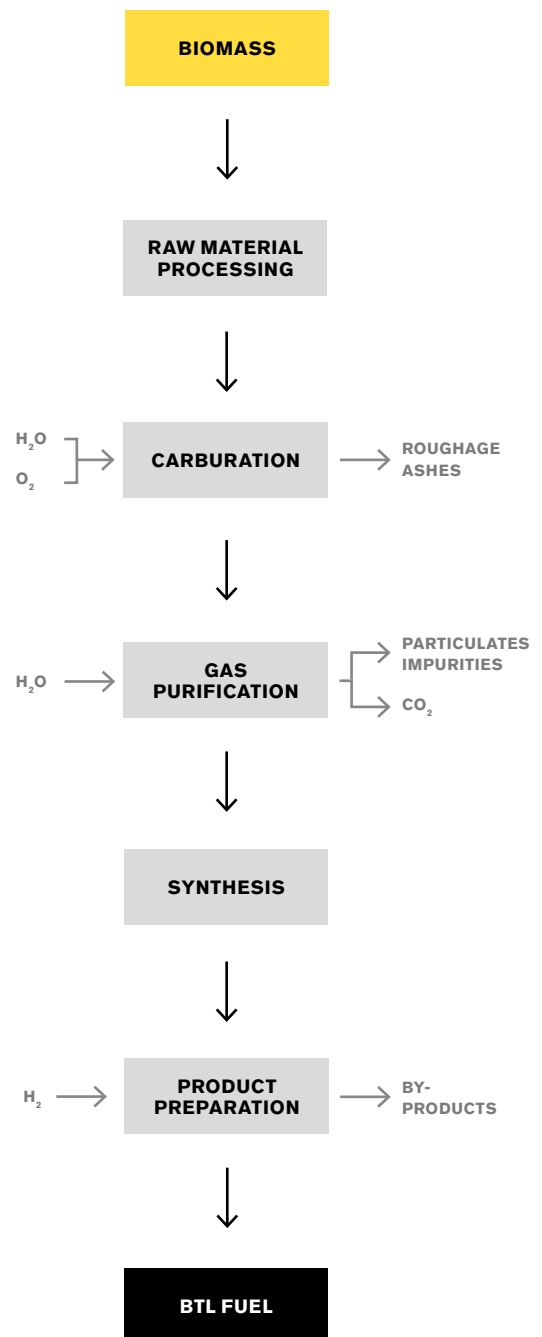
TEXT: RALPH DIERMANN

Second generation biofuels could solve the food versus fuel conflict, because the energy crops involved do not need to be cultivated on arable land specifically reserved for them, which would then no longer be available for food production. Researchers around the world, including Ferdi Schüth, Director at the Max Planck Institute für Kohlenforschung, and Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion, are working on the production of both economically viable and low-emission biofuels.

FUEL FROM BIOMASS

It took nature millions of years to create the raw material that allows us almost unrestricted mobility, namely crude oil formed from dead marine organisms buried under sedimentary rock where they were exposed to high pressure and high temperature over a vast period. So fuels, such as gasoline or diesel, are like a greeting from the deep history of the Earth.

But this process can also be accelerated: refineries are producing high-quality biofuels that are similar to gasoline and diesel from rapeseed, cereals, corn, sugar beet and sugarcane. These fuels can therefore be used in contemporary combustion engines without having to fundamentally change the engines. Biofuels can be distributed via the existing network of gas stations. Because their energy density is almost as high as that of fossil fuels, motorists can get about the same number of miles to the gallon. But, above all, they are much more climate-friendly than their fossil fuel counterparts, because the combustion process within the engine only releases the same amount of carbon dioxide as the plants had previously sequestered. Yet biofuels are by no means climate-neutral, because the cultivation and processing of the crops produces greenhouse gases.



Biopetroleum for fuel and chemical raw materials

Those of us currently filling our tanks with alternative fuels, such as biodiesel or bioethanol – whether in a pure form or as an admixture to gasoline (“E10”) or diesel – are filling them with so-called first-generation biofuels made from grain or seeds. What this means, however, is that these biofuels stand in direct competition with food production. Rapeseed, for example, can be used to produce both a fuel and a healthy edible oil. According to the Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe – FNR), 800,000 hectares of energy crops are currently being cultivated for fuel in Germany, which corresponds to seven percent of the country’s total arable land. Given the continuously expanding global population and the scarcity of agriculturally usable land around the world, the production of first-generation biofuels is resulting in a so-called fuel-food conflict, a good reason for researchers around the world, including scientists at various Max Planck Institutes, to be working on biofuels that can be produced from other organic materials that are not suitable as foodstuffs. The objective is to defuse the fuel-food conflict by expanding the biomass supply for climate-friendly fuels, whereby the researchers are planning to use as many biomass components as possible. Their current focus is on lignocellulose,

Biomass is crushed and dried to obtain liquid fuels from straw or waste wood. With the aid of oxygen, it is then converted into synthesis gas, which primarily consists of carbon monoxide and hydrogen.

After removing any impurities, the synthesis process produces liquid hydrocarbons which can then be used as fuels.



Sawdust as a raw material: wood mainly consists of lignocellulose, from which both biofuel and raw materials for the chemical industry can be derived.

which forms the structural framework of plants and consists of cellulose, hemicellulose and lignin. Its high proportion of carbon and hydrogen makes it an attractive raw material for alternatives to gasoline and diesel, which are nothing more than hydrocarbons. However, it can also be used to produce the substances from which chemical products, such as plastics, can be made. Either straw or agricultural waste can be used as raw material for both applications. Theoretically, the straw (or stubble) alone that is leftover in Germany each year could cover up to three percent of the country's primary energy demand.

Second generation biofuels can be produced in various ways. In the so-called Biomass to Liquids (BtL) process, the biomass is first subjected to heat to produce a synthesis gas consisting mainly of hydrogen and carbon monoxide, but which also includes sulfur and nitrogen compounds (the latter have to be removed, be-

cause they hinder further processing). The synthesis gas is then processed to form liquid hydrocarbons, for example by using the Fischer-Tropsch process, which was developed almost a hundred years ago to liquefy coal. Crude oil refinement processes are then used to transform the resulting mixture of various hydrocarbons into biofuels. "This process," explains Ferdi Schüth, Director at the Max Planck Institute für Kohlenforschung in Muelheim an der Ruhr in Germany, "makes it possible to produce so-called drop-in fuels, which can be used in modern combustion engines with no issues." The BtL process is also suitable for almost any type of biomass.

The process does, however, pose a logistical challenge: due to its relatively low energy content as measured by volume, enormous amounts of biomass are required to keep a production plant running at full capacity. This requires countless truck deliveries to



Mixing makes all the difference: Ferdi Schüth and his team are working on making biofuels more competitive. In the laboratory, the researchers are searching for ways to use biomass not only to produce fuel but also costly raw materials for the chemical industry.



bring sufficient straw and other biomass from the field to the production plant. This problem can be solved through a spatially separated pyrolysis process carried out upstream of the synthesis processes. Among other things, a so-called pyrolysis or bio-oil, consisting of various oxygenated organic compounds and water, is produced; which contains around three quarters of the energy content of the biomass, with a significantly reduced volume. “The bio-oil,” Schüth explains, “is then transported by tanker or train to the BtL plant, where it is processed in the standard manner.” However, this detour via the pyrolysis production process is not only attractive in terms of logistics; it also enables refineries to use the bio-oil to produce other chemical raw materials in addition to fuels.

Enzymatic processes offer an alternative to the BtL concept. “These involve breaking down the biomass following a mechanical pre-treatment with the aid of special enzymes,” Schüth explains. The challenge is to separate the lignin from the cellulose and hemicellulose, the latter of which can be fermented into ethanol. Biomass can also be chemically converted as an alternative to the enzymatic process, which enables the production of a wider range of potential

fuel components, such as furan derivatives. One of the benefits of ethanol and furans is that they burn more cleanly than such things as BtL fuels.

According to a study by the German Environment Agency (UBA), second-generation biofuels could provide between 13 and 19 exajoules of energy globally by 2050. This is still far from enough to cover the entire mobility energy requirement, which the UBA estimates will be between 100 to 179 exajoules worldwide by 2050. However, in terms of climate protection within the transport system, they are a necessary adjunct to electric vehicles and other alternative fuels.

Work on biofuels by researchers in science and industry has already come a long way: major proof of concept plants for both BtL and enzymatic processes demonstrate that, from a technical perspective, these processes work well in principle. Yet the high costs in-

involved are still an issue. “Currently,” says Schüth, “all of these processes are still far too expensive for large-scale commercial use.”

The purification of the synthesis gas from sulfur and nitrogen compounds in the BtL process, for example, is what drives up the cost. In the enzymatic processes, which themselves are anything but trivial, it is the enzymes in particular that are costly. The same applies to the chemically-based decomposition of biomass. Nor is the integration of these enzymatic and chemical processes into existing biorefinery processes particularly easy. “The main thing we need in this context,” Schüth explains, “is to find the optimum balance between the production of fuel and chemical products.”

So there is still a lot to be done by science and industry experts as well as researchers at the Max Planck Institutes, some of whom have been researching biofuels for many years. The Max Planck Institute für Kohlenforschung, for instance, is currently working on synthesis methods for refining bio-oil produced by biomass pyrolysis. “We want to help refineries to be able to produce rather costly chemical raw materials and fuels from bio-oil in the right ratio in an economically viable manner,” says Schüth. In addition to water, bio-oil contains various compounds of carbon, hydrogen and oxygen, such as carboxylic acids, aldehydes and phenols. Processing the bio-oil into fuels and chemical raw materials requires the targeted removal of individual oxygen atoms from the compounds, which is where the Max Planck researchers come in: they are trying to find catalysts that enable such a selective deoxygenation, while minimizing the energy needed to achieve it.

Fewer pollutants

Researchers at the Institute have also developed a novel mechanochemical process which involves grinding cellulose in a ball mill to break it down. This process is faster than conventional methods and generates fewer worthless by-products. “However,” Schüth cautions, “we have to be honest about the fact that nobody could currently apply this process in a commercial setting given the current market situation.”

If the biopolymers are first split from the biomass and then assembled almost at will into new molecules for the production of second-generation biofuels, then it may also be possible to tackle another problem for which road traffic is repeatedly criticized, apart from its poor CO₂ performance, which is the pollu-

SUMMARY

Whereas biofuels from plant waste such as straw do not compete with food production, they are still too expensive.

Biofuels are already being produced in pilot plants using either the biomass-to-liquids process or enzymes, and could cover around one tenth of the global energy demand for transport.

Max Planck researchers are attempting to make the use of lignocellulose more profitable, by using it to produce not only fuels but also rather costly basic materials for the chemical industry among other things.

Altering their molecular composition can reduce both soot and nitrogen oxide emissions from biofuels. In the case of fossil fuels, the emissions of either one of these pollutants can only be reduced at the cost of increasing the emissions of the other.

tion mainly of city centers primarily with particulates and nitrogen oxides. This is because the BtL process could potentially be designed to produce a low-emission fuel.

Researchers at a cluster of excellence at RWTH Aachen University known as The Fuel Science Center, in which the Max Planck Institutes für Kohlenforschung and for Chemical Energy Conversion and the Forschungszentrum Jülich are involved, are pursuing this basic concept. The researchers are particularly interested in the soot-NOx conflict, which is a problem with all fuels derived from pure hydrocarbons, whether fossil or renewable. The term refers to a conflict of objectives during combustion: the less oxygen is present during combustion, the more soot is produced in the form of harmful particulates. However, the more oxygen is present, the more nitrogen oxides (NOx) the engine emits. “What this means,” explains Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion in Muelheim an der Ruhr, “is that the levels of either one or the other pollutant is increased in the exhaust gas.”

28 Scientists at the Fuel Science Center have therefore modified the molecular composition of alternative fuels to reduce both soot and NOx emissions. “We’ve more or less tailored these fuels to reduce emissions,” says Leitner. Not only are the researchers working with bio-based fuels, but also with synthetic, electrically-based fuels. This fuel, which is also known as e-fuel, is made of carbon dioxide and hydrogen, which is produced through electrolysis using electricity from wind turbines, photovoltaic plants or hydroelectric power stations. With fuels such as these, drivers do not have to sacrifice engine efficiency. “Their molecular composition,” the researcher explains, “can even be beneficial, for example by increasing knock resistance and thus engine performance.”

Yet the Cluster of Excellence’s focus is not only on fuels, but also on engines. “Our colleagues from the engineering sciences are modifying traditional gasoline and diesel engines to make the best possible use of the benefits of the optimized fuels, in terms of both emissions and performance,” Leitner explains. The researchers are working, for example, on engines fed by different fuels from two tanks, one of which contains a fuel that ignites particularly quickly therefore optimizing the combustion process, whilst the other supplies the actual operational fuel. But such conceptual engines are still far from being ready for series production. “This is not least due to the fact that the automotive industry is currently putting a lot of focus on other technologies,” says Leitner.

It is quite possible that this may change if policymakers were to create the framework conditions to make

this type of innovative engine concept more attractive to the automotive industry. The same applies to the use of fuels from renewable sources. “They will only win out if the market rewards their use,” as Ferdi Schüth of the Max Planck Institute für Kohlenforschung explains: “And that requires a new course from politicians.”

It is true that the Bundesimmissionsschutzgesetz (German Federal Immission Control Act) already provides an incentive to bring eco-fuel to the gas pumps, as it obliges the fuel industry to continuously reduce the CO₂ emissions of its products. However, to meet this requirement, the companies primarily mix first-generation biofuels, which are significantly cheaper than those made of cellulose, with gasoline and diesel. This is primarily because the industry has been producing fuels from grains and seeds such as rapeseed or sugar cane on an industrial scale over a long period, which keeps costs down in spite of the expensive raw materials.

To bring second-generation biofuels to market, demand must be stimulated to make it worthwhile for the industry to build up the requisite production capacities, as the greater the production volumes, the lower the costs will be. But at least the EU stipulated in the most recent version of the Renewable Energy Directive 2009/28/EC that the proportion of “advanced biofuels in the transport sector” – meaning all fuels made of biological waste and residual materials – should be at least one percent by 2025 and at least 3.5 percent by 2030. With a view to possible land use conflicts, the EU has limited the proportion of first-generation biofuels to seven percent. Yet because second-generation biofuels may be counted twice, the actual maximum target for these is only half as high.

“A CO₂ tax on fossil fuels could help to negate their current cost advantage.”

FERDI SCHÜTH

However, rather than a quota, Schüth and his research colleague Leitner prefer a different instrument, namely CO₂ pricing. “An appropriately priced CO₂ tax on fossil fuels could help to ensure that they lose their current cost advantage over more climate-friendly alternatives,” says Schüth. Leitner, however, points out that this would only apply if blending bio-based or even synthetic, electrically-based fuels is recognized as an emission-reducing measure, “which,” says Leitner, “is not yet the case under current EU regulations. There is an urgent need for action in connection with the forthcoming amendment, so that not only CO₂ emissions from engines, but also CO₂ binding during production are taken account of. Initially,” he continues, “biofuels and e-fuels do use CO₂ to enable the utilization of renewable energy. They are, so to speak, putting sunshine in the tank.”

<https://www.mpg.de/podcasts/biooekonomie> (in German)



GLOSSARY

BIOMASS-TO-LIQUIDS PROCESS (BTL)

This term refers to the thermochemical processes by which biomass is converted into liquid fuels. A synthesis gas, i.e., a mixture of carbon monoxide and hydrogen, is first produced from the biomass. This is then used to produce liquid hydrocarbons, for example using the Fischer-Tropsch synthesis process.

FISCHER-TROPSCH SYNTHESIS

Originally, this process was developed to produce liquid fuels from coal, but it can also be applied to biomass. The process involves the synthesis of liquid hydrocarbons from carbon monoxide and hydrogen, which are obtained from the solid raw material.

LIGNOCELLULOSE

Lignocellulose is the structural material of plants and consists of the polysaccharides cellulose and hemicellulose as well as lignin, a complex biopolymer.

An alternative to the alternative: as Walter Leitner sees it, biomass is not the only source of climate-neutral fuels. He is also making progress with the conversion of CO₂ and hydrogen from renewable sources into hydrocarbons and other chemical products.

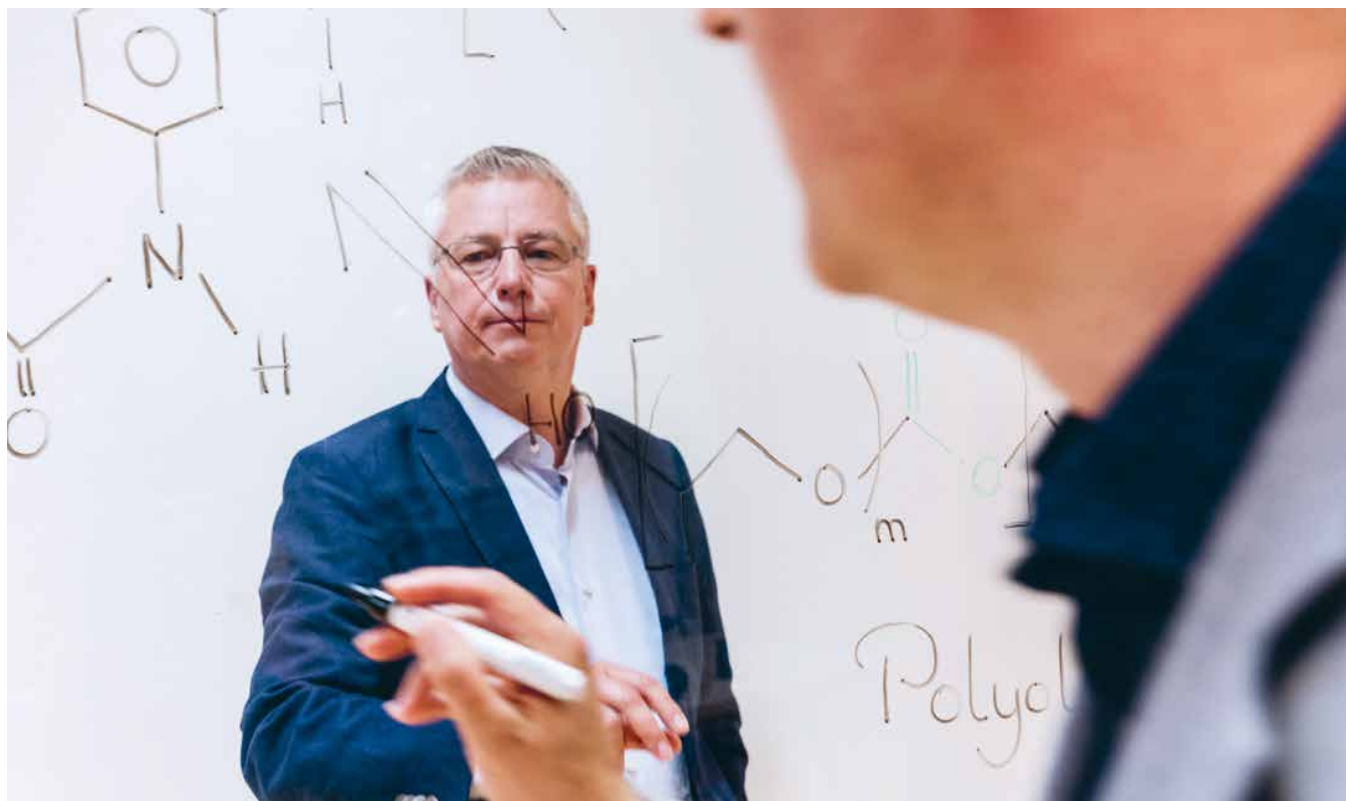


PHOTO: ANSGAR PUDENZ



30

FIELD FACTORIES

TEXT: CATARINA PIETSCHMANN



PHOTO: MARKA/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Factories of the future will be growing in fields – at least according to Ralph Bock and his team at the Max Planck Institute of Molecular Plant Physiology in Golm.

