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Max Planck RESEARCH

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The Roots of Humankind

SOCIAL POLICY
A New Rule for Public Pensions

OPTICS
Glass Fibre Rainbows

3D PRINTING
Built with Light

CLIMATE RESEARCH
Sailing Close to the Wind

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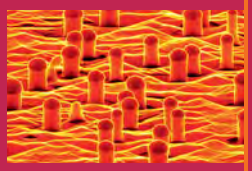

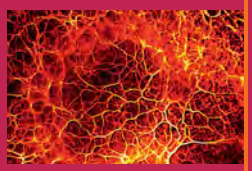

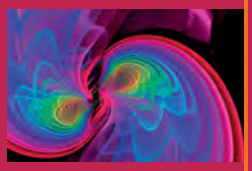

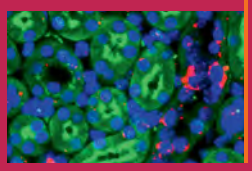

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Connecting Science and Business

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Photo: Valérie Schwab-Lavrič

At the End of the World

Dusty, windy, desolate – "an end one would rather not see" is how Argentinian author Mempo Giardinelli describes the Patagonian *mesetas*. Yet Gerd Gleixner and his colleagues from the Max Planck Institute for Biogeochemistry specifically chose the region for one of their research expeditions: its enormous, grassy, high plateaus of volcanic origin offer conditions that are hard to find anywhere else in the world.

The steep slopes of the Andes mean that the clouds arriving on westerly winds from the Pacific release their rain on the Chilean side of the mountain range. But the clouds carried over from the east also pass over the flat plateaus, the only significant rainfall in the region occurs near the mountains. These exceptional geographical circumstances of the *mesetas* make it possible to take soil and sediment samples over thousands of miles along a north-south route that always has identical precipitation conditions, thus affording a unique opportunity to investigate the effect of temperature on the soil's carbon exchange rate isolated from the influence of rainfall.

Gleixner's research group is particularly interested in how ecosystems react to climate change. By identifying resistant biomolecules and using them as biomarkers, the researchers are able to exploit the soil and sea sediments in the Argentinian *mesetas* as a climate archive. Gleixner's team is reconstructing climatic events from the past 10,000 to 20,000 years in order to determine the capacity of organisms and ecosystems to adapt to future climatic changes.

For the researchers, the old refrigerator in the middle of this image, which someone disposed of in the grassy expanse of the plateaus, symbolized the need to find parameters that can help cool our planet's climate systems down again.

18 THE ROOTS OF HUMANKIND

ON THE COVER "Where did we come from?" is one of the fundamental questions of humankind. Archaeologists, anthropologists and geneticists are finding more and more clues about where the first humans came from, how they spread throughout the world and how they lived.

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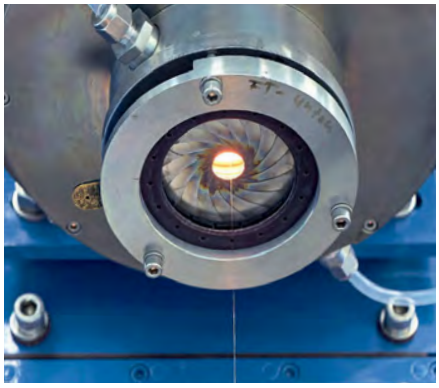

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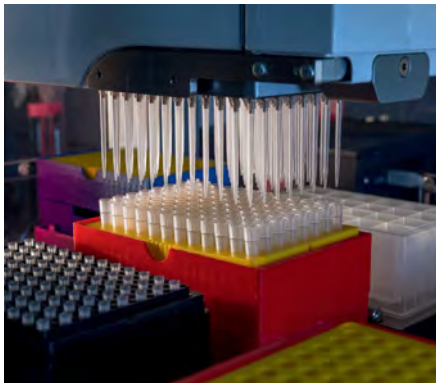

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SPECTRUM

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MATERIALS & TECHNOLOGY

ENVIRONMENT & CLIMATE

REGULAR FEATURES

Photos: Tilman Weishart, Axel Griesch, Ulrike Weis/MPI for Chemistry (left to right)

New Ways to Promote Talent

Annual Meeting of the Max Planck Society focuses on junior scientists

A ceremonial setting: Max Planck President Martin Stratmann speaks during the Plenary Assembly in the Kaisersaal in Erfurt.