The researchers are hoping to turn plants into production sites for substances that would otherwise be difficult and expensive to produce.

One plant that has recently been somewhat scorned could experience an unexpected renaissance in pursuit of this goal.

A tobacco plantation in Italy. These plants could also be cultivated for the production of pigments or vaccines in the future.



PHOTO: SCIENCE PHOTO LIBRARY / AMI IMAGES

Electron microscope image of the alga *Chlamydomonas reinhardtii*. Researchers want to produce the pigment astaxanthin in algae such as these (center: nucleus, black: chloroplast).

32

Plants don't grow by fresh air and love alone. They can, however, produce an incredible variety of substances from comparatively few initial materials. Carbon dioxide from the air, sunlight, plus water and minerals – these are the ingredients from which plant cells produce carbohydrates in a process known as photosynthesis. These sugars form the basis for a vast range of carbonic substances such as cellulose, starch, fatty acids, amino acids, proteins, hormones, and vitamins in addition to various pigments, odoriferous substances and toxins. Plants produce all of these substances for their own use, but they also incidentally serve as food for humans and animals.

These “green factories” work extremely efficiently, sustainably and without producing any environmentally harmful waste. On the contrary, microorganisms decompose dead plant matter completely, and then reintroduce it into the natural cycles of material. All of these properties continue to make every chemist green with envy. But couldn't we put the potential of plants to even better use for humans?

This concept is known as “molecular farming.” One particularly promising approach is based on targeted genetic modifications within the so-called chloroplasts, the organelles within the plant cells that are responsible for photosynthesis. Chloroplasts have their own genomes and are therefore able to produce some of the proteins used in photosynthesis themselves.

Ralph Bock is hoping that these changes to the genome will enable his plants to produce substances that are of importance to humans. The pigment astaxanthin, for example, is a substance produced by *Haematococcus pluvialis*, a unicellular marine alga, and is a powerful antioxidant. Fish and crustaceans absorb astaxanthin via their food and use it to form red-colored muscle tissue. In contrast, farmed salmon have to be fed extra pigment, otherwise their meat remains white and cannot be sold at such a high price. As a food supplement, astaxanthin is not cheap: it costs USD 15,000 per kilogram, because it has to be extracted from the

“Making biofuels from rapeseed is both economic madness and a sin against the environment.”

RALPH BOCK

algae using a complex process. Bock and his team are relying on tobacco plants instead: “If,” says Bock, “we integrate the metabolic pathway for the production of astaxanthin into the plants, they’ll be able to produce it at a significantly lower cost.”

The quantity of astaxanthin produced by the leaves of genetically modified tobacco is visible at a glance from their orange hue. Viewed under the microscope, it can be seen that this is due to the chloroplasts which are closely packed within each plant cell: whereas regular tobacco leaves are green, due to the natural leaf pigment chlorophyll, the astaxanthin crystals color the leaves of the modified plants a bright orange. But why are the researchers using chloroplasts as bioreactors instead of the entire plant cell? “After years of intensive research,” Bock explains, “we now know that non-native genes are easier to activate within the chloroplasts. In addition, they are only inherited from the female plant so the risk of modified genes being blown to neighboring fields via pollen and transferred to non-modified plants is minimal.” Another major advantage is that each chloroplast contains up to 100 copies of a given gene; at about 100 chloroplasts per cell, this adds up to 10,000 copies. “So we can produce much larger quantities of a given substance in this way,” says Bock.

Tobacco plant with the astaxanthin genes (left): the pigment formed within the chloroplasts gives the leaves a reddish hue.



PHOTO: MAX PLANCK INSTITUTE OF MOLECULAR PLANT PHYSIOLOGY

Tobacco, which is already one of the model plants used in biology, is ideally suited to large-scale molecular farming; its genome can be altered more easily and quickly than that of other plants, for reasons that are still not understood. It also grows extremely quickly, which means that its leaves can be harvested several times a year.

There is also a social aspect involved: because less and less tobacco is needed for cigarettes, many tobacco farmers in the U.S. are struggling to survive. “Farmers in Kentucky and Virginia are very conservative,” Bock explains: “For them, the idea of switching to wheat, corn or potatoes is completely unthinkable.” So, existing tobacco acreage could continue to be used and the tobacco farmers would gain new opportunities for the future – a classic win-win scenario. But tobacco has another property that almost predestines it for use as a botanical bioreactor: its toxicity. The nicotine within the leaves is so toxic that just consuming a single leaf could kill a human being. “Anyone hoping to produce pharmaceutically active substances in a certain plant species naturally wants to avoid these substances entering the food chain at all costs,” says Bock: “The risk of this is negligible if a plant is inedible from the outset.” So, tobacco that contains astaxanthin is unsuitable as fish food for farmed salmon, because the nicotine would have to be removed from the tobacco extracts. A much better approach would be to equip an organism that can be added directly to fish food with the relevant metabolic pathway, which is why Bock’s team are relying on red and green algae. Both are cheaper and can be added to the fish food in desiccated form.

Artemisinin, an antimalarial drug, is one example of a medicinal substance derived from plants. It is derived from *Artemisia annua* (sweet wormwood) an annual short-day plant grown in China, Vietnam and some countries in southern Africa. However, the plant only contains 0.1 to 0.4 percent of the active ingredient in its dry mass. Even genetically modified plants developed by the researchers in Golm contain no more than that. Tobacco, on the other hand, produces much more biomass than the small wormwood plant. The greater yields would also increase the quantity of artemisinin per hectare that could be harvested many times over.

Tobacco is therefore the model that Ralph Bock uses to test out his ideas. The researchers must first discover which metabolic pathway could best be repurposed for the production of the desired substance and how much of a given molecular intermediary step the plant could live without. “We mustn’t interfere with the metabolic processes too much, or the plant won’t grow enough.”

→

Scientists have collected vast amounts of data on the concentrations and activities of metabolic products over the years, so they know precisely what quantity of a given enzyme is required to enable the plant to produce a new substance. They therefore first have to couple the new genes with existing signaling structures, so-called promoters, which determine the extent to which the gene should be activated and transcribed. Next, they coat nanoparticles of gold with different variants of the relevant DNA segments and “shoot” them at pieces of a leaf using a kind of pressure gun. A small quantity of these particles get lodged inside plant cells, which can then read and transcribe the DNA to produce the desired proteins. The genetically modified leaf cells are then grown into complete plants in culture media.

Certain technical questions are also of central importance: is there a simple and inexpensive way of enriching the substance and, if so, could it be scaled up? Substance extraction can be lengthy and costly; the extent to which it is or is not worthwhile depends crucially on the intended use of the molecule. “If, for example, we can only isolate ten milligrams of a given substance from one kilogram of leaves at great expense,” Bock explains, “then of course it is not suitable as a fish food supplement. The same quantity may however be sufficient for a highly effective cancer drug.”

It is easiest if the desired molecule can be produced in an edible plant. “Tomatoes, for example, are ideal for health-promoting substances, such as vitamins, because you can eat them raw.” Tomatoes are rich in the red pigment lycopene, the precursor to vitamin A. Vitamin A deficiency, which is prevalent in large parts of Africa and South Asia, impairs vision, increases susceptibility to infectious diseases and causes growth and fertility disorders. “Using a relatively simple enzymatic conversion process,” Bock explains, “we can produce vitamin A from lycopene in tomatoes.” Genetically modified plants could also be used to produce edible vaccines. To prevent a loss of efficacy, vaccines used for vaccination campaigns in the tropics usually have to be refrigerated for transportation and storage. But tomatoes, for example, could be cultivated directly on site and could also be stored for a certain period. Cereals, nuts or pumpkin seeds could also serve as “factories” and natural packaging for future vaccines.

A whole host of applications are conceivable. But the term “genetic engineering” still raises hackles among large sections of the population in many industrialized nations. Surveys suggest that 70 percent of Europeans are against so-called green genetic engineering, which involves the genetic modification of fruit,

vegetables and cereals, yet 90 percent of soya products currently come from genetically modified plants. And another fact that most consumers are unaware of is that traditional breeding techniques often involve the use of mutagenic chemicals or radiation, which cause a large number of random mutations in the genome.

The situation is exactly the opposite when it comes to using transgenic plants to produce drugs: 70 percent of those surveyed think that these green genetic engineering applications are a good idea. Actually, this is absurd, as scientists are unanimous in their opinion that inserting or modifying genes to protect a crop against insect damage or to make it more resistant to drought is harmless. If, on the other hand, a new, highly potent active substance is produced in a plant, researchers first have to clarify a number of safety issues, because, under no circumstances must the substance be permitted to enter the food chain accidentally. “One would think,” says Bock, “that would cause more concern. But this is the very point that the populace views least critically.” In his opinion, these contradictory survey results reflect the priorities of Europeans. “Immanent health risks include stress, cancer, cardiovascular diseases and dementia and we need new drugs to tackle them. By contrast, we have no lack of food. Africans, of course, view things quite differently,” Bock emphasizes.

It is currently virtually impossible to carry out field experiments with genetically modified plants in Germany. “We have almost given up on that entirely,” says Bock. Whilst researchers can apply for the regulatory approval of the release of transgenic plants for research purposes, the relevant experiments are barely feasible in practice. “Although we were very candid about our experiments and invited public participation, activists cut fences at night and destroyed the plants.” The experiment had to be repeated a year later under stringent surveillance. “That protected field experiment cost us EUR 30,000. After that, we decided only to perform release experiments when the expected knowledge gain would be so great that the expense would be justified.” As a result, Bock and his team usually only study their

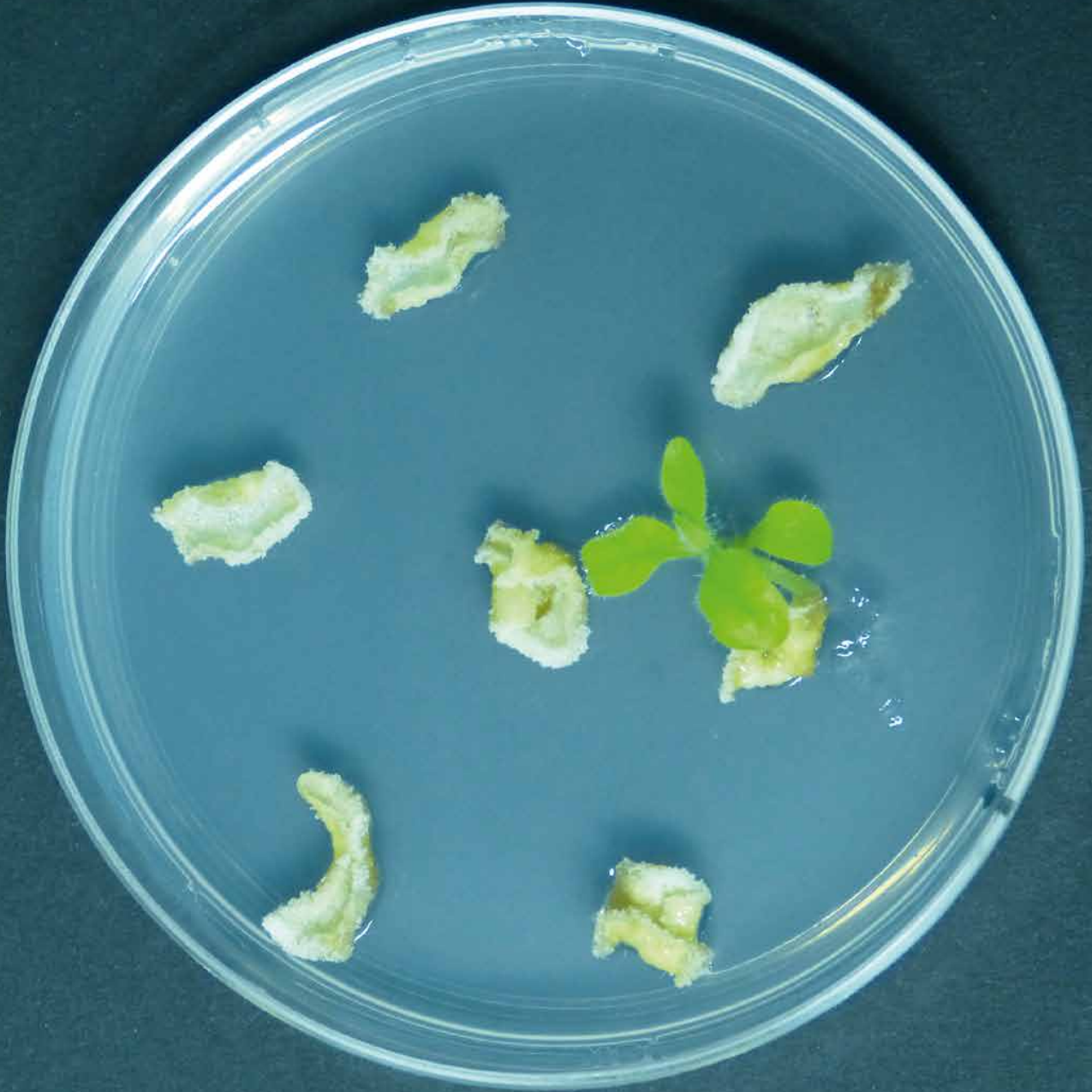
SUMMARY

Researchers are transforming plants into “green factories” by inserting genes into the chloroplast genomes.

Plants can use the new genes to produce such things as vaccines and vitamins.

Because they can produce large quantities of any given substance, tobacco plants are particularly well suited to being used as “green factories.” But other crops as well as unicellular algae can also be converted into “green factories” in bioreactors.





To insert genes into the cells, researchers bombard leaf cells with tiny, DNA-coated nanoparticles. The leaf fragments then grow into complete tobacco plants with novel properties in special culture media.

plants in the greenhouse. Whenever the results look promising, researchers from both the Max Planck Institute of Molecular Plant Physiology and Knowledge Transfer of the Max Planck Society seek partners in industry to continue the development to market maturity.

Yet regardless of how environmentally friendly and sustainable molecular farming may sound, could it not suffer a similar fate to that of plant-based biofuel production? After all, the initial enthusiasm for energy crops quickly subsided once the world became aware of the consequences of immense cornfields and palm oil plantations, which included the replacement of species-rich meadows by monotonous arable land and tropical rainforest clearances. Whilst biofuels may be good for climate protection, they can have disastrous consequences in terms of biodiversity. “Bioenergy from the field” is something that even Ralph Bock is skeptical of. “For example, in contrast with tobacco plants containing active substances, only a fraction of the biomass of rapeseed can be used. Only a few liters of biodiesel are extracted from the seeds at huge expense and at the cost of severe environmental pollution. This is both economic madness and a sin against the environment.”

There is another reason that the area required for molecular farming is significantly smaller than that of energy and fodder crops: “We’ve done the math on artemisinin,” Bock explains: “We would need a cultivation area the size of the city of Boston to cover the global demand with our tobacco plants.” Not a great deal, when one considers the fact that this could be used to treat the more than 200 million people who become infected with malaria every year. Transgenic plants are, therefore, an elegant and cost-effective alternative for the production of active pharmaceutical ingredients compared with traditional pharmaceutical production methods, which often still rely on the use of petroleum, particularly because it is even possible to produce several active substances in parallel in a single plant, for example as combination vaccines.

In one sense, molecular farming represents a return to the roots of medicine, as, for thousands of years, people have been treating their ailments with natural active agents. Medicinal plants have always been mankind’s pharmacy, and could now become so once again, but with the benefit of 21st-century know-how.

<https://www.mpg.de/podcasts/bioeconomie> (in German)



In Ralph Bock’s view, genetically modified tobacco plants offer a more sustainable way to produce substances in the future.



PHOTO: SEVENS+MALTRY, MAX PLANCK INSTITUTE OF MOLECULAR PLANT PHYSIOLOGY

GLOSSARY

CHLOROPLASTS

... are the organelles responsible for photosynthesis in plant cells. Whereas some unicellular algae have just a single chloroplast, more advanced plant species can have several dozen of them per cell. With the aid of the leaf pigment chlorophyll, chloroplasts convert solar energy into chemical energy, which enables them to form carbohydrates from carbon dioxide and water.

Chloroplasts evolved from microorganisms that were originally independent and therefore have their own distinct genomes.

Their ring-shaped DNA molecule, which contains around 100 genes, is considerably smaller than the genetic material within the cell nucleus.



Back to the Future ...

Did you read the headline, remember a 1980s film, and ask what frontier research has to do with it?

Like a VCR, your brain just generated a stream of memory-related sequential activity patterns.

The Foundation supports Yingxue Wang at the Max Planck Florida Institute for Neuroscience; she tackles the question how the hippocampus processes information, when our brain integrates past and future into the present.

The Max Planck Foundation has supported the Max Planck Society for more than ten years by providing targeted funding for top-level innovative and cutting-edge research at the more than 80 institutes, enabling breakthroughs in frontier science. As a patron, you can make a crucial difference by creating additional scope to keep this research ahead of the curve in the international scientific competition. Join us!

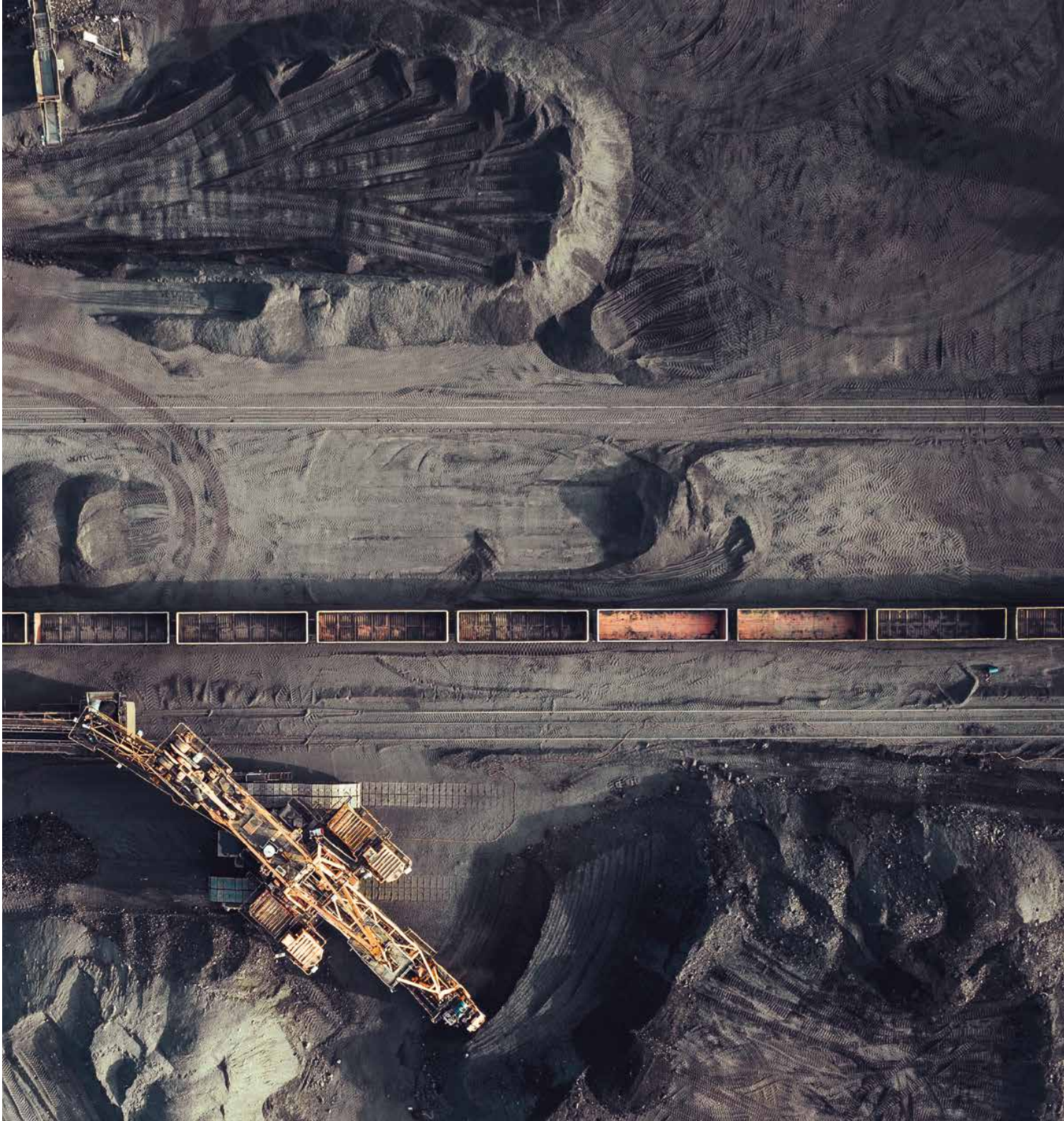
Max-Planck-Foundation
Deutsche Bank
IBAN DE46 7007 0010 0195 3306 00

ADVERT

www.maxplanckfoundation.org



MAX PLANCK FÖRDERSTIFTUNG
FOUNDATION



AN INVENTORY OF THE FOSSIL FUEL AGE

TEXT: JEANNETTE GODDAR

PHOTO: MARK AGNOR / SHUTTERSTOCK



Black wasteland:
open-pit coal mining
has a massive impact
on the landscape.

The changing climate necessitates saying farewell to oil and coal. But our society, and especially our ideals of freedom and prosperity, are heavily dependent on the use of fossil fuels. Researchers at the Max Planck Institute for the History of Science in Berlin are investigating just how strong this dependency is and how we can free ourselves from it.

There are days in Germany when the energy transition is on every channel. For example, on the day in January when the Chancellor discusses life after the internal combustion engine with automobile industry leaders at noon and then meets with the Prime Ministers of the four coal-producing states for the coal summit in the Federal Chancellery in the evening. Two meetings that make it clear: there's much more at stake than just oil and coal and billions of euros. Tens of thousands of jobs, structural policy, the already sensitive relationship between East and West and deeply rooted traditions are also affected.

If you ask Benjamin Steininger from the Max Planck Institute for the History of Science, fossil resources have an even greater impact on our world than such days make it seem: "We live in cities that can only be reached in motorized vehicles, we wear Goretex and nylon, we use artificial fertilizers in our food production and we rely on drugs – all based on oil, gas and coal. From both a concrete and an abstract viewpoint, our lifestyle is affected by fossil resources in ways in which we are only dimly aware." Steininger adds that even a sociopolitical achievement such as the abolition of labor by children and workers without rights became possible only when and because their tasks were taken over by machines powered by fossil fuels. Fundamental modern concepts such as individual freedom, prosperity and progress have also developed alongside the technical system of utilizing fossil fuels.

But this is not an appeal to cling to the mass combustion of resources that is harmful to the climate. Instead, it is a call to recognize that it's not enough to switch to electric motors and say goodbye to plastic bags. Steininger demands – and promotes – a study of the intangible heritage of our fossil fuel-based modernity that has been largely ignored until now: "For two centuries, fossil resources have been pushing the limits of technical feasibility and with them our understanding of growth, of freedom, and our desires." Together with Alexander Klose, Steininger is curating an exhibit on petro-modernism at the Kunstmuseum Wolfsburg and is producing a cultural atlas of oil, which was also the source for the image on this page. "You can't just leave a house you've been living in for 200 years," he says. "We have to take an inventory."

A small group is taking just such an inventory within a larger group at the Max Planck Institute for the History of Science. In addition to media and cultural theorist Benjamin Steininger, the smaller group includes ethnologist Gretchen Bakke and historian Helge Wendt. The larger project group is called "Knowledge in and of the Anthropocene" and takes a comprehensive approach to understanding the



PHOTO: ARCHIV ROHSTOFF-GESCHICHTE

**“For two centuries,
fossil resources
have been pushing the
limits of technical
feasibility and with
them our understanding
of growth, of freedom,
and our desires.”**

BENJAMIN STEININGER



Oil production in 1932: because the tanks of the production plant in Zistersdorf in Lower Austria were not large enough to contain the escaping oil, workers directed the excess into hastily-dug pits. This image illustrates just how much the methods of handling crude oil have changed in Europe.

geological period influenced by humans. It is cooperating in this project with the Haus der Kulturen der Welt in Berlin, which has been working since 2012 on event series, publications and exhibitions about the presentation and understanding of all the processes with which people are significantly changing our planet. The Max Planck Institute is inviting scientists to participate and is working on an Anthropocene curriculum and an “interdisciplinary culture of knowledge and education.” It was last involved in an event and research project on the Mississippi River over several months in 2019, also with Benjamin Steininger.

Historian Helge Wendt is focusing on the resource that is still very much present in Germany: coal. Wendt is studying a process around the world that was also an energy transition – that from wind, water and wood to the entire range of coal types from lignite to anthracite. “Even the Romans knew of hard coal,” explains Wendt. “But to this day, it is not really known what they used it for.” From the 16th century onwards, coal was mined on a larger scale in a number of countries, ranging from China and India to Eu-

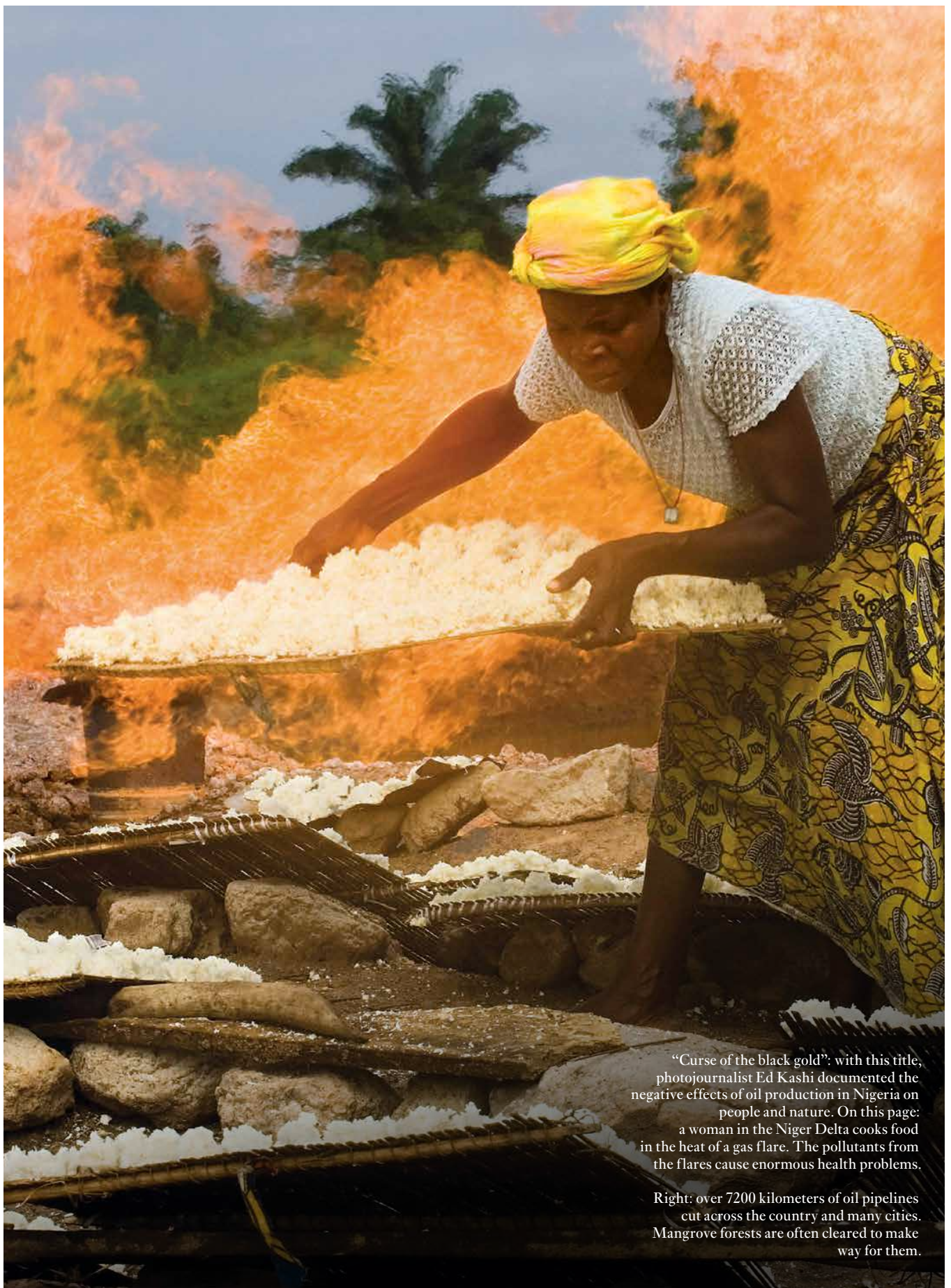
rope. This mining began relatively simultaneously, even though the global flow of knowledge at the time was sparse. The greatest hurdle to mining that had to be overcome everywhere was that of groundwater. It was not until the invention of the steam engine that the mines no longer had to be laboriously drained by horses. The first steam engine, Wendt explains, was not at all the one invented by James Watt in 1769 and described in schoolbooks around world. A certain Thomas Newcomen had already invented a model, albeit not a very energy efficient one, in the early years of the 18th century. This engine first helped to supply water for the English royal family before being used for mine drainage.

Contrary developments often occur at the same time

Wendt collects not only anecdotes but also knowledge: about combustion temperatures and the storage properties of different types of coal, as well as about their implementation, such as in coking. This process releases detrimental sulfur and phosphate components from the coal and produces coke, with the help of which metal smelters were developed on a large scale in the 19th century, leading to the German steel industry and later the automotive industry. Even more interesting is a consideration of “all the byproducts and waste products that led to industries we hardly even think about when discussing coal.” For example, the coking process also produced coal gas, which was found to be useful for illuminating factories, homes and streets, and coal tar laid the foundation for the paint and pharmaceutical industries. It is also largely forgotten by the public today that the acronym BASF stands for “Badische Anilin- & Soda-Fabrik” – aniline is a byproduct of coal processing.

Starting from all these somewhat hidden uses for coal, Helge Wendt rolls back history, as it were, and asks in each case what could have been used instead. And consequently: “Can coal be replaced everywhere? What can or should we do without? And is it conceivable – as a parallel to the energy transition towards coal – that today’s shift towards renewable energies will also lead to useful byproducts?”

Benjamin Steininger explains that when considering the key resources of modern culture and history, it is just as important to focus on the chemical processes resulting from them. His research therefore takes him to both the Max Planck Institute for the History of Science and the UniSysCat Cluster of Excellence at the Technische Universität Berlin, which is dedicated to the contribution of catalysis to a more sustainable chemical industry.



PHOTOS: ED KASHI/VII/LAIF

“Curse of the black gold”: with this title, photojournalist Ed Kashi documented the negative effects of oil production in Nigeria on people and nature. On this page: a woman in the Niger Delta cooks food in the heat of a gas flare. The pollutants from the flares cause enormous health problems.

Right: over 7200 kilometers of oil pipelines cut across the country and many cities. Mangrove forests are often cleared to make way for them.



Dependent on coal and oil:
a transition to sustainable
material cycles is also necessary
in the chemical industry.



“In the case of oil, it is not a black natural substance that has determined our history. Rather, it is a substance that has seeped into every aspect of our lives through chemical reactions,” explains Steininger. This is especially the case in Germany, a country which has hardly any raw materials, but a tremendously strong chemical industry. If the social sciences and humanities are essential for a successful energy transition, wouldn't it be good if this also became common knowledge in the chemical research industry? “Certainly,” answers Steininger, “because that would mean accounting for these long-term effects from the start and thinking in terms of sustainable cycles of both energy and materials. That would be a radically new innovation.”

The Max Planck Society has been implementing such approaches for a number of years now. Scientists from the Max Planck Institutes for the History of Science and for Chemical Energy Conversion regularly combine their perspectives and work on common agendas. Shortly after the kickoff event, Directors Jürgen Renn (History of Science) and Robert Schlögl (Chemical Energy Conversion) published a joint manifesto on the energy transition in April 2017.

This states with a directness that is atypical for scientists: “In both climatological and geopolitical terms, now is the right time to undertake a massive transformation of the system.”

Now, almost three years later, at least a deadline has been set for the exit from coal. After years of tough negotiations, the aforementioned coal summit in the Federal Chancellery succeeded in deciding on a deadline for the end of production within Germany: 2038. However, many climatologists say this is far too late, with a bluntness that is no longer so unusual today.

The good news: there are many encouraging approaches for the more sustainable use of resources. This is pointed out by ethnologist Gretchen Bakke, who is involved in the Anthropocene project through a guest professorship at the Humboldt University of Berlin. She has achieved a certain degree of fame in the U.S., and was only recently directly attracted to Germany – and thus to a place where great importance is attributed to climate research. She was conducting research in Quebec, Canada until 2018. She recently wrote a book that Bill Gates put on his

top 5 book list: “The Grid,” meaning the power grid in the U.S. In addition to establishing that this grid is (dis)organized by an incredible number of 3600 utility companies, Bakke acquired insights that she can now apply in Europe. Of these, a key one is that there are many, often contrary, developments that occur simultaneously, and these are not always consistent with common expectations. For example, sunny Florida uses hardly any renewable energy – while wind energy supplies 50 percent of the power to the currently Republican state of Iowa. Bakke: “What is interesting for me is when change takes place, and where: which culture, which values and which incentives promote or prevent transformation?”

She is therefore searching for dialog partners in politics and science, as well as in civil society, but she also deals with questions that, as she says, “are increasingly also being aired in the elevator: why do people use cars instead of trains, trains instead of cars, planes instead of trains? The fact that these discussions are even taking place is a sign of change,” she explains: “There are always pioneers, and there are always areas where there does not – yet – seem to be any progress.” She also brought with her an American example of the effect pioneering can have: “Just ten years ago, the idea of using the sun as a source of energy was still considered absurd in the U.S. – that was something for hippies or Germans. Today, solar energy is slowly but surely spreading in the U.S. as well.”

The ethnologist points out that essentially, there is not one energy transition, but two – one towards renewable energy and another away from fossil fuels. This soon becomes clear when she considers less obvious innovations, such as the production of cement and steel by more climate-friendly processes that release less CO₂. “It's technically possible,” she says, “but political support is necessary for such products to become marketable – including approaches that make previous technologies less attractive.” Now political solutions such as the coal compromise always take time – just like the construction of factories and changes in production. Bakke therefore sums up her findings as follows: “Change is happening. Whether it's happening fast enough, I can't say.”