To attract the best international talent, you need an enticing offer and high visibility – as Max Planck President Martin Stratmann discussed in his closing speech at the 68th Annual Meeting, held in late June in Erfurt, Jena and Weimar. One central issue was the Max Planck Schools: interregional research and education networks established in collaboration with the German Rectors' Conference and other partners. In his address, Georg Schütte, State Secretary in the Federal Ministry for Education and Research, confirmed his ministry's intention to promote the networks.

The Annual Meeting began with the presentation of the Stifterverband Science Prize. Peter H. Seeberger, Director at the Max Planck Institute of Colloids and Interfaces, received the award and the accompanying cash prize of 50,000 euros for his pioneering work on automated sugar synthesis. In addition, outstanding junior scientists were presented with awards including the Otto Hahn Medal, which recognizes outstanding scientific achievement by doctoral students.

In the meeting of the Max Planck Senate, Rüdiger Willems was confirmed as the new Secretary General of the Max Planck Society. The lawyer has held the office on a provisional basis since February 2017 and previously served as Deputy Secretary General for more than ten years.

Flowering Research

"Jugend forscht" – The Max Planck Society congratulates young researchers

The most talented participants in Germany's "Jugend forscht" initiative were honored at a ceremony held in Erlangen in May. The Max Planck Society has donated the prize in the physics category for some time now. Gerd Leuchs, Director at the Max Planck Institute for the Science of Light, presented the first prize in this year's national competition to three elementary school students from Berlin. Matthias Grützner, Julian Egbert and Arne Geipel jointly uncovered a surprising phenomenon: when a jet of water encounters a coarse surface, such as a wooden board, regular spiral-shaped patterns can form that are reminiscent of a sunflower's disc florets. The 16-year-olds found an explanation for this in the minute protrusions in the rough surface, which break up the running water and thus form the pattern. The three pupils tested their theory using an experiment in which they allowed water to fall onto a nail and then recorded the flow with a camera. The results confirmed their tentative explanation. The jury praised the resourceful and intelligent manner in which the young researchers investigated the phenomenon they had uncovered – and the fact that they independently reached a theoretical description.

Proud winners: Matthias Grützner, Julian Egbert and Arne Geipel (from left) receive their "Jugend forscht" certificates from Max Planck Director Gerd Leuchs.

Photos: Amac Garbe (top), Stiftung Jugend forscht e. V. (bottom)

"The euro project has failed"

Fritz W. Scharpf, Director Emeritus at the Max Planck Institute for the Study of Societies in Cologne, strongly criticizes the monetary union

Mr. Scharpf, your criticism of the European Monetary Union attacks its very foundation. Has the euro project failed?
Fritz W. Scharpf: In its current form, yes. A technical system was constructed by which currencies were equalized. However, nothing was done to develop citizens' political identification with the monetary union.

Does the problem lie in the fact that there is no European identity? Or did we start from the wrong end?
We started from the wrong end. The monetary union is a case of economic over-integration. A European identity could develop if Europe does something that both the member states and their voters want. Or if there is pressure from outside – consider, for example, Trump, the Ukraine or the Middle East. After the Second World War, we resolved that we would never take up arms against each other again. Instead, we wanted to reinforce and enhance Europe in all its diversity.

What role do citizens play?
In Greece, Portugal and Italy, there is currently a suppressed rebellion against the restraints of the monetary union. And in the countries of the economic North, at least a part of the population is frustrated about the risks of bailout loans, as well as the lack of gratitude and reliability of the countries to be saved. But this conflict can't be resolved, as there is no democratic basis for dealing with these issues at the European level.

There are signs of progress. But is completely changing a country's path a legitimate approach?
The Greek economy has shrunk by a quarter; at the same time, though, its export ratio has grown by more than a third. That was the plan. And if such a restructuring ultimately succeeds, it is hoped that others can grow in the same export-oriented manner. In this respect, to answer the second part of your question, this has been a foolhardy experiment in social engineering, but it can be justified.

Are there actually any other options? Would it be an option to say: okay, this or that country has to leave the euro?
The most economically prudent option would actually be for Germany to leave the euro. That's because Germany is the largest and most competitive economy in Europe, and because this fact is rooted in a historically and geographically unique situation, especially since German reunification. Problems could be combated more easily in a monetary union without such an overpowering national economy. But of course Germany is the very last country that would unilaterally renege on its loyalty to European integration. Europe wouldn't be able to cope with that.

Fritz W. Scharpf

So, what now?
I would consider it sensible to introduce rules now to enable a two-level monetary system to come about – in due course and without acute pressure so that, if it came down to it, the chaos option wouldn't be the only choice, and so that a controlled transition to a better structure would be possible.

What might that look like?
One structure would be the countries that, together with Germany, form a highly competitive economic system in the current monetary union. This includes the old "Deutschmark block" that existed before the monetary union, namely Germany, Austria, the Netherlands, Denmark and Finland. Since then, the Baltic member states have joined. This would be a hard currency group based on the German model that could integrate much better and would also function much better. For the other part, a backup structure already exists: the Exchange Rate Mechanism II …

… which emerged from the European Monetary System that Helmut Schmidt and Giscard d'Estaing created in 1979. Is it still in keeping with the times?
It still exists. The member states cooperated in defining their exchange rates and supported one another when they came under international pressure. If there were long-term differences in their competitiveness, then the currencies were revalued or devalued. Today, a decision on support for foreign exchange markets would be made by the European Central Bank.

The strong countries return to the safety of community, with all of its opportunities and benefits, and the less strong countries would enjoy the flexibility of exchange rates. Is that a Europe with two speeds – or two classes?
The members of Exchange Rate Mechanism II enjoy not only flexibility but also protection against speculation on capital markets and the risk of inflation or devaluation spirals. But identification with Europe would be institutionally supported in both groups of countries: they would be in the EU. This block would still have a strong communal presence on global finance markets, so Europe would likely hold greater sway in the world – as Norway and Switzerland might also consider accession. In fact, all of Europe could find its place in a more broadly defined monetary union.

Interview: Martin Tschechne

Photo: Private collection

Global Movement for Science

At more than 600 locations worldwide, people took to the streets for the "March for Science"

On April 22, researchers, students and citizens around the world took part in the "March for Science" to support science and its role in politics and society. According to the organizers, the focus at the demonstrations in Germany was on promoting the "value of science, facts and evidence-based conduct in an age of alternative facts." Max Planck scientists also participated, helping with planning in the organizational team, distributing flyers, giving speeches or marching. Demonstrations were held in more than 20 cities in Germany, in many cases with active participation of local Max Planck Institutes. Indeed, leading Max Planck scientists, including Nobel Prize laureates, spoke out in support of the "March for Science" in Berlin.

In his speech at the demonstration in Munich, Max Planck President Martin Stratmann warned that scientific freedom was coming under increasing pressure internationally. "We cannot accept that, in times when people are changing this planet on a scale never seen before, decisions are made without due consideration of scientific facts," Stratmann said. "We must not act dumber than we are."

Creative protest: At the "March for Science" in Munich, scientists from the Max Planck Institute for Ornithology advocated intelligent actions with an umbrella reading "Let it Brain."