<https://www.mpg.de/podcasts/bioeconomie> (in German)

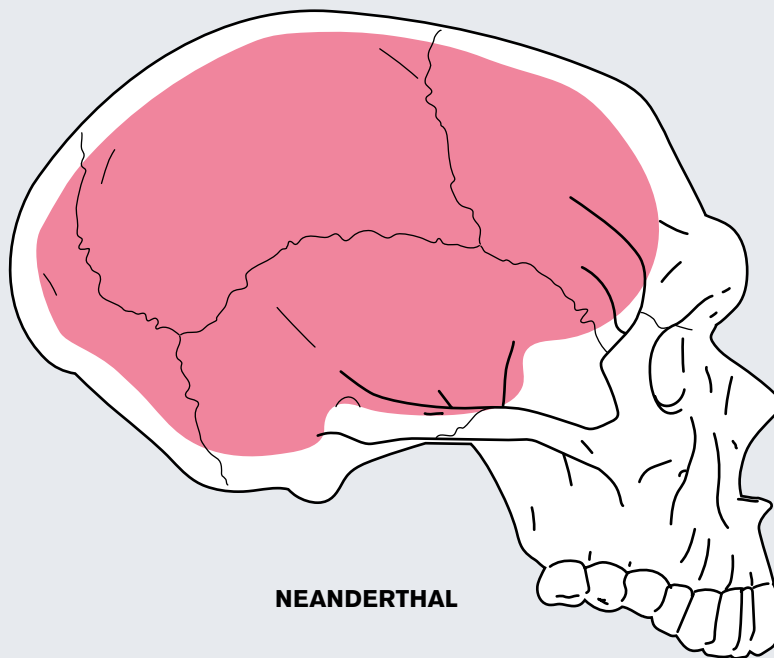
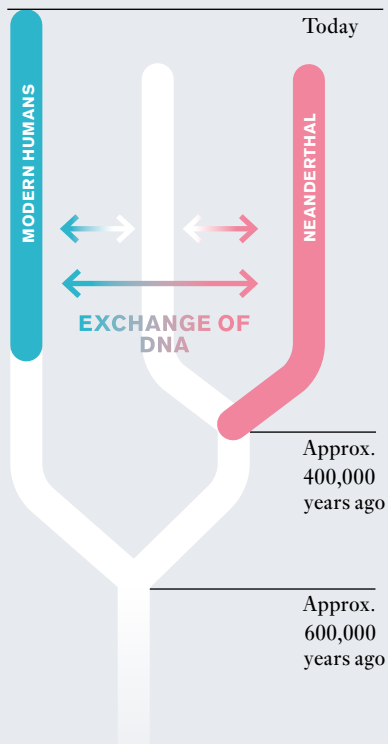
SUMMARY

The last energy transition, in which water, wind and wood were replaced by coal, shows that such a transition has many side effects.

Today, coal and oil are not only an important source of energy, but also form the basis for countless chemically produced substances and materials. Thus the chemical industry will also have to undergo a reorientation.

In addition to politics, the present energy transition is also affected by factors such as culture, morals and convictions.

THE NEANDERTHAL IN US



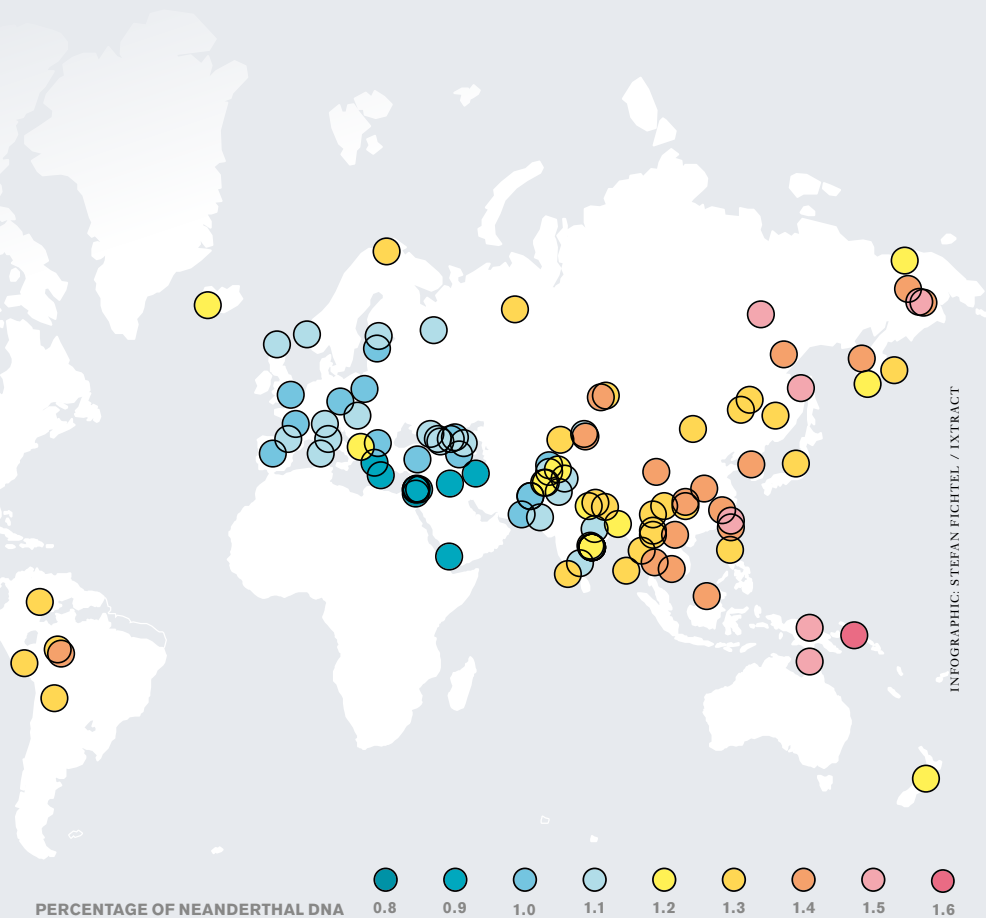
46

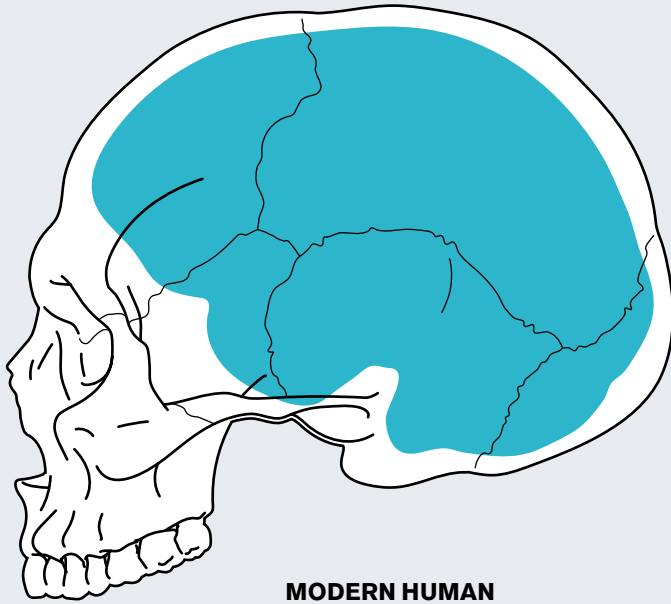
BUSH INSTEAD OF TREE

The human family tree is not so much a tree with a single trunk, but more a bush with many branches. For many thousands of years, several lines of descent existed simultaneously, which intermingled several times.

TRACES OF STONE-AGE ENCOUNTERS

Since Neanderthals never lived in Africa, they did not come into contact with the modern humans who emerged in Africa. It was not until after leaving the African continent that modern humans encountered Neanderthals in the Middle East and Europe and reproduce with them. Varying degrees of genetic traces from such encounters can still be found today in the genome of people outside Africa.



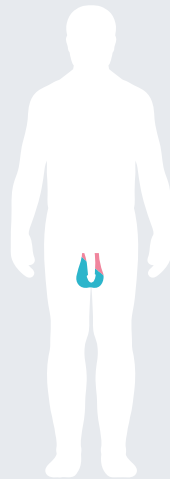


52 m
436,860 A4 pages



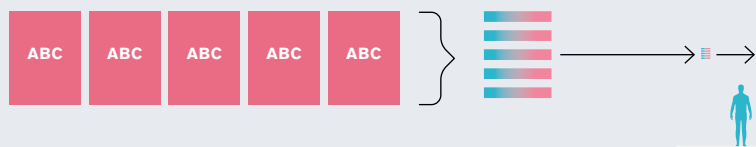
THE LEGACY OF NEANDERTHALS

Neanderthals and modern humans exchanged genetic material: on average, people living today carry between one and two percent Neanderthal DNA. To date, 40 percent of the entire Neanderthal genome has survived in modern humans. Neanderthal genes influence the development and function of many different organs. The testes are an exception, where the Neanderthal versions of genes are less active.



EXTRINSIC LETTERS IN THE GENETIC CODE

The genetic code of modern humans consists of 3.2 billion letters. This corresponds to 436,860 A4 pages in 10-point writing. Stacked on top of each other, this would amount to 52 meters, about the height of a utility pole. The mixing with Neanderthals has led to the alteration of 31,000 letters in the human genome. Combined on A4 pages, this stack would be 0.6 millimeters high.



THE PHILOSOPHER OF THE BIG BOUNCE

Humankind has always been fascinated by the mythical concept of a cyclic universe that ends in a cosmic conflagration and is then reborn. Modern Big Bang theory that suggests an infinitely expanding universe rules out this possibility. But has the final word been spoken on the issue? Anna Ijjas investigates this fundamental question at the Max Planck Institute for Gravitational Physics in Hannover.

TEXT: THOMAS BÜHRKE

More than 1,600 years ago, the famous theologian Augustine posed the question of what God may have been up to before creating the world. His answer was both simple and surprising: “Before God made heaven and earth, He did nothing.” This actually agrees pretty well with the Big Bang theory that cosmologists use to describe the beginning of the universe. Before the Big Bang, nothing existed, neither space nor time. Our current knowledge of physics enables us to describe all the processes that started within the hot fireball about one billionth of a second after the Big Bang. Whatever happened before that is beyond our knowledge. And the actual Big Bang? It’s a “singularity” that both pillars of modern physics – the theory of relativity and quantum physics – fail to explain.

But what if there never was a Big Bang? Could our universe have originated from a precursor? Anna Ijjas at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Hannover, Germany is breathing new life into this age-old cosmological model.

You have to be a fast walker to keep up with the lively researcher as you follow her along the corridors of the Institute to her office. The office itself is still sparsely furnished with little more than a laptop on the desk. The janitor stops by briefly to check on something. Anna Ijjas has only been in Hannover since early September 2019. She is one of the first nine group leaders of the Lise Meitner Excellence Program recently established by the Max Planck Society. She was selected out of nearly 300 candidates from 42 countries.

With the Lise Meitner Excellence Program, the Max Planck Society intends to increase the number of female scientists in leadership positions with the goal of identifying future female Directors for the Society. Within five years, Lise Meitner Excellence Group Leaders are guaranteed participation in a tenure procedure for an associate professorship (W2). Upon positive evaluation, they will be permanently granted the W2 position with group resources. The selection process was tough, and the final decision for Anna Ijjas offers insights into the current situation in basic research. The scientist had previously spent several years at Princeton University. “Research in the U.S. is very conservative,” she says. “Junior scientists there often follow well-trodden paths.” Ijjas credits the selection committee of the Lise Meitner Excellence Program for having consciously chosen a candidate who embraces a more unconventional approach.

—>

VISIT TO

ANNA
IJJAS



PHOTO: FRANK VINKEN

Unconventional: Anna Ijjas is taking an unorthodox approach to investigating the origins of the universe at the Max Planck Institute for Gravitational Physics.

However, in the field of cosmology – the study of the origin and evolution of the universe – it seemed that much of the science had already been settled. “Theorists made great strides from the 1970s to the 1990s,” says Anna Ijjas. With string theory, a comprehensive description of all forces of nature appeared to be found. And the hypothesis of an inflationary universe promised to solve all the problems associated with the Big Bang cosmology.

Inflation is an integral part of today’s Big Bang cosmological model. It describes a rapidly accelerating expansion of the universe beginning right after its birth. Subsequently, the universe continued to expand at a decelerating rate. “Today many theorists are convinced that we have come very close to the big answers and that we only need to clarify a few more details,” says

never lost sight of her goals. Anna Ijjas was born in a small town in Hungary in 1985. Her father was a physician and knew a German who gave private lessons. So Anna began to learn German at the age of five. Later, while at high school in Budapest, she went to Bavaria for two months as part of a student exchange. After graduating, it was clear to her that she wanted to study abroad. But she did not agree with her parents’ wish for her to become a lawyer. Instead, she enrolled at Ludwig-Maximilians-Universität to study mathematics and the philosophy of religion in Munich, with the goal of eventually becoming a high-school teacher. Later, she also added physics to her curriculum.

Upon completing her undergraduate degrees, Ijjas concentrated her efforts on the natural sciences and obtained a doctorate in philosophy. The title

“It would be pure arrogance to claim we have already figured out nearly everything. Quite the opposite – we need new ideas.”

Ijjas. However, she has a completely different take on the situation. First, we know next to nothing about 95 percent of the universe: dark matter and dark energy remain great mysteries. String theory is still unable to provide any concrete predictions that can be tested by astronomical observations or physical experiments. And the theory of inflation has so many flexible parameters that it can be adjusted to fit nearly any observations. “Andrei Linde, one of the founders of the theory, likes to say that there will never be an observation that could be used to refute inflation,” says Ijjas. “It would be pure arrogance to claim we have already figured out nearly everything. Quite the opposite – we need new ideas.”

The path to this insight was long and by no means a straight one for the researcher. However, she

of her thesis was inspired by an aphorism credited to Einstein: “The Old One with the Dice: On the Metaphysics of Quantum Mechanics.” There, she maintained that an interdisciplinary dialog between science and religion is both possible and fruitful. At first, she tried to unite both fields, especially in conversations with friends. Now she regards them as two realms that have little to do with one another: “Science and religion can coexist,” she says.

At the time, she was unsure whether she was good enough to become a researcher. But then she was encouraged by her mentor, Harald Lesch. Armed with a scholarship, she went to the U.S. and sought out two particular scientists as mentors who are known for their creative ideas. One of them, Paul Steinhardt, had made a significant

—>



Probing the heavens: the Simons Observatory, a project in which Anna Ijjas participates, is under construction in the Atacama Desert in Chile. These telescopes could answer the question of whether or not we live in a cyclic universe.



PHOTOS: DEBRA KELLNER / SIMONS OBSERVATORY

contribution to the development of the inflationary paradigm. In 2002, though, Steinhardt surprised his colleagues with an alternative hypothesis that assumes a cyclic universe. This ekpyrotic universe forgoes a Big Bang out of nothing and without space and time. With the term “ekpyrosis” or “conflagration,” Steinhardt revived old myths of the world ending in a fiery catastrophe and being reborn from the ashes.

Inflation requires very special initial conditions

Since then, Anna Ijjas has had increasing doubts about inflation theory. In her opinion, the theory has two critical weaknesses: on the one hand, it necessitates very special initial conditions, and on the other, the theory leads to the claim that an infinite number of universes are created, each with different properties. One of these is our universe.

“What bothers me about this is that we cannot go on to explain the origin of these properties,” says the Max Planck researcher. Everything is possible, and physics can’t even predict what is probable. Ijjas refuses to accept this arbitrariness. She demands that physics meets a different standard: “I want to know why the world is the way it is.” In this, she pursues Albert Einstein’s enigmatic question: did God have any choice when He created the world?

Ijjas addressed problems of the inflationary paradigm in her second dissertation, which she concluded by examining a new class of cyclic models. “These don’t need as much fine tuning,” she summarizes in her thesis. And she circumvents yet another unsolved problem of the Big Bang theory, namely the Big Bang itself. There is no explanation for how the universe could have originated from a quantum fluctuation based on the laws of physics as currently known to science. Both relativity theory and quantum physics fail under these circumstances. Most theorists try to get around this dilemma by seeking a unification of the two theories: quantum gravity. Thus far, however, all attempts in this 40-year-long endeavor, including string theory, have failed.

As a result, researchers are now trying out various other models. “Although quantum gravity is essential for some problems in physics,” Anna Ijjas says, “our cyclic universe approach does not need it.”

In all the cyclic models, our world passed through a transitional phase: a previous universe had slowly contracted and expanded again. According to this picture, the Big Bang was actually a Big Bounce. “In that moment, space and time were in a state that can still be described by the laws as we know them,” says Ijjas. “To describe the Big Bounce, we only have to introduce a new type of interaction between matter and spacetime.”

The cosmologist has produced key new results over the past three years. In one of her calculations, the previous universe contracted down to a size of 10-25 centimeters before it underwent the Big Bounce. This is only one trillionth of the diameter of a proton, yet it can still be described with today’s physical laws. This model also explains all the issues associated with the original Big Bang theory which inflation failed to resolve. The Big Bounce scenario put forward by Anna Ijjas and her colleagues manages entirely without inflation. It also accounts for dark energy, which otherwise has been difficult to accommodate, especially within string theory. Seen in this way, the cyclic universe has many advantages. But does it describe reality? And how can we find out if it does?

In her first doctoral thesis, Ijjas had come to the conclusion that many physicists follow their personal preferences and world view more often than they would care to admit. Intuition as already invoked by Einstein plays a major role. “This applies to me as well,” she admits. “However, in the end, we have to be able to make an empirical decision as to whether a theory is right or wrong.” The scientist follows Karl Popper’s approach here. Strictly speaking, according to his philosophy of knowledge, theories cannot be proven experimentally, they can at best be falsified. Those theories which survive empirical tests prevail in a selection process. “Dissatisfaction with the theory of cosmic inflation in this regard has led me to conceive of the alternative,” says Anna Ijjas.

End and beginning: according to the Big Bounce model, the present universe developed from a predecessor. At the end of its existence, this predecessor contracted to a tiny volume that then rebounded to create our cosmos.