Impressive Ceremony to Mark Centenary

Japanese research organization RIKEN celebrates 100th birthday

Five research campuses and some 2,000 scientists, primarily in the fields of physics, chemistry, and life and computer sciences make up RIKEN Japan's leading organization for basic research. While the Max Planck Society also covers the human sciences, both organizations focus on research at the frontiers of knowledge – and enjoy a close relationship, thanks in no small part to decades of collaborative endeavors. Martin Stratmann emphasized this in Tokyo, where he was the only international representative among the 600 invited guests to be asked to give a brief congratulatory speech on the occasion of the research organization's 100th birthday.

Their Imperial Majesties Emperor Akihito and Empress Michiko personally attended the ceremony, while further prominent speakers included two Nobel Prize laureates – particle physicist Takaaki Kajita and stem cell researcher Shinya Yamanaka – both of whom gave commemorative speeches. During his trip, Stratmann also held discussions with various people on deepening scientific cooperation, including the President of RIKEN, Hiroshi Matsumoto, and the President of the University of Tokyo, Makoto Gonokami. There were also meetings between scientists from both countries. These included the opportunity for Stratmann to meet with nearly 20 Max Planck alumni.

At the evening reception for the 100th anniversary celebrations: Martin Stratmann (right) was invited to perform *kagami-biraki* – the traditional ceremony for breaking open a sake barrel. Also pictured are RIKEN President Matsumoto (left) and Science Minister Tsuruho.

Photos: Amac Garbe/MPG (top), RIKEN (bottom)

Center for Systems Biology Opened

Joint venture of the Max Planck Society and the Technische Universität Dresden seeks to unravel cellular processes

It's a delicate balance: molecules arrange themselves to become cells, cells form networks to make tissue and tissues form organs. This process occurs only in the correct spatial arrangement and chronological sequence. At the Center for Systems Biology Dresden, a joint venture of the Max Planck Institute of Molecular Cell Biology and Genetics, the Max Planck Institute for the Physics of Complex Systems and the Technische Universität Dresden, researchers seek to understand how cells synchronize with one another to form tissue with a specific size, form and function.

At the Center's opening in May, speakers included the Minister President of Saxony, Stanislaw Tillich, and Max Planck President Martin Stratmann. The guest of honor was American biochemist and entrepreneur Craig Venter, who played a significant role in decoding the human genome. The Center for Systems Biology Dresden brings theoretical and practical specialists together in one location. Following the startup phase, around 120 scientists will conduct research at the facility. The Center is headed by Max Planck Directors Gene Myers and Frank Jülicher, as well as Ivo Sbalzarini from the TU Dresden.

Prominent guest: Biotech pioneer Craig Venter at the opening of the Center for Systems Biology Dresden.

Photo: MPICBG

On the Net

Science on Board
From Bonn to Straubing: The exhibition ship *MS Wissenschaft* has set sail once again. After dropping anchor in more than 30 towns and cities across northern Germany during the past year, the current route will take it along rivers and canals in the south of the country and into Austria. Visitors to the exhibition in the ship's hold can travel even much further: to mudflats, tropical coral reefs, the deep sea and the polar sea. With more than 30 different exhibits, the exhibition offers insights into ongoing research projects, including initiatives by three Max Planck Institutes.
https://ms-wissenschaft.de/english

Neural Network Goes Grunge
Artificial intelligence aficionados Ivan Yamshchikov and Aleksei Tikhonov from the Max Planck Institute for Mathematics in the Sciences have recently published a mini-album. In their musical endeavour, the programmers enlisted a rather unusual songwriter: the lyrics of all four songs were written by an artificial neural network trained to resemble Nirvana vocalist Kurt Cobain. The vocals were recorded by Rob Carroll, a musician from New York. You can check out the AI-created verse in a YouTube video created by the researchers; the song is called "In the Back of Your Glass."
http://bit.ly/2rWEVJP

Secrets of Fish Schooling
Collective behavior is embodied in swarms of insects, flocks of birds, herds of antelope and schools of fish. Studying this behavior in schools of fish has been incredibly challenging, because the cues that drive it occur at lightning speed, come from multiple directions and sources, and of course because all of it takes place underwater. Iain Couzin and his colleagues at the Max Planck Institute for Ornithology at the University of Konstanz are using new observation techniques and technologies – including high-speed video, motion-tracking software and advanced statistical modeling – to reveal the mysterious mechanics of schooling fish.
www.biographic.com/posts/sto/lens-of-time-secrets-of-schooling

A New Rule for Public Pensions

Few if any socio-political topics prey on the mind as much as financial security in old age. Few if any offer such a fertile electoral battleground. In our author's view, however, perceived truth is a poor foundation on which to base pension security. Instead, he lays out the facts and their consequences.

TEXT **AXEL BÖRSCH-SUPAN**

In 2015, around 30 percent of the working population across all age groups in Germany stated that they expected to receive no more than a basic public pension – that is, social assistance in old age or its equivalent. By last year, the press was reporting that as much as 50 percent of the population will face poverty in old age. This year, the competent minister has spoken of a "slippery slope" on which the level of pensions is heading downhill unchecked, such that it's time to draw a line to make it stop. Such statements naturally trigger emotions.

The German pension system, in particular, is highly rule driven, and makes for very dry reading. In addition, the factors that determine long-term pension development generally change slowly and steadily, with the result that future pensions are quite easy to forecast. Half of the approximately 30 percent of the working population who stated in 2015 that they had only social assistance to look forward to were actually entitled to a far higher pension – they just didn't know it. And the forecast of a 50 percent poverty rate in old age was the product of two serious errors in reasoning. First, it was incorrectly assumed that young people with little or no current earnings (such as trainees and students) would remain poor in old age. And second, those who don't receive a public pension (such as civil servants and housewives), were also classed as poor even if they actually receive a generous income, especially in a household context. After correcting these errors, the forecast dropped to around 5 percent.

> The false forecast of a 50 percent poverty rate in old age was founded on two errors in reasoning

So is it possible to employ scientific methods and sober analysis to stem the agitation regularly prompted by the emotive issue of pensions? Let us try.

The public pension is a pay-as-you-go system in which the contributions paid by younger people are immediately disbursed to their older counterparts. Leaving aside a relatively small reserve of at most one and a half months' disbursements, the idea of a well-

Working or retired: The point at which people no longer have to work is one of the main points of dispute in pension policy.

Photo: Sebastian Kahnert/dpa

filled pension fund is absurd. What is paid out always equals what is paid in; nothing is left over. This is the first important mechanism of the German public pension system – and it's a problematic one. Demographic change means that the number of elderly is increasing while the number of younger people is declining. Hence, pension expenditures will rise while contributions will fall. But more on that later.

The second important mechanism involves the way in which contributions and benefits are split between individuals. The rule here in Germany is that contributions up to a certain upper limit (the contribution ceiling) are strictly proportional to earned income, and the pension benefits paid, in turn, are strictly proportional to the contributions paid over the recipient's lifetime. This second fundamental mechanism underlying the German pension system is also not without its problems, since those with low earnings during their working life will receive a low pension when they retire.

> The deluge of young refugees won't compensate for the birth deficit

Each individual's share of the funds paid out by the pension system is equal to the proportion they paid in on average over their working lives. This equivalence contrasts with a progressive income tax and the many other redistribution mechanisms inherent in our tax and transfer system. In other countries, such as Switzerland and the US, this proportionality doesn't apply. Instead, the poorer receive a disproportionately high, and the richer a disproportionately low, pension. On the other hand, in both of these countries, there is a far lesser degree of redistribution via taxes on income.

We therefore need to tackle two major issues that nourish people's fears and anxieties surrounding pensions: the threat of poverty in old age, and demographic change. Let us first address the latter.