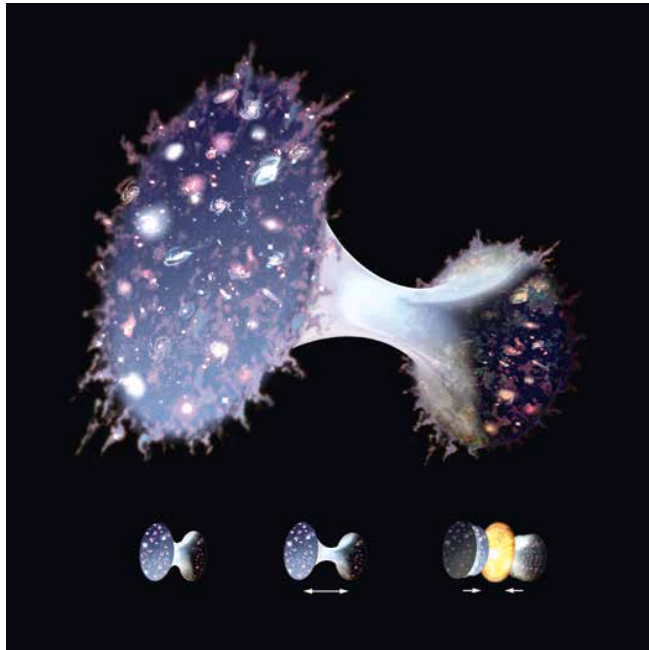


ILLUSTRATION: MIKKEL JUUL JENSEN / SCIENCE PHOTO LIBRARY

She needs a strategy to be taken seriously at conferences

It's not always easy for her at conferences with this unconventional cosmology – especially not as a woman who looks younger than she is. She was often not taken seriously. “People thought I was simply a student who had nothing to offer,” she recalls. She has no issues with objective criticism but had to develop a strategy to even be noticed. “I don’t want to give others the feeling that they are wrong; I just want to present my own standpoint without claiming to be the sole purveyor of truth.”

Anna Ijjas enjoys fact-based discussions and respects differing opinions. She lives for science and hardly has any time for hobbies. Running every day, an occasional evening at the opera or a hike in the mountains, is about all she has

time for. She has learned to play the violin, but she has no opportunity to practise. She doesn’t own a TV, and after work, she often continues her calculations on the cyclic universe at home. And this model does actually offer the possibility of falsification as stipulated by Popper. If an event as violent as inflation occurred, gravitational waves would have to have formed. By contrast, the reversal in the cyclic universe was gentler, without severe shocks in spacetime. Traces of this primordial phase should still be detectable in the cosmic background radiation.

This background radiation, which can be observed everywhere in the sky, is considered to be the oldest information in the universe. It formed about 380,000 years after the current expansion started and exhibits subtle fluctuations that serve as seeds for the subsequent evolution of galaxies and galaxy clusters. Gravitational waves must produce a polarization pattern – a partial alignment of the waves in the background radiation. In the spring of 2014, a report went around

→

Lively debate:
Anna Ijjas in discussion
with cosmologist
Paul Steinhardt (center)
from Princeton
University and Roman
Kolevatov, who is a
PhD student there.



PHOTO: FRANK VINKEN

54

the world in which researchers claimed to have measured exactly this polarization with the BICEP2 telescope. The proof for the inflationary universe appeared to be at hand. However, this claim was later refuted by more detailed analyses using data collected with ESA's Planck space telescope: the measured polarization of the background radiation was caused by dust in the Milky Way galaxy. Since then, the search for this Holy Grail of cosmology has continued to gain momentum.

Anna Ijjas will be working with one of the new telescopes at the Simons Observatory in the Atacama Desert in Chile. The project is financed by U.S. billionaire Jim Simons. With her latest results mathematically modeling the Big Bounce, Ijjas recently convinced him to continue supporting her research even after her move to the Max Planck Institute for Gravitational Physics. This constitutes a unique exception, as the Simons Foundation only supports projects in the U.S. "Jim prefers the theory of a cyclic universe for philosophical reasons," says Ijjas.

The Simons Observatory could solve the question of polarization within the next five to ten years. What if it were actually found, refuting the prediction of the cyclic universe? "According to Popper, this would be an ideal situation, because we would at least know what the universe is not like, and that alone would teach us a lot," says Ijjas. In that case, she would have to turn to new ideas – something she has no problem doing.

Incidentally, on the tricky question of what God was doing before creating the world, the theologian Augustine quotes a colleague who had facetiously answered: "He was preparing Hell for those who pry too deeply into such great secrets." Anna Ijjas will just have to hope that this anonymous philosopher was mistaken....

←

RESEARCH DOESN'T HAVE TO BE HEAVY.

The Max Planck Society's magazine is available
as an **ePaper**:

www.mpg.de/mpr-mobile
www.mpg.de/mpresearch

DOWNLOAD THE
EMAGAZINE FOR FREE!



The fruit fly *Drosophila melanogaster* only grows to a size of two to three millimeters. Scientists use a brush to separate individual insects with differing characteristics.



THE METHUSELAH COCKTAIL

TEXT: KLAUS WILHELM

KNOWLEDGE FROM

— BIOLOGY & MEDICINE

Linda Partridge and her colleague Sebastian Grönke at the Max Planck Institute for Biology of Ageing in Cologne can't promise eternal life – but they are at least discovering ways to lead a healthier one. The researchers' findings in fruit flies and mice have revealed astonishing new insights into aging that will also benefit us humans.

The fruit flies of Sebastian Grönke that made it into the tubes marked “Rapa” have won the lottery. They reach an age of two months – an advanced age for flies – and are still fit and healthy. “Rapa” stands for “rapamycin”, a drug that’s one of the most promising anti-aging substances of our time.

Flies exposed to rapamycin – up to now prescribed as an immunosuppressive drug following kidney transplant – don't just live considerably longer, they also stay healthier. The Max Planck researchers can measure such improvement by means of a specially devised fitness test for flies: “When rapamycin is added to their food, they still perform at the same level at 60 days old as they did when they were young,” Grönke explains.

In addition to a daily dose of rapamycin, their food contains two other drugs: lithium, known as a mood stabilizer to treat depression, and the drug trametinib, which is used to treat cancer patients. “The triple cocktail extends the usual lifespan of the fruit flies by almost 50 percent,” explains Linda Partridge, who heads the Department of Biological Mechanisms of Ageing at the Max Planck Institute in Cologne. The drugs have enabled some of the insects to live for as long as four months – the highest age ever attained through the administration of drugs. Typically, the flies die between two and three months of age.

On the strength of such results, Partridge is optimistic that such advances will also enable humans to remain generally healthy into very old age. “We won't be able to do away with death,” she says, “but we can certainly reduce illness and infirmity in old age.” Her life as a researcher has mostly been devoted to unravel-

ing how cells, tissues, and organisms age. She now heads research teams at the Max Planck Institute in Cologne and at University College London. Numerous biological mechanisms are conserved across species, and that's why scientists usually perform research on flies and mice. “Time isn't on our side; life expectancy is continuing to rise in many western industrialized countries,” Partridge says. It has been calculated that in 2060, there will be more than ten million people over the age of 80 living in Germany. Every fifth baby born today could live to be 100.

When it comes to aging, genes only play a minor role. “Their contribution to life expectancy is less than 20 percent – perhaps even less than ten,” the biologist explains. Environmental factors, individual behavior, and a person's social and economic status are far more important. Unhealthy habits such as overeating, sedentary lifestyle and smoking have been proven to reduce life expectancy. →

Experiments on different animal species are continually revealing new ways in which the biological clock can evidently be turned back. Two years ago, for example, a discovery by Dario Valenzano, a colleague of Partridge at the Institute, caused a stir. He had found that fish fed microorganisms from the guts of younger fish of the same species live longer. In another study, colleagues in the U.S. discovered that replacing the blood plasma of older mice with that of younger animals had an astonishing effect on the aging process.

In many animals, exercise and diet are the primary factors influencing the speed of aging. Mice that are allowed to consume only 60 percent of their normal diet live considerably longer and remain healthier than mice fed a standard ration. Rhesus monkeys have also been to live longer under dietary restriction when the diet contains sufficient quantities of vitamins and minerals. In recent years, however, Partridge and her team have come to suspect that the key to living a longer and healthier life into old age isn't calorie restriction; instead, it's the particular nutrients in an animal's diet. It is eating too many of these, they suggest, that will reduce life expectancy and increase the risk of age-related diseases.

In the laboratory, Sebastian Grönke points to an ordinary-looking shelf lined with dozens of cans. These contain chemicals for the flies' food. In a time-consuming process, Partridge's colleagues in London developed a fly food with a chemically defined formulation. This allows the scientists to modify the diet of the flies at will. This enabled Grönke to discover which nutrients prolong lifespan and improve health in old age. Fruit flies fed on a diet high in protein and amino acids die earlier. To compensate, the insects lay a large number of eggs. Conversely,

flies fed on a diet with less protein live longer. And this comes at the cost of reduced growth and lower fertility.

The scientists, however, wanted more detailed information. "Our results show that not all amino acids are equally important. Essential amino acids such as leucine, isoleucine, or valine are particularly important for longevity," Grönke explains. Essential amino acids are those that the body can't synthesize itself; they have to be ingested with food. They regulate a signaling pathway known as "TOR," which is involved in important aging processes in cells.

The researchers observed the same phenomenon in mice. One study has revealed that consuming lower quantities of certain essential amino acids can actually have a positive effect on health – including in humans. However, it's still unclear whether this also results in longer life. The scientists also used the genome information of the fruit flies to define their dietary amino acid requirements. "This allowed us to develop a specialized diet for fruit flies that contains neither too few nor too many amino acids," says Grönke. "Animals fed this food feel full earlier and therefore eat less. Nevertheless, they grow faster, become larger, and lay more eggs than other fruit flies fed with standard food. And, despite this, they live just as long," Grönke explains.

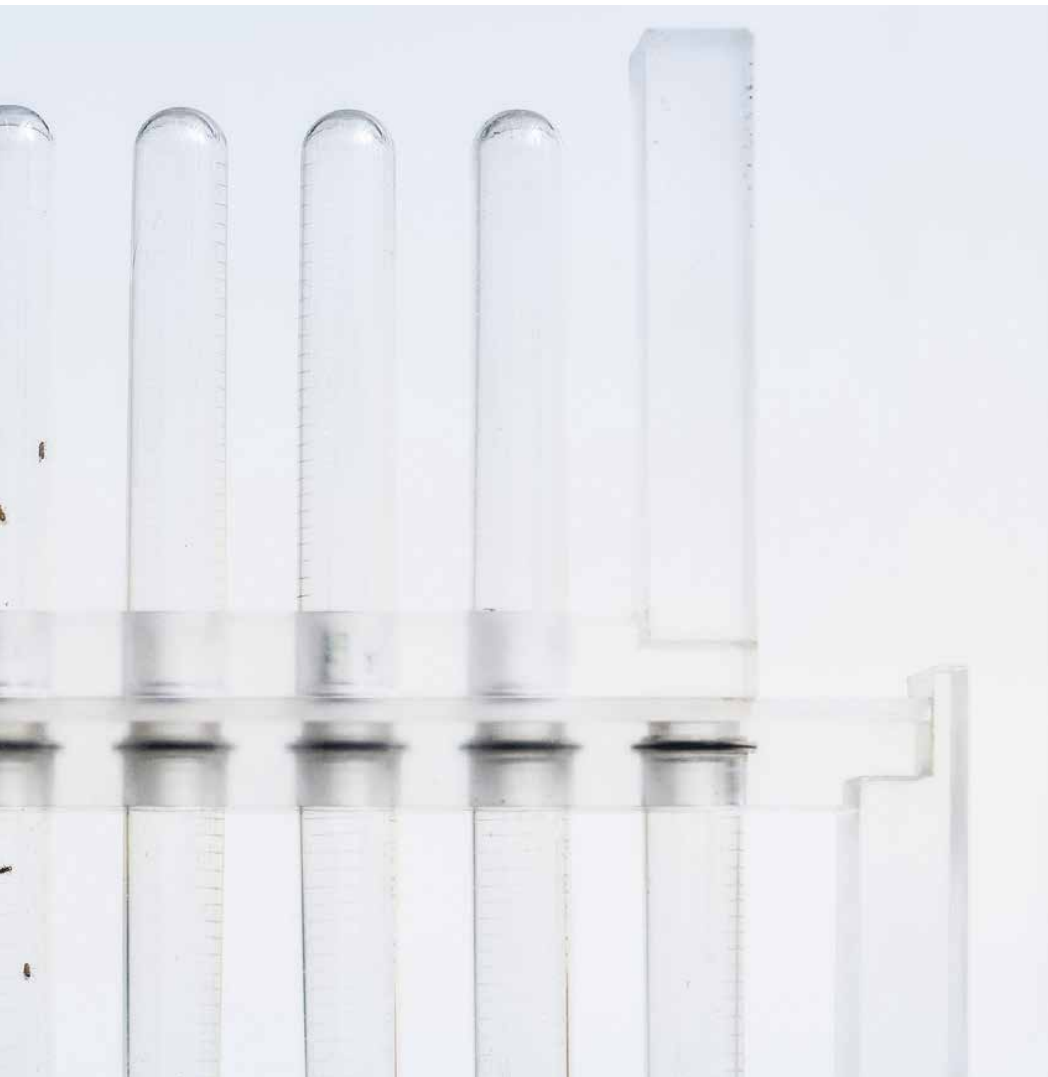
Reducing the quantity of essential amino acids has an impact on a network of cellular signaling pathways known as the "IIT network." This network is active in a wide range of organisms, from fruit flies to humans, and controls development, cell proliferation, growth, reproduction, and the stress response. The network includes "insulin/IGF-1" and "mTOR" signaling pathways, each with a large number of differ-



PHOTOS: FRANK VINKEN

The fruit flies in Linda Partridge's and Sebastian Grönke's laboratory live in finger-length tubes sealed with a gas-permeable stopper.





Fitness test for flies: only physically fit flies can climb up the tubes quickly. When the first ones have reached the top of the left-hand tube, the upper section is moved to the right, and the next round begins. Gently tapping the tube sends the flies back to the bottom and then they have to repeat their climb to the top. This procedure is repeated five times, until the fittest flies have reached the far right section.

59

ent signaling molecules, the most important of which are IGF-1 and mTOR. Flies and mice that have the modified genes for these molecules age more slowly and become genuine Methuselahs. Like a precise sensor, the IIT network measures the nutrient status in the body and adjusts metabolic processes as required, based on the demand for and availability of food. Reduced food consumption evidently puts a brake on the activity of the network.

The drugs lithium, trametinib, and rapamycin also have an effect on various signaling molecules of the IIT network, reducing its activity. Each

individual substance extends the longevity of the flies by an average of eleven percent. A combination of two of them increases life expectancy by around 30 percent, while all three increase life expectancy by nearly 50 percent. At the same time, they complement each other when it comes to reducing side effects. Rapamycin on its own induces adiposity, while lithium appears to negate this.

Drugs that can slow down and promote healthy aging, it seems, are no longer a mere pipe dream. Metformin, used to treat diabetes, is another possibility. Its impact on life expectancy will soon be investigated in a large-scale

study in the U.S. involving several thousand participants. People who are unable to prolong their lives even with optimal nutrition could benefit from such drugs. Most of us, after all, find it difficult to stick to a dietary regimen for decades on end.

The researchers have also searched for other anti-aging candidate drugs. They trawled through a database of active agents with known effects and performed computer simulations to find out whether these bind signaling molecules in the IIT network.

They soon discovered what they were looking for. A drug known as tane-



spimycin had already proven its potential in the model organism most frequently studied by researchers on aging: the nematode *Caenorhabditis elegans*. It blocks the heat shock protein Hsp90 and reduces the number of “senescent cells.” These are mature cells that increase in number in old age and emit substances that facilitate chronic infection. As a result, they contribute to diseases associated with old age, such as heart attack and cancer. In young people, the immune system removes these cells. In the elderly, however, they are protected from destruction by precisely the Hsp90 protein.

“mitochondria”, the power generators of the cell, and, this was also sufficient to extend the lifespan of the animals. The IIT network therefore controls various life-extending processes in different tissue types.

and measured the impact on life expectancy. In the young animals, the results were as expected. The mice on a restricted diet lived to a very old age and were still comparatively healthy even at an advanced age. In contrast, animals fed a restricted diet only later in life experienced little or no benefit.

Tanespimycin is associated with severe side effects, however, and needs to be administered with caution. “Even so, it might be feasible to combat old age-related diseases with short-term localized administration, such as in cases of macular degeneration of the eye, the commonest cause of age-related blindness,” Partridge explains. This prompted the researchers to investigate whether drugs targeting the IIT network might delay aging throughout the body, even though they are activated only in certain tissues. They analyzed whether the brain, muscle, gut, and adipose tissues of a fruit fly produce the same proteins when the IIT network is less active. “That clearly wasn’t the case, as we discovered. The various cell types respond differently,” Partridge explains. Of the 6,000 proteins studied, 2,400 are synthesized at differing levels in the brain, muscle, gut, and fat. The gut, for example, produces more enzymes that control the quality of protein synthesis when the IIT network is less active.

SUMMARY

The IIT network has a major impact on how organisms age. Pharmacological and genetic inhibition of this cellular signaling network results in increased life expectancy.

Dietary restriction and reduced consumption of essential amino acids decrease the activity of the IIT network. Fruit flies and mice therefore live longer in laboratory tests when they are given a restricted diet.

A combination of rapamycin, lithium, and trametinib significantly increases the life expectancy of fruit flies. The drugs also reduce activity of the IIT network.