As already described, the age structure of Germany's population is currently changing drastically: there will be more and more older people, and fewer and fewer younger ones. There are three causes of this. First, there were significantly more births per year in the 1960s than in the decades before or since. The annual cohorts of the baby boom years have a very strong influence on various averages in our country, from savings and consumption habits to age in general. As the baby boom generation ages, the average German population ages with them.

The second cause lies in the fact that we are living longer thanks to improved health. Life expectancy in 1960 was 69; 50 years later, it had risen to 80 – an increase of more than two years per decade. This is due in part to advances in medicine, but also to improved working conditions, the reduction in environmental hazards and – so far at least – a healthier diet.

The third cause is the decline of the birth rate since the 1970s. Since there have been far fewer births in recent decades than would have been needed to maintain a constant population, we now lack, relative to the preceding generation, around a third of the young people needed to finance our pensions.

Two points are worth noting. For one thing, the forecast for the number of young people whose task it will be to finance our pensions over the next, say, 25 to 30 years is highly reliable. These people have already been born. And it is a trivial matter to forecast the future age of any given cohort. On the other hand, changes in birth and death rates affect only a limited number of cohorts. Demographic development through 2045, looking a generation ahead, is therefore largely a matter of facts that are no longer open to change. Only with very long-term forecasts does accuracy become blurred. Secondly, even the recent deluge of young refugees will only minimally reduce the birth deficit, since even these massive flows are small in comparison with a shortage of one third of a generation.

How does one compensate for the burden placed on the public pension system by an aging population? Given the scale of the demographic challenge,

it would be unwise to respond with but a single socio-political countermeasure. What is needed instead is a package of measures oriented toward the individual causes. This is precisely what I meant when I referred above to a scientific approach based on sober analysis.

The first cause is beyond changing. The rapid progression from baby boom to the effects of birth control is historic fact. We must therefore accept the consequences while doing what we can to limit the damage. This is achieved through the sustainability factor introduced in 2005, which distributes the demographic burden about equally between the older and younger generations by raising contribution rates and lowering pension benefits by around the same percentage as the demographic burden increases. It was a wise decision to introduce this mechanism as a fixed rule in the law, thus protecting it from the changing moods and electoral panic attacks of politicians.

However, the sustainability factor has made it more difficult to calculate pensions in Germany, making the whole system less transparent. Whereas everyone understands what it means when the contribution rate rises, there is great uncertainty as to what it means when the so-called "pension level" falls. This is due to the misleading term "pension level", which actually defines, not a level, but a proportion – namely the average pension divided by the average earned income subject to social security insurance contributions. In Anglo-Saxon terms, it is more like the replacement rate rather than the level of a benefit.

The sustainability factor will lower this replacement rate by around half of a percentage point per year through 2045. So pension benefits will rise by one half of one percent less than wages. Since, however, long-term average wages are increasing by around 1.5 percent per year after adjusting for purchasing power, one whole percentage point remains for pension benefits to rise in terms of purchasing power. The part of demographic change precipitated by the switch from baby boom to baby bust can therefore be financed through growth, without eating into the very substance of pension benefits. On the contrary, this substance can continue to grow by around one percent per year. Taking average inflation into account, pension benefits will no longer rise by 3 percent, but still by around 2.5 percent in an average year.

As to the second cause of demographic change, there is no desire for change. Rather, it is a great gift for us to remain healthier longer and live longer lives.

Since 1957, the time for which pensions are paid has more than doubled

So far, increased lifespans have been reflected almost exclusively in the extended – substantially extended – time for which pensions are drawn: since the introduction of the pay-as-you-go system in 1957, this time has more than doubled from nine to currently 20 years. If the retirement age were to remain unchanged, it would increase by a further seven years by 2045. However, pay-as-you-go funded pension systems can remain stable only if the ratio of working life to life in retirement also remains unchanged.