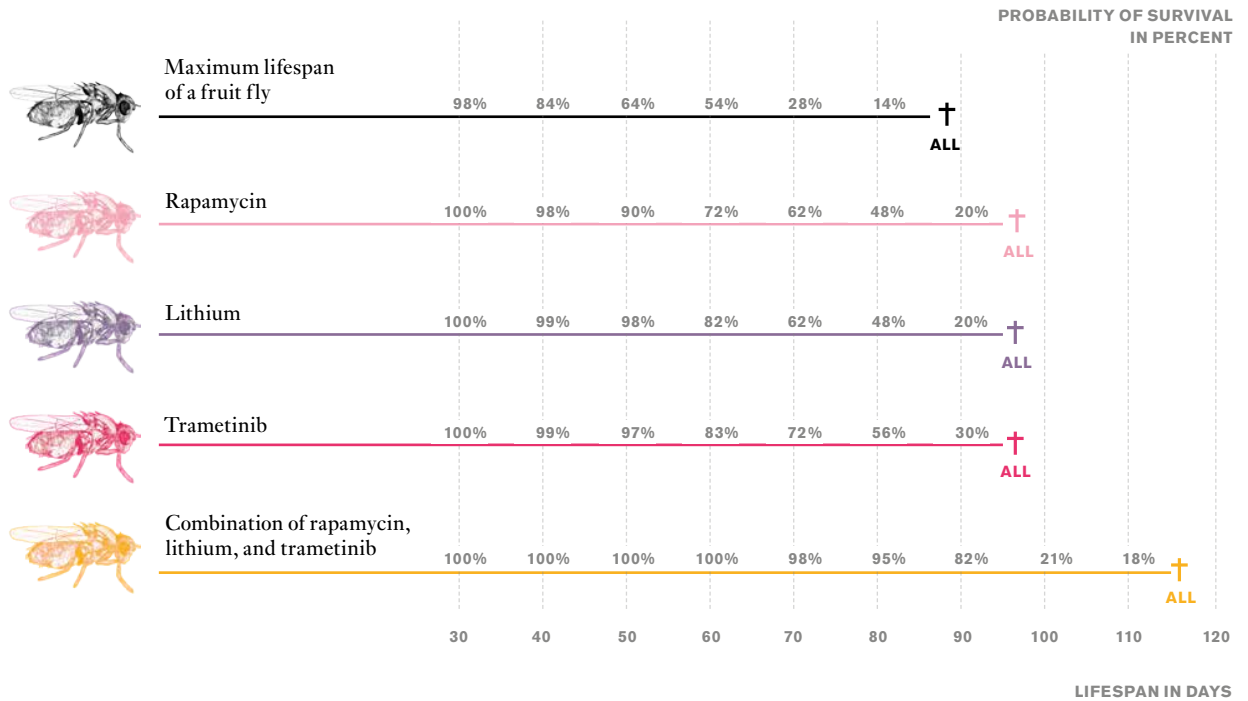
The adipose tissue possesses a type of memory for environmental influences and lifestyle. For this reason, dietary modification in mice only extends life expectancy if it is implemented at young age.

External influences also have varying effects on different tissue types, depending on age. For example, the Max Planck researchers put young and older mice on a restricted diet

Analyzing gene activation in various tissues showed that the liver adapted quickly to the new diet. By contrast, in adipose tissue, the researchers observed a memory effect of the previous diet. Activation of fat metabolism genes in the precursor cells of the actual fat-storing, adipocyte cells can be influenced by lifestyle in youth, but not later on. As a result, the mice that only began to fast later in life did indeed lose weight, but the genes in the adipose tissue remained active at a similar level to that of animals with a normal diet. In addition, the changes in the composition of lipids in old mice were less marked. The various lipid molecules have different functions: triglycerides, for example, are used by the body to store fat, phospholipids are components of cell membranes, and cholesterol act as signaling substances.

Adipose tissue therefore has an important part to play in the body’s aging process. There, dietary habits chiefly affect the mitochondria. If the animals consume less food, these cellular power generators are produced in greater numbers – but only if the animals eat less early on in life. In the case of mice, “early on” means after just a few months, as a further study by the researchers in Cologne has shown. This memory effect may be based on “epigenetic” alterations of genes, in which DNA is tagged by small molecular groups, switching genes on or off. In this way, environmental factors can have a relatively rapid impact on genes, and their effects can even be passed on to the next generation.

GRAPHIC: GCO MEDIENAGENTUR



Studies in the U.S. have shown that some epigenetic changes are age-related. On the basis of around 350 such DNA modifications, scientists can determine the biological age of a person with astonishing accuracy. The epigenetic clock ticks at the same pace in all the cell types studied – whether in cells that are continuously being regenerated or in those that originally developed in the embryo. The precise impact of these DNA modifications is still unknown.

Dietary restriction clearly has an effect on age-related epigenetic changes. It also stimulates lipid metabolism reprogramming. This protects the body from the harmful effects of fat deposition in the liver, as well as against insulin resistance – a typical sign of age-related, type-2 diabetes.

If the results of the studies on mice are transferred to humans, it is clear

that anyone who wants to live a long time needs to start early. “Our research shows that such dietary habits need to be adopted at an early age. The foundations for a healthy old age are already laid in early adulthood,” Linda Partridge explains.

A further discovery made in the laboratory by the researchers in Cologne might offer an incentive to start thinking about your own aging process early on.

Together with colleagues from Leiden University Medical Center in the Netherlands, they took blood samples from tens of thousands of people and searched for molecules that indicate the remaining lifespan a person is likely to have. Following extensive analysis, the scientists identified 14 biomarkers, including various amino acids, the ratio of “good” to “bad” cholesterol, fatty acids, and signaling molecules involved in infections. Initially, the scientists aim

to employ these biomarkers in age research on animals and in clinical studies on humans. However, blood biomarkers may eventually help young people find out, with a high degree of certainty, whether they will suffer from certain illnesses in old age. Then everyone would be able to decide for themselves whether they should exercise more and eat a healthier diet, or whether they should even take preventive medication to improve their health in old age.





IMAGE: JASON HESSELS-ASTRON / DANIELLE PUTSELAAR-ARTSOURCE.NL / B.P. IRWIN / D. VAN DE WATER / SHUTTERSTOCK

Signs in the heavens: in recent years, fast radio bursts coming from the depths of space have been detected by telescopes like the one at the Arecibo Observatory.

THE MYSTERY OF THE HEAVENLY BURSTS

TEXT: HELMUT HORNING

A cosmic lightning storm is playing out all around us. At any given moment, somewhere in the sky, a burst of radiation flashes and then fades away. Only observable with radio telescopes, these bursts last one-thousandth of a second and are one of astrophysics' greatest mysteries. Scientists rather doubt this is evidence of warlike aliens fighting "star wars" in the vastness of space. Experts have named them "fast radio bursts" – but where do they come from?

The Parkes Observatory in Australia is a gigantic dish of metal mesh gazing at the sky. With a diameter of 64 meters, this radio telescope was once the largest fully mobile radio telescope in the Southern Hemisphere. It registered a very mysterious radio burst in 2001, and nobody noticed it! It wasn't until five years later that astrophysicist Duncan Lorimer and his student David Narkevic stumbled upon the signature of the signal in the telescope data virtually by chance. Even then, the specialists couldn't make sense of the phenomenon. But this was not the only "Lorimer burst" to be discovered.

"We now know of more than a hundred," says Laura Spitler. Since March 2019, Spitler has headed a Lise Meitner Research Group on fast radio bursts (FRBs) at the Max Planck Institute for Radio Astronomy. Spitler has dedicated herself to these transient flickers in space for many years. In 2014, an international team under her leadership discovered the first FRB in the Northern Hemisphere in the constellation of Auriga. At the time, the astronomers were making observations in Puerto Rico using the dish of the Arecibo Observatory. This dish, with a diameter of 305 meters, is constructed and supported in a natural depression and can only focus on a relatively small section of the sky.

"Statistically, only seven eruptions should occur per minute, dispersed over the entire sky. So it takes a lot of luck to align your telescope to the right position at the right time," said Spitler after announcing her discovery. The properties of the observed

radio flash and the derived frequency of such events closely matched the data obtained by astronomers for all previously recorded bursts.

The findings did indeed confirm statistical estimates that about 10,000 of these unusual cosmic phenomena flare up somewhere in the sky every single day. This astonishingly large figure was reached by calculating how much of the sky would have to be observed and for how long, in an attempt to explain the comparatively few observations made to date.

The Arecibo observation also removed the last doubts about whether the radio bursts really come from the depths of the universe. After the discovery of the first bursts, scientists had suggested that they were being generated way beyond the Milky Way. This was deduced utilizing an effect known as "plasma dispersion." Radio signals that travel a long distance through the universe collide



PHOTO: HENNING ROSS



Pursuing the mystery: Laura Spitler researches fast radio bursts (FRBs) at the Max Planck Institute for Radio Astronomy.

SUMMARY

Fast radio bursts last only a thousandth of a second and were discovered by chance almost 15 years ago.

They originate from galaxies at great distances and appear to be produced in different environments.

Astronomers now know that more or less regularly repeating radio bursts, known as “repeaters”, also exist. The source of the radio bursts is still unknown.

64

with a large number of free electrons in interstellar space. Plasma dispersion decreases the velocity of lower-frequency radio waves producing a characteristic spread in the frequencies of the signal. The dispersion of the radiation burst discovered at the Arecibo Observatory was three times larger than would be expected from a source within the Milky Way.

But where do the radio bursts come from? Are they really from aliens using huge light sails to propel space probes? This idea was originally put forward by Abraham Loeb – a researcher at the renowned institution of Harvard University no less – and was recently seized on by the media. But most astrophysicists believe the bursts have a natural source and have come up with diverse explanations – all of them relatively bizarre. Many of these potential scenarios involve neutron stars. Neutron stars, only 20 kilometers in diameter, are the remnants of the massive explosions, known as supernovae, of high-mass stars.

Matter is so densely packed in a neutron star that on Earth’s surface, one teaspoonful of it would weigh about as much as Germany’s Zugspitze massif mountain. Neutron stars rotate rapidly around their axis, and some of them have exceptionally strong magnetic fields. Explanations for FRBs have varied. They may be generated during supernovae themselves, or perhaps during the fusion of two neutron stars in a compact double system as the magnetic fields of both stars collapse simultaneously. Or perhaps a neutron star collapses still further to create a black hole and this generates a burst.

Such scientific scenarios initially sound plausible. However, they have one flaw: they predict the occurrence of only one radio burst in each event. “If the radio burst is generated during a cataclysmic event that destroys the source, then we would expect to see only one burst per source,” says Laura Spitler. Indeed, only single bursts were observed in the years right after their discovery – until news of the first “repeater” burst,

called FRB 121102, was reported online in 2014. “This disproved all of the models explaining FRBs as the result of a catastrophic event,” says Spitler.

FRB 121102 (which was also discovered at the Arecibo Observatory) was subsequently monitored by the researchers using the Very Large Array in New Mexico. After 80 hours of observation time, they registered nine bursts and determined the source’s position to within one second of arc. At this position in the sky, there is a permanently radiating radio source; optical images show a faint galaxy about three billion light-years away. With a diameter of only 13,000 light-years, this galaxy is a dwarf; the Milky Way is about ten times larger. “However, many new stars, and perhaps even particularly large ones, are being born in the galaxy, and this might be a clue as to the source of the radio bursts,” says Spitler.

She is referring to the possibility that FRBs may be pulsars – cosmic light-

houses that regularly emit radio radiation. This brings neutron stars back into play, because pulsars are rapidly rotating neutron stars that have strong magnetic fields. If the rotational and the magnetic axes of such an object are misaligned, a light-house like, bundled radio beam can be produced. Each time this celestial spotlight sweeps across the Earth, astronomers measure a short pulse.

The bursts from most radio pulsars are too weak to be detected from a great distance. However, short and extremely strong “giant pulses” are another matter. Born in a supernova explosion observed in 1054 AD, the Crab Pulsar is a textbook example of this type of astronomical object. Its giant pulses would be visible even from neighboring galaxies.

“One promising model suggests that FRBs are similar in nature to the Crab Pulsar, but they originate from extragalactic neutron stars that emit much larger pulses and are much

rarer. Or perhaps they are younger and more energetic than the Crab Pulsar,” says Spitler. “FRB 121102’s home galaxy fits this model, as it has the potential to produce just the right type of stars that become neutron stars at the end of their lives.” But whether this model is correct is still literally “written in the stars.” Insight into their cause is not getting any easier, but observations are ongoing.

In the summer of 2019, for instance, the European VLBI Network of radio telescopes examined another repeater. During the five-hour observation period, FRB 180916.J0158+65 emitted no fewer than four radiation bursts, each lasting less than two milliseconds. Recently, the researchers also identified a roughly 16-day rhythm: for four days at a time, the source emits one or two bursts every hour then goes silent for twelve days. The source of this radio burst is in a spiral galaxy about 500 million light-years away. Even though such a distance is truly “as-

tronomical,” this object is the closest source ever observed. The findings also revealed that stars are evidently born at a high frequency in the vicinity of the burst.

Its position in the galaxy differs from that of all the other bursts investigated so far. FRBs, in conclusion, can apparently flare up in all kinds of cosmic regions and diverse environments. “This is just one of the reasons why we still do not know whether all bursts have the same type of source or are generated by the same physical processes,” says Spitler. “Their origin remains a mystery.”

←

GLOSSARY 65

EUROPEAN

VLBI NETWORK

A network of radio telescopes located primarily in Europe and Asia. The network uses interferometry to link up the telescopes to form an enormous virtual telescope with an extremely high resolution.

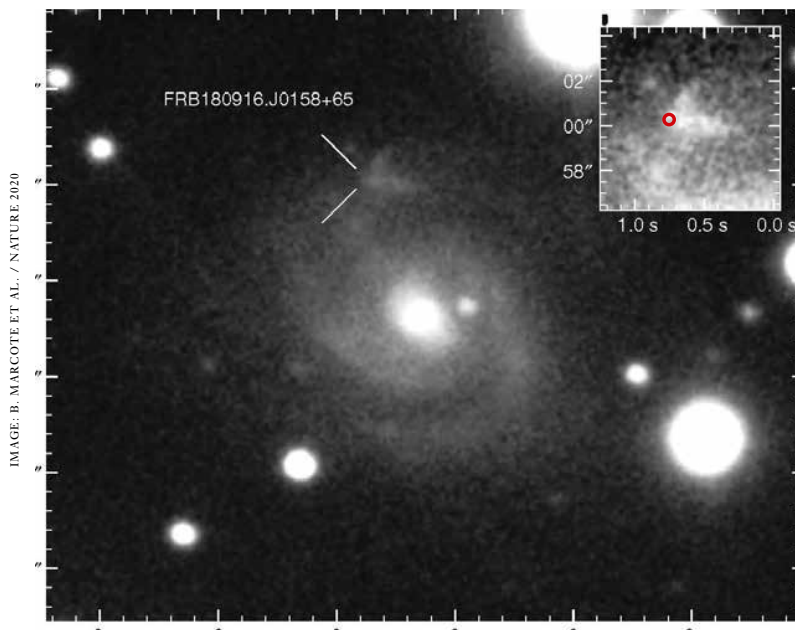


IMAGE: B. MARCOTE ET AL. / NATURE 2020

Fast radio burst: optical image of the source galaxy of the burst FRB 180916.J0158+65, obtained using the Gemini North telescope in Hawaii. The contrast in the magnified section has been enhanced, revealing the galaxy’s star-formation region where the burst was discovered. Its position is marked by a red circle.

JUST BE PATIENT!

TEXT: MARTIN ROOS

For many people, waiting is simply a waste of time. According to Matthias Sutter, however, “those who can wait get more out of life.” At the Max Planck Institute for Research on Collective Goods in Bonn, the behavioral economist is studying how children and young adults can be trained to manage money sensibly and follow a stable path in life.

66

If you believe the Experimental Economics Group in Bonn, patience is by far the best way of coping in the age of quick chats, seconds-long videos, constant exposure to advertising and the never-ending quest for more money and a successful career. The Experimental Economics Group, a young research group in the field of behavioral economics, was set up by Matthias Sutter, Director of the Max Planck Institute for Research on Collective Goods. He has now presented the group’s latest results. The studies were based on economic experiments in German schools. It quickly became clear that alongside intelligence and social background, patience was one of the most important factors for success in

life. Also, people who learn to be patient early on will also be better able to manage their money.

Matthias Sutter seems surprisingly unconventional. Anyone who meets the 52-year-old Austrian in the small former German capital of Bonn will immediately see that he’s a real team player. Sutter is friendly, unpretentious and very interested and inquisitive, and as a result, has one important quality that makes him a good researcher: the ability to listen.

Since 2017, he has been Director and Scientific Member of the Max Planck Institute for Research on Collective Goods. Thanks to his studies on patience and stamina, Sutter has now clearly succeeded in reviving a long-forgotten virtue that had previously seemed obsolete. Today, the topic is not only of interest to parents and nursery school teachers, but also to personnel officers and managers. Now, Sutter gives presentations at industrial companies and in banks.

The results are encouraging. Claudia Zoller, a member of the Experimental Economics Group, explains: “In our studies, we were able to show that children’s stamina increases as they get older, and that girls are more hard-working than boys.” However, when it came to challenges such as solving a difficult puzzle, the boys have the edge. At any rate, it became clear that stamina begins developing early in life. “People who learned to be more patient as children will be more contented later on in adult life,” she says.

“Being patient” should not be misinterpreted as meaning that you should let fate decide. “Patience is an active process of working to achieve a goal,” Sutter explains. Or, as the French writer George Sand once said: “Patience is nothing other than a form of energy.” The ability to stop oneself from immediately following an impulse may be learned in early childhood, but according to Anna Untertrifaller, another member of the Experimental Economics Group, “It’s

→

ILLUSTRATION: ALESSANDRO GOTTARDO



hard to explain why some people are generally more patient in life than others.” No reliable research has been conducted into possible genetic factors.

68 One pioneering researcher in the field of patience was the American psychologist Walter Mischel. In 1968, he developed his legendary marshmallow test to study patience among children. They had the option of either eating a marshmallow right away or waiting for a few minutes and receiving another sweet. The results led Mischel to assume that the ability to control one’s impulses was an indicator for success. Even if Mischel’s studies have recently been subject to criticism, other results, such as those presented by the research group headed by Terrie Moffitt at Duke University, confirm the connection between self-control and success. Experts agree, however, that external factors such as the social environment also play a role. “Reliability is extremely important,” says Anna Untertrifaller. “Children need to experience very early on that it’s worth being patient and waiting.” Sutter adds that patience needs to be learned through role models. In this respect, upbringing is very important: “This is where the parents come in. They can make a positive contribution by demonstrating a certain amount of patience and stamina themselves.”

Go for the quick money or wait for a larger amount?

Studies have shown that patience and self-control also pay off when it comes to managing money. However, this requires a basic knowledge of finance that has not been sufficiently covered in school curricula to date. The latest study by the behavioral researchers in Bonn therefore focuses mainly on how finance-related

subjects can be taught in schools in such a way that they have a positive impact on financial behavior when the children become adults.

The specialist term used is “financial literacy.” In general, this is regarded as being the ability of the individual to manage money wisely, in other words, to make sensible, well-founded decisions when it comes to making investments, saving money and controlling one’s purchasing habits. So far, researchers agree that there is a connection between financial competence and financial behavior. Studies show that test subjects who are less well-educated in financial matters are less likely to set aside sufficient funds for their retirement, they obtain lower returns on their savings accounts and are less interested in loan, saving and investment practices. Lower levels of financial knowledge and skills also correlate with sub-optimal property financing and higher credit card debts.

“However, until now, it was not clear how and why financial competence impacts financial behavior,” Sutter explains. His new research is therefore aimed at teaching financial skills to German grammar school pupils, while clarifying whether this type of basic education enhances their interest and increases their level of engagement with economic issues, and whether it has an influence on economically relevant attitudes, such as patience and the willingness to take risks.

In total, 645 pupils at eleven grammar schools in Germany took part in the study. For example, for one month, the pupils from grades nine to twelve were confronted with topics such as inflation, interest rates and monetary targeting for two hours every week. They were given lessons and took part in experiments. During the experiments, their patience was tested by giving them the option of receiving EUR 10 on the day of the experiment or waiting for three weeks

to receive a higher amount (up to EUR 14). Impatient pupils immediately opted for the EUR 10, even when they were offered EUR 13 or EUR 14 in three weeks’ time, while more patient pupils were able to wait for three weeks even for just EUR 11 or EUR 12.

Financial illiteracy

Sutter’s approach differs from studies conducted to date: “Our experiment involved three temporal points of contact with the pupils: one week before the intervention as a base measurement, then one week afterwards to measure the short-term ef-



PHOTO: STEFAN FINGER / LAIF

SUMMARY

Stamina and patience are important qualities that are needed for developing personal wealth. Both can be fostered through upbringing and education.

Like elsewhere in the world, financial competence is underdeveloped in Germany. Pupils in all schools in Germany should be taught basic financial knowledge. This would help them manage their money in a better way.

A proponent of financial education: according to Max Planck Director Matthias Sutter, teaching pupils how to manage money sensibly should be included in school curricula throughout Germany.



facts, and then around five months later to ascertain the long-term impact.” This enabled researchers to check whether individual aspects of the financial education had faded with time or had been retained. “Every financial decision involves a certain degree of risk and a temporal dimension. That’s why we were particularly interested in the level of willingness to take risks and how pronounced the time preference – or in other words, patience – actually was.”

The result: “It is highly probable that basic financial education among children and young adults has a positive influence over later financial behavior,” Sutter explains. The basic financial education measures also enhanced test subjects’ skills and made them more open to the subject of finance. “When it came to willingness to take risks, our surveys and tests led to greater risk aversion,” Sutter explains. However, the improvements in financial competence during the test phase counteracted this effect. Pupils therefore be-

came somewhat bolder and less risk-averse. “Also, young adults become more patient when they’re learning about basic financial concepts,” he adds.

That’s the result of the study in eleven schools in the whole of Germany. However, “to put it mildly, general financial education is extremely limited throughout the world,” he says. He points to studies by Annamaria Lusardi, Professor of Economics at George Washington University and Olivia Mitchell, Professor of Economics at Wharton School in Pennsylvania. Their project, “Financial literacy around the world”, showed that many people are effectively illiterate when it comes to financial matters, even though the Organization for Economic Cooperation and Development (OECD) classifies financial competence as an essential life qualification.

“People all over the world have trouble understanding what appear to be simple concepts, such as interest, risk distribution and the relation-



ship between inflation and purchasing power,” Sutter explains. Even in the U.S., where there is a strong financial market, the two researchers found that just 43 percent of people over the age of 51 understood even simple financial concepts. Among those under the age of 34, the figure was just 18 percent.

The situation in Germany isn’t encouraging either. A team of researchers led by Tabea Bucher-Koenen at the Max Planck Institute for Social Law and Social Policy in Munich has conducted several studies on financial competence among Germans. The test subjects were presented with three questions on the calculation of interest and inflation and about the purchase of shares and equity funds. Fortunately, about half gave the right answers to all three questions, while three-quarters knew the answer to the first two. However, one in ten respondents was unable to give the right answer to any of them. Around eight percent selected the “Don’t know” option for all questions.

70

Scientists are not in a position to offer practical guidance. However, they can provide important information that influences decisions on educational policy in Germany. “Teaching pupils in schools is the best way to make financial knowledge accessible to everyone,” says Sutter. However, to date, financial skills have not been included in the standard curricula in schools. According to Sutter’s research, 39 different school subjects include aspects of financial education in Germany. Currently, Baden-Wuerttemberg is the only federal state to include “Business and professional orientation” in its school curriculum. The subject has been taught in all schools there since 2018.

Sutter is critical of the current situation: “The splintering of financial education in the German federal school system leads to a lack of transparency when it comes to the level of financial competence among the younger generation.” He doubts that

this fragmentation in financial education will guarantee the long-term, cumulative development of skills. After all, according to the education psychology theory of skills development, this requires both continuous support and a solid professional knowledge base. Sutter will probably have to wait a while before his research has any real impact on education policy.

Long-term study in Bangladesh

Sutter expects to gain further knowledge about the interrelationship between patience, financial competence and personal prosperity from longitudinal studies running over several decades. This information will make it possible to draw far more precise conclusions about changes among the test subjects and their possible causes. Matthias

Sutter’s team chose a country with a very different social, cultural and sociopolitical background for this study: Bangladesh.

There is a practical reason for doing so: “The people we selected here have more or less spent their entire lives in just one place. In other words, we can keep track of them,” Sutter explains. His team is monitoring the development of the selected individuals in relation to patience, risk behavior and social preferences in order to understand better how economic behavior – particularly patience – develops at a young age and in relation to the example set by a child’s parents. To date, it has emerged that being patient and practicing patience clearly has an impact on a person’s financial situation, or is at least related to it. “We still have a long way to go,” he says, laughing. After all, he knows very well that good research requires stamina and patience.



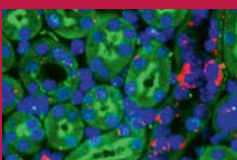
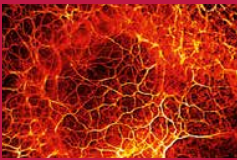
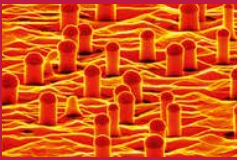
A test of patience: children who do jigsaws can learn that patience pays off.



PHOTO: FROM A VIDEO INTERVIEW WITH MATTHIAS SUTTER / MPI FOR RESEARCH ON COLLECTIVE GOODS



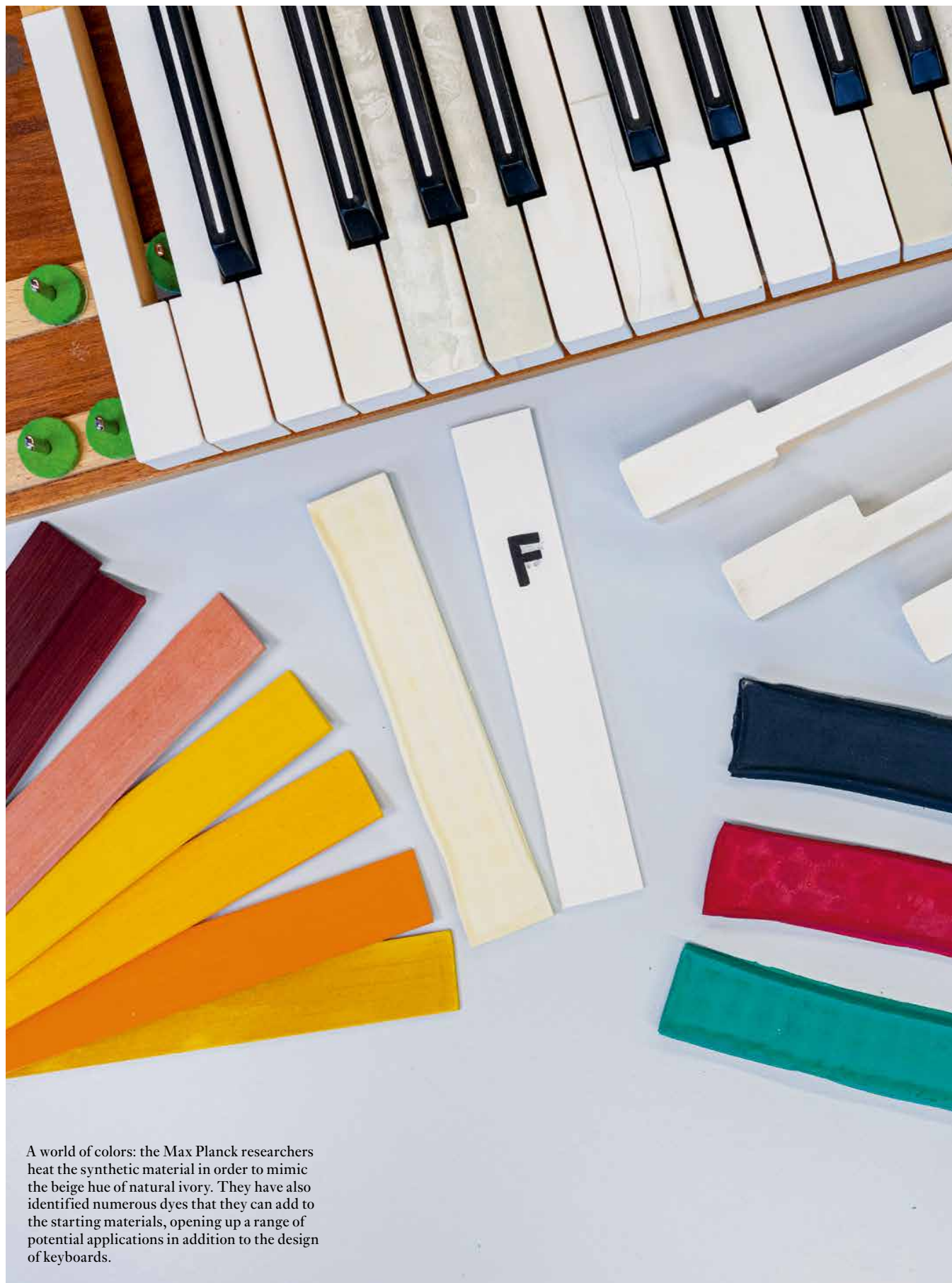
Connecting Science and Business.



Max Planck Innovation is responsible for the technology transfer of the Max Planck Society and, as such, the link between industry and basic research. With our interdisciplinary team we advise and support scientists in evaluating their inventions, filing patents and founding companies. We offer industry a unique access to the innovations of the Max Planck Institutes. Thus we perform an important task: the transfer of basic research results into products, which contribute to the economic and social progress.

Connecting Science and Business





A world of colors: the Max Planck researchers heat the synthetic material in order to mimic the beige hue of natural ivory. They have also identified numerous dyes that they can add to the starting materials, opening up a range of potential applications in addition to the design of keyboards.

IVORY FROM A TEST TUBE

TEXT: PETER HERGERSBERG

For a long time, pianists have had to live without the sensation of playing on ivory keys. One remedy for this is synthetic ivory, a substitute developed by Dieter Fischer, Sarah Parks, and Jochen Mannhart, who usually spend their time researching quantum electronic phenomena at the Max Planck Institute for Solid State Research in Stuttgart. Now, a start-up is planning to produce the material on a large scale – and not only for use in piano keys.

Jochen Mannhart had not expected his Christmas trip to have such a lasting effect on him. In 2014, he and his team opted to visit a piano maker for their annual end-of-year excursion – a rather unusual destination for a group that studies effects relating to quantum electronics at the Max Planck Institute for Solid State Research in Stuttgart. Whereas in previous years' visits – to suppliers of lasers and machine tools or automotive manufacturers and sup-

pliers – seemed like fairly obvious choices, there was not exactly an urgent need for technical contacts in the piano-making industry.

In any case, the 2014 excursion brought the group to the Black Forest town of Spaichingen to visit Sauter – by its own account, the oldest pianoforte workshop in Germany. “I was really amazed at how much time they spent with us – even the Managing Director,” says Jochen Mannhart. “It’s not as if we had much to offer Sauter, either as a customer or for recruiting new staff members.” At the end of the visit, Mannhart asked whether there was anything Sauter wished scientific researchers would invent. The answer he received from Otto Hott, Managing Director and joint owner of the company, was not only succinct but also surprising: “Synthetic ivory.”

When it comes to the veneer applied to piano keys, ivory remains the material of choice for pianists. But the

international trade in ivory from elephant tusks was banned in 1989 to protect the animals from extinction – and piano makers have yet to find a substance that offers pianists the same feel as the natural material. Although the properties of ivory depend to a certain extent on its origin and the animals’ diet, it is always warm to the touch, absorbs moisture effectively, and is preferred by pianists when it comes to slip resistance.

With this in mind, the team of Stuttgart researchers took Otto Hott’s wish back to their laboratories and set about making it come true. This task fell to Dieter Fischer and Sarah Parks, who normally spend their time producing inorganic materials such as unusual metal structures or complex metal oxides, in which exotic quantum effects take place. In order to produce such substances in the greatest possible purity, they have always needed expensive apparatus and an ultra high vacuum. “But

it was immediately clear to me that we could rule out all production methods in a vacuum from the word go,” says Dieter Fischer. Even if this approach could create a substance resembling natural ivory, large-scale production would be impractical and too expensive.

A simple idea that no one had tried yet

With a view to developing a workable formula for ivory, he first embarked on an in-depth study of the material and of the approaches that scientists had previously pursued (in vain) in order to produce it by chemical methods: ivory is partly made up of hydroxylapatite crystals, which also provide hardness in bones. These mineral particles are embedded in a framework made up of a protein called collagen, which gives the material its robustness. The first patent for the synthetic replication of ivory was awarded at the end of the 19th century to the chemists A. and S. De Pont, who had even attempted to replicate the formation of the natural material by growing hydroxylapatite crystals within a collagen framework. Although this approach failed to produce a viable substitute for ivory, it seems that many scientists who also tried to make ivory assumed they would have to follow a similar path.

74

Dieter Fischer wanted to conduct a much simpler experiment first. Why not simply mix a suspension of hydroxylapatite particles with dissolved gelatin (which is derived from collagen)? This was a radical idea by virtue of its sheer simplicity, but he was not about to leave its implementation to chance. “We first gave some thought to which parameters might be important for direct synthesis,” says Dieter Fischer. “And luckily, the ones we chose worked quite well from the outset.” For instance, the temperature and the concentration of the components turned out to be crucial factors in production.

The joy of playing: Dieter Fischer led the development of the synthetic ivory and is seen here trying out the piano at the Max Planck Institute for Solid State Research. The instrument, whose keys are covered with the material his team developed, was a gift to the researchers from the piano maker Sauter.

PHOTO: WOLFRAM SCHEIBLE



The right conditions also produced the right result when the researchers mixed the two components. They first obtained a milky liquid, from which they then evaporated most of the solvents. The viscous mass that remained was poured into flat molds and left to dry on a lab bench. Dieter Fischer describes the resulting white substance as “jellybabies with hydroxylapatite” – and it was a very good approximation of natural ivory.

However, it still took the researchers in Stuttgart a few more attempts to turn this substance into a material that was barely distinguishable from its natural counterpart – both visually and to the touch. For this, they enlisted the help of the staff at Sauter, whom they provided with several batches of samples. The piano makers machined the plates using exactly the same methods as had traditionally been used for natural ivory and tested them in their keyboards.



75

They then reported back to the research team in Stuttgart to tell them which properties still needed to be optimized.

In the meantime, the scientists Sarah Parks and Dieter Fischer set about analyzing different variations of the synthetic ivory in their laboratory, where they performed a range of experiments to measure the material's moisture absorption, thermal conductivity, and hardness, as well as the

amount of grip it provided. In order to analyze slip resistance, they built a special artificial finger – a spring-loaded rod with a leather-covered tip. “Although leather is not identical to human skin, it is quite similar,” says Sarah Parks. “Besides, we were more interested in comparing different samples.” To do so, the scientist would apply the test finger to one of the materials and measure the horizontal force required to move the plate.

Both in the laboratory and at the piano-forte workshop, the synthetic ivory passed the tests with flying colors: it feels as warm as its natural counterpart, is able to absorb moisture from the pianist's fingers just as well, and provides similar slip resistance. The material's grip can even be optimized according to players' individual requirements. However, given that what really matters is how the keys feel to play, the synthetic ivory met its litmus test not in the labo-

—>

ratory but rather under the fingers of an actual pianist – and of course, the team of Stuttgart researchers traveled to Spaichingen for the occasion. Sauter had manufactured a piano with white key veneers made of the material from the Max Planck Institute for Solid State Research and had arranged for the instrument to be played by a trained musician. Surrounded by piano makers and basic researchers, Eugene Mursky took to the ivory keys to perform pieces by Chopin, Schubert, and Liszt, but his audience was more delighted with his ensuing praise for the material than with the concert itself: “It’s fantastic – it feels warm

like real ivory,” said Mursky, who has had the opportunity to play on historical pianos with real ivory keys in the past.

Ivortec will market the synthetic ivory

The fingers of many people have since played on this keyboard made with the synthetic ivory. “The first pianists to play our instruments so far have all had positive things to say about the playing characteristics of the synthetic ivory,” says Sauter’s Managing Director, Otto Hott.

The unanimous verdict was that the material is less slippery than substitute materials used in the past. After these successful tests, Sauter is obviously keen to fit its pianos and grand pianos with the synthetic ivory as standard in the future. However, producing the necessary quantities of the material is no longer a job for the Max Planck Institute. It was with this in mind that Jochen Mannhart founded the company Ivortec with the Max Planck Society in July 2019, bringing in David Butcher as the external Managing Director. The company will be responsible for marketing the synthetic ivory – and not only as a veneer for piano keys.

Numerous potential applications: a member of the Max Planck team used a lathe to make chess pieces from the synthetic ivory. However, the material could also be used in the furniture or yacht building industries.

76



The Max Planck researchers also made contact with a jewelry designer, who has fashioned a pendant from the elegant-looking material. Likewise, an artist has carved a replica of a Stone Age bird figure out of the ivory, and Manfred Schmid, a member of Mannhart's group, has used it to produce a set of chess pieces on a lathe in one of the Institute's workshops. The sheer versatility of the test-tube ivory is partly thanks to a slightly modified process by which Sarah Parks and Dieter Fischer have managed to give it a cylindrical shape. It's no surprise, then, that David Butcher has a long list of potential applications in mind. As Managing

Director of Ivortec, he is therefore working not only to raise start-up capital and forge collaborations with production companies, but also to reach out to firms that may be interested in synthetic ivory as a material. In many situations, it could act as a substitute for plastics or even wood. "The ivory has attracted considerable interest from furniture manufacturers and yacht builders, not only for its elegant looks but also because it doesn't burn until it reaches 1,000 degrees Celsius – so it's like decorative fireproofing," says Butcher. The material also scores highly in terms of sustainability, especially in comparison with plastics. For one thing,

it is not made from petroleum and is biodegradable at the end of its life cycle. The synthetic ivory therefore not only offers pianists a playing experience that would otherwise be off limits for the sake of wildlife conservation, but – unlike plastic – it also leaves behind no waste.