As a first step in this direction, the retirement age is due to increase gradually over the next 13 years, from age 65 to age 67. It's worth noting that this increase is one year less than the anticipated increase in life expectancy over this period. So the "retirement at 67" rule also implies that pension benefits will be paid for an extra year. Behind the two-to-one ratio – the retirement age pushed back two years and pensions paid for an extra one year – lies the wise decision to preserve the proportions of life itself. At present, after an average working life of about 40 years, we draw our pensions for a further approximately 20 years. So an extra year of retirement must be funded by two years of work.

It would also be prudent to preserve these proportions after 2030 – ideally on the basis of a fixed rule

Photo: Sebastian Kahnert/dpa

so they don't fall prey to clientelism. The appropriate soberly analytical step would therefore be to introduce, post-2030, a dynamic two-to-one rule by which either increases in life expectancy are divided at regular intervals into two parts of longer time spent working and one part of longer time spent receiving a retirement pension; or – what we don't hope to see – by which reductions in life expectancy are equally automatically compensated for by a two-to-one reduction in employment time and retirement time.

A dynamic retirement age of this kind is the still-missing counterpart to the dynamic wage adjustment introduced in 1957 and the dynamic adjustment with respect to the increasing dependency ratio by means of the sustainability factor introduced in 2005. 2030 is still some way away, so there is no need for immediate action. However, people must be made aware of changes in pension law at an early stage so that they can plan their lives accordingly.

Only the third cause of demographic change has the potential for eradication, at least in theory. Practical politics has yet to find a way to turn the higher birth rate so often wished for into reality. Despite a variety of family policy measures backed by per capita funding almost as high as that in France, a country renowned in this respect, the birth rate has been stagnating for decades. Whether the recent, still modest increase will become a long-term trend remains to be seen – but even a long-term rise would take at least around 20 years to have any effect on pensions, when the first of these children begin their working lives.

As for which measures one might recommend to politicians in order to raise the birth rate in Germany, science is somewhat at a loss. For every measure that works well in one country, there are conflicting examples elsewhere. Scientists are, however, united in the belief that if one is effectively unable to increase the quantity of children, one should at least invest in the quality of education so that the few children may be all the more innovative and productive. And on this point internationally, as various educational surveys show, we in Germany languish in mediocrity.

The second major issue in the pension debate is the threat of poverty in old age. Currently, the poverty rate among the elderly – defined as the proportion of over-65-year-olds receiving only the basic retirement benefit – a kind of social assistance in old age – stands at around 3 percent. Every such individual is one too many, certainly; but the proportion is substantially lower than in the population as a whole (around 9 percent) or indeed among single parents (almost 25 percent).

Demographic change can be funded through growth

The fear of poverty in old age is based on two developments that present a risk to the level of pension payments. These are, on the one hand, the pension reforms that are intended to stabilize the German pension system but that – as described above – are reducing the growth of pension benefits and increasing the retirement age; while on the other hand there has been an increase in the number of people whose employment circumstances allow for only very low or even zero public pension insurance contributions.

The fear that each reduction in the growth rate of pension benefits increases poverty in old age is based on the aforementioned misunderstanding of what "pension level" means. The purchasing power of pensions will continue to increase, rendering poverty all the less likely.

It's the increase in the retirement age that is more trenchant. It is an undisputed tenet among social scientists and epidemiologists that health correlates strongly with income; any differences of opinion relate solely to the weighting to be applied to the diverse reasons for this. People who have low earnings in their working lives and are therefore at risk of poverty in old age often also have physically more strenuous occupations and substantially poorer health. Many of them will be unable to carry on working up to a higher retirement age.