←



PHOTO: WOLFRAM SCHEIBLE

SUMMARY

A Max Planck team has succeeded in producing synthetic ivory that closely resembles the natural material.

During synthesis, the researchers mix hydroxyapatite particles into dissolved gelatin, which is formed from collagen, the organic component of ivory. Chemists had previously assumed that the hydroxyapatite crystals had to grow within collagen, just like in the natural formation process.

Among other applications, the synthetic ivory will be used as the veneer for piano keys, as it offers pianists the same feel as its natural counterpart. However, it could also be used as a flame-resistant and biodegradable alternative to wood and plastics.



Watching the sky: the Barbados Cloud Observatory (BCO) is equipped with numerous meteorological instruments with which scientists can investigate the distribution of clouds, aerosols and water vapor, for example.

78

Max Planck researchers cooperate with partners in around 120 countries all over the world. Here, they write about their personal experiences and impressions. Theresa Lang from the Max Planck Institute for Meteorology spent around two weeks on the Caribbean island of Barbados for the cloud research project EUREC4A. She talks about weather balloons, friendly island inhabitants and an unexpected highlight.

Getting off the plane in Bridgetown on January 20 almost knocked me sideways. The combination of extreme heat and high humidity was too much of a contrast to the cold, wet weather in Hamburg that I had left behind me just a few hours before. However, within two days I'd become accust-

omed to the tropical temperatures – which was just as well, because the weather barely changed at all over the two weeks that followed.

The weather was also the subject of our research. I was taking part in EUREC4A, an international project which is investigating how clouds react to climate change and how these changes will affect climate development in the long term. We were specifically interested in low-level clouds, i.e. clouds at an altitude of two kilometers, which are typical of regions like Barbados that lie within the trade wind belts. These clouds act as particularly intensive sunlight reflectors, which means their impact is formidable. That's why we are interested in finding out how climate change affects their behavior. We also want to find out why clouds arrange themselves in different ways. These arrangements appear to be completely random: some-

times clouds are scattered across the sky, other times they group together in large clusters. We employed an entire fleet of research ships, aircraft and ground-based measurement stations to shed light on these processes. My initial fear that I might have nothing to do dissipated faster than a storm cloud on a summer day.

There was no shortage of tasks, particularly during the first few days. One of my jobs was to help evaluate the previous day's measurements in order to generate daily weather summaries. I also found it exciting to prepare the weather balloons that were released into the sky every four hours.

In all, there were around one hundred people working at the project site. Like myself, many of them worked for the Max Planck Institute for Meteorology; we were also joined by researchers from every country under the sun – all in all, a colorful interna-



BARBADOS, CARIBBEAN

tional crowd. The people in charge at EUREC4A also attached great importance to involving the local residents in our research. We worked in close cooperation with the island's Caribbean Institute for Meteorology and Hydrology to make weather forecasts.

This collaboration ensured that the project was warmly received by the local population besides creating a pleasant working atmosphere. That also meant it wasn't so bad if we sometimes had to work longer hours or get up at 2:30 a.m. to help prepare a weather balloon. Regular work hours are normally very important to me, but that didn't matter on Barbados; you always wanted to be in on the action. Especially as I still had the opportunity to lie on the beach and explore the island. People often approached me during my outings and I found the Barbadians very friendly.

I will miss their hospitality – as well as the wonderful weather and the glorious sunsets. However, I don't feel as nostalgic about the food. It was quite tasty, but eating grilled fish every day does get rather monotonous. Since I worked in a team and lived in shared accommodation, there were always people around and I sometimes missed having time to myself.

But all in all, these two weeks were a once-in-a-lifetime experience that offered countless highlights. One of the best was flying in HALO, the German Aerospace Center's research aircraft. While the pilot followed a previously defined flight path, my colleagues and I released dropsondes, which then glided to the ground. I'd never have expected to be allowed to go along on a flight in this plane. And even though the flight was relatively short, I will never forget the views from above this idyllic island.



PHOTO: PRIVATE

Theresa Lang

25, studied meteorology at the University of Hamburg and the University Centre in Svalbard (Spitzbergen). Since July 2019, she has been working on her doctorate at the International Max Planck Research School of Hamburg University and the Max Planck Institute for Meteorology. She works in the "Atmosphere in the Earth System" Department led by Director Björn Stevens, where she is investigating the distribution of water vapor in the free troposphere.

PRESERVING CULTURAL HERITAGE

In November last year, representatives of an indigenous group celebrated the repatriation of their ancestors' remains. These have now also been buried. The skulls, which are more than 200 years old, were returned to the Wanniyalaeto by the University of Edinburgh. Scientists from the Max Planck Institute for the Science of Human History in Jena also attended the ceremony.

The skulls became part of the University of Edinburgh's anatomical collection more than 100 years ago (the British colony of Ceylon remained in existence until 1948). During the repatriation process, the Jena-based research team led by Patrick Roberts and Oshan Wedage investigated the human remains under the supervision of the tribal elders and obtained new information about these indigenous hunter-gatherers. While some tribe members cultivated trade relations with farmers and made use of colonial power structures, others preferred to live independently on the resources provided by the tropical forest.

By performing biochemical analyses of the skulls, the Max Planck scientists were able to prove for example that the tribe had long been managing the tropical forest. "Like many indigenous peoples, the Wanniyalaeto are now losing their livelihoods and the right to hunt on what is traditionally their territory," says Roberts. The study is now helping the tribe assert their hunting rights. Another goal is to actively involve tribal members in wildlife conservation by having them work as rangers, thus giving them access to additional sources of



PHOTO: JEFF J. MITCHELL / GETTY IMAGES

Veddah chief Uruwarige with one of the nine skulls during the repatriation ceremony at the University of Edinburgh.

income. The knowledge gained will also feed into the Wanniyalaeto's cultural heritage museum in Dambana, where the indigenous group is preserving its language, subsistence strategies, social structures and burial practices for future generations. The dead are particularly important to the Wanniyalaeto: "Although the remains of our ancestors were in Edinburgh, their spirits stayed with us in Sri Lanka. The reuniting of their spirits and physical remains is a very special moment for my people," said Wanniyalaeto chief Wanniya Uruwarige in Edinburgh.

Several news outlets, including the BBC, the Times and various local news channels and newspapers in Sri Lanka, reported on the ceremony in the Scottish university town. "We are delighted to be returning these culturally important artefacts," said Tom Gillingwater, Chair of

Anatomy at the University of Edinburgh. "It was an honor for us to work with the Wanniyalaeto, to consult with them and learn more about their traditions and cultural heritage," says Roberts. The theft of the skulls was just one of a series of atrocities that took place in colonial times. "I hope that other European institutions will follow the example set by the University of Edinburgh and develop clear policies on the return of ancestral remains."

Oshan Wedage, who is still working with the Wanniyalaeto in Sri Lanka, adds: "Although the need for repatriation is the product of a sad period in history, I hope that this repatriation ceremony will elevate the cause of the Wanniyalaeto and encourage the government of Sri Lanka to consider that the tropical forests are best preserved in collaboration with their traditional stewards."

ASSISTANCE WITH CHILDCARE

Part of the pilot project offering childcare for infants is again being extended. Doctoral researchers with funding contracts and post-docs with contracts based on the Collective Wage Agreement for the Civil Service (TVöD) will continue to receive funding from the Max Planck Foundation enabling them to pay for childcare for their infants. However, in view of the family policy measures adopted by the federal states, this will only be available for the first year of their

child's life (from the 3rd to the 12th month). For the most part, the family packages offered by the federal states do not take this age group into account.

At the beginning of the year, the family service agreement with pme was extended for another six years. The services previously offered are set to continue: staff will still be able to make use of extensive consulting services and get help finding care services for children above and below man-

datory school age (usually from 0 to 14 years) and for relatives in need of long-term care. As a rule, the consulting and placement fees charged by pme are covered centrally by the MPG. The actual childcare or long-term care service must be paid for by the employees themselves. New provisions have been introduced, particularly for childcare during conferences and in-house care during vacation periods; these relate for example to minimum group sizes.

COMMUNITY NEWS



On the podium at the inauguration of the Planck Academy on February 13, 2020: chairperson Marion Schmidt; Anna-Maria Karl - Head of Global Talent Sourcing, Daimler AG (until December 2019); Norbert Sack - Leadership Consultant, Berlin; Katharina von Knop - founder and CEO Digital Trust Analytics; Thomas Weitz - Professor at the University of Goettingen (from left to right).

NEW WAYS OF DEVELOPING TALENT

What do people need who are deciding on their next career steps in times of great mobility and flexibility? What is important for young people undergoing training, for leaders in the field of science management, or for Directors? The newly founded Planck Academy, a central element of the “MPG 2030” process, has the answers.

“Attracting talented people, no matter what stage they are at in their careers, familiarizing them with the particularities of our organization and supporting them as they develop their careers – these are important goals for the Max Planck Society,” said President Martin Stratmann at the inauguration of the Planck Academy, which took place at the Harnack House in Berlin on February 13, 2020.

“What’s more, the development of talent is one of the competitive factors critical to the success of research facilities, since top employees at all levels can now choose where they want to work.” The continuing edu-

cation and advanced training programs offered by the Planck Academy focus on the individual needs of each employee. It bundles all centralized personal and career development services under one virtual roof, and targets all employees from Directors, Max Planck Research Group Leaders and executives in science management and administration to junior scientists and employees in administration, IT and technology. The projects currently focus on leadership, talent management, onboarding and diversity.

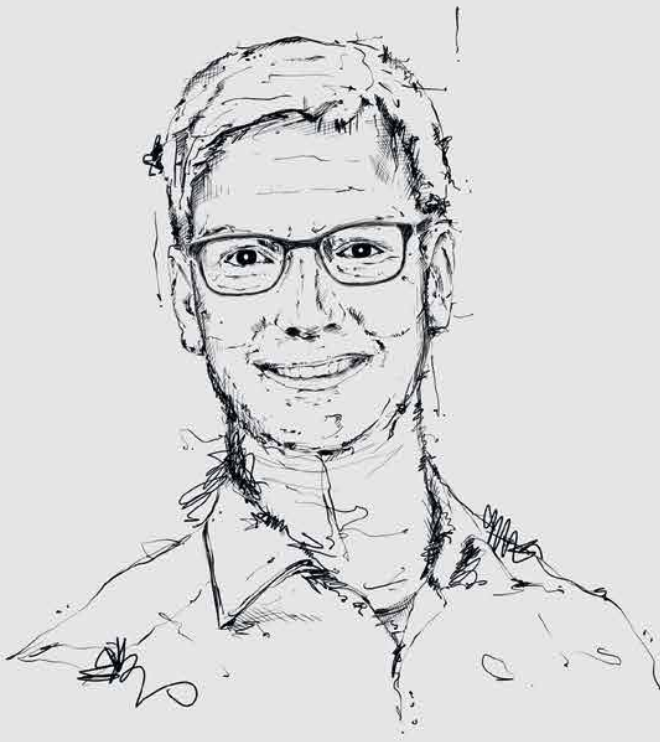
The Planck Academy’s program is easy to access. Various learning, development and network formats are used alongside classroom and online formats, coaching, mentoring, and tools for self-reflection. One key point is that the Planck Academy combines classroom teaching with virtual offerings such as e-learning modules, how-to videos and webinars. These are based on the Learning Management System, LMS for short.

More about the Planck Academy in MAX

POSITION ON CLIMATE PROTECTION

A conference held by the Alliance of Science Organizations in Germany in November 2019 included a presentation by the Max Planck Society of its “Climate Protection Strategy”. This paper, which was approved by the President in consultation with the Presidential Council, also contained material from a position paper compiled by the Directors (Bodenschatz/Erb: “How to CO₂-mpensate? – Max Planck Action for Sustainable Science”) and points raised in a paper on CO₂ compensation published by the Max Planck Sustainability Network.

The Presidential Committee “Climate Protection at the MPG – Goal-Based Measures and Their Prioritization” was established with Tobias Bonhoeffer and Ariane Rauschek as co-chairs for the purpose of advancing the subject within the Max Planck Society. Moreover, during a meeting of the Scientific Council held on February 20, the following statement by the committee regarding sustainability within the Max Planck Society was approved by a show of hands (with two abstentions and one vote against): “The members of the Max Planck Society’s Scientific Council see climate protection as a supremely important social issue. Each organization and each individual is called upon to focus their activities accordingly. This also applies to the Max Planck Society. The members of the Scientific Council therefore request the Administrative Headquarters to ensure that the Max Planck Society makes an ambitious, clearly visible contribution to climate protection as soon as possible.”



FIVE QUESTIONS

ABOUT PROTEST VOTING

FOR ARMIN SCHÄFER

Professor Schäfer, your subject is the fascinating question of political inequality. What conclusions have you drawn?

82 ARMIN SCHÄFER My research team and I have found that political decisions made in the Bundestag are biased against less well-educated people with lower incomes. This in turn can deter people from voting, because when they feel like they are no longer being represented, they turn away from politics and stay at home on election day. We observed this pattern during the last three parliamentary elections, i.e. in 2009, 2013 and 2017. In all the German cities for which this data is available, it was clear that the poorer the district and the lower the average income of its residents, the lower the voter turnout.

Does the rise of populism have anything to do with political inequality?

The AfD mobilized some former non-voters, but the majority stayed home as before. All the same, stronger polarization is causing more people to become involved. Some of them want to issue a warning, while others want to prevent populists from being successful in the elections. This makes the picture a bit more complicated. However, a higher percentage of protest votes shows us that there are population groups who feel that they are not yet properly represented. They don't feel that the esta-

blished parties are appealing to them or offering them something that could change their circumstances.

Why do people decide not to vote?

One thing we know is that voting and abstaining from voting is "contagious". People don't decide all by themselves whether or not to go and vote. The decision also has something to do with their family, their friends, perhaps even the area they live in. Another aspect is that when politicians treat different groups unequally, this can trigger a vicious circle. People who feel like they are not being represented don't vote – and people who don't vote are represented less successfully. As a result, the interactions involved in making political decisions become biased in favor of those who take part and whose circumstances are better in any case.

Does that mean that the parties and parliaments are becoming less and less representative of a cross-section of the population?

More than 80 percent of the members of the Bundestag went to university compared to less than 20 percent of the general population. There is also a far higher proportion of civil servants, entrepreneurs and lawyers in the parliaments than there is among the general population. This shows that there are significant differences between those who

make the political decisions and those who are affected by them. Over the last thirty years, the Bundestag's decisions have coincided much more frequently with the preferences of people who have high incomes or whose circumstances are generally better. This discrepancy is particularly significant when the rich and the poor want different things.

How can we break out of this vicious circle?

We know that people don't spontaneously become involved in politics and are more likely to do so when they are actively addressed and encouraged to become party members. The parties need to take a closer look at who they are appealing to. This is already happening to some extent in the case of women, and to a lesser degree in the case of immigrants. Parties should not encourage only people with university degrees to stand for election. Democracy encompasses the promise that diverse groups will at least have the opportunity to voice their concerns when political decisions are being made. I believe that a systemic failure to give this opportunity puts democracy at risk.

Interview: Jürgen Zurheide

Professor Armin Schäfer was the Scholar in Residence at the Max Planck Institute for the Study of Societies in Cologne during the winter semester 2019/20.

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

The Netherlands

- Nijmegen

Italy

- Rome
- Florence

USA

- Jupiter, Florida

Brazil

- Manaus

Luxembourg

- Luxembourg



PUBLISHER'S INFORMATION

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

Publisher's mailing address

Hofgartenstraße 8
D - 80539 Munich
Tel: +49 89 2108-1719 / -1276 (before midday)
Mpf@gv.mpg.de
www.mpg.de/mpresearch
App for free download: www.mpg.de/mpr-mobile

Content Authority

Dr Christina Beck (-1276)

Editors-in-Chief

Peter Hergersberg (Chemistry, Physics, Technology; -1536)
Helmut Hornung (Astronomy; -1404)

Editorial Staff

Dr. Harald Rösch (Biology, Medicine; 1756)
Mechthild Zimmermann (Culture, Society; 1720)

Photo editor

Susanne Schauer (-1562)
Annabell Kopp (-1819)

Conceptual Advice

Sandra Teschow and Thomas Susanka
www.teschowundsusanka.de

Translation

Proverb oHG
Marktplatz 12
70173 Stuttgart
Tel: +49 711 164090 0
e-mail: proverb@proverb.de

Layout

GCO Medienagentur
Schaezlerstraße 17
86150 Augsburg
www.gco-agentur.de

Printing & Distribution

Vogel Druck & Medienservice GmbH
Leibnizstraße 5
97204 Höchberg

Advertising

Beatrice Rieck
Vogel Druck & Medienservice GmbH
Leibnizstraße 5
97204 Höchberg
Tel: +49 931 4600-2721
e-mail: beatrice.riECK@vogeldruck.de

MaxPlanckResearch seeks to keep partners and friends of the Max Planck Society up to date on the latest research conducted at the Max Planck Institutes. Four editions of the magazine are published in German each year, all of which are translated into English (*MaxPlanckResearch*). At present, the German version has a circulation of 85,000 copies (*MaxPlanckResearch*: 10,000 copies). It is free of charge. Reprint of texts is permitted only with the prior approval of the publisher. Photographic rights may be granted by agreement. None of the views and opinions expressed in *MaxPlanckResearch* may be interpreted as representing the official views of the Max Planck Society and its associated bodies.

The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. (Max Planck Society) comprises 86 institutes and research facilities where around 23,900 employees, including some 6,900 employed scientists, work and conduct research. The annual budget for 2019 was EUR 1.86 billion. Research activities of the Max Planck Society focus on basic research in natural sciences and the humanities. The Max Planck Society is a non-profit organization registered under private law as an incorporated association. Its central decision-making body is the Senate, with members from the world of politics, the scientific community, and the professional public, providing for a well-balanced partnership.

MaxPlanckResearch is printed using FSC®-certified and other controlled materials.



MAX PLANCK
GESELLSCHAFT