Unfortunately, this also correlates with the second development that will intensify the problem of

Photo: Sebastian Kahnert/dpa

poverty in old age, because these people are often in precarious employment with low pension entitlements. The data here shows clear patterns that could be used as a basis for targeted countermeasures. A retirement age that increases dynamically in line with average life expectancy demands clear exceptions for those whose earning capacity is reduced on health grounds. The current disability pensions are insufficient. The long-term unemployed currently drop out of the pension insurance system and are therefore also at risk of poverty in old age.

A third well-defined group at risk of post-retirement poverty comprises those who are self-employed and who currently also have no social safety net. They should be mandated to enroll in social insurance after a certain qualifying period.

So the pension issue can be considered on a well-founded scientific basis. Causes and problems can be isolated and analyzed individually. Demographic change is fortunately happening at a snail's pace, and is equally fortunately paralleled by better health and a longer lifespan. Consequently, it can largely be financed through growth rather than through reducing benefits – that is, through increasing productivity and wages as well as through longer lives. From the socio-economic data available at the individual level here in Germany, problem groups can readily be identified, allowing targeted countermeasures to be developed without opening the floodgates, as would happen with a general increase in the pension level.

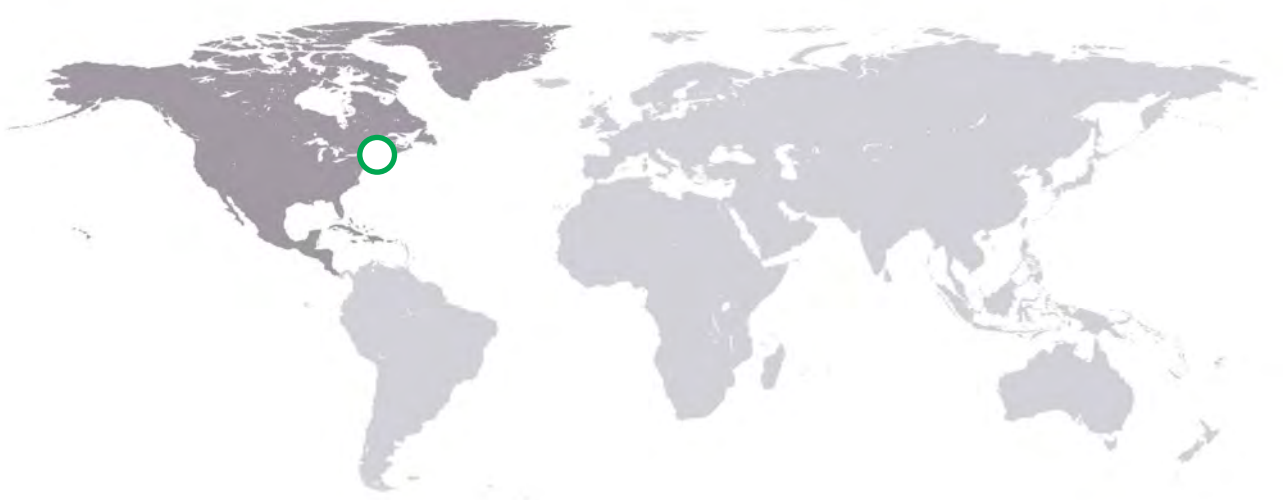
The social value of socio-political research lies in its empirical foundation. The collection of socio-economic and epidemiological data, for example, sheds light on the correlation patterns between wealth and health, poverty and reduced life expectancy, and facilitates the identification of many of their causes, allowing us through sober analysis to highlight problem areas for the benefit of politicians and to recommend suitable countermeasures – also at election time. ◀

An abridged version of this text appeared as a Saturday Essay in the Süddeutsche Zeitung on July 1/2, 2017.

Photo: Andreas Müller

THE AUTHOR

Axel Börsch-Supan, born in 1954, studied economics and mathematics before being awarded a doctorate from MIT in Cambridge (USA) in 1984. He worked as an Assistant Professor at Harvard University until 1987. Back in Germany, he initially taught at the Universities of Dortmund and Mannheim. Since January 2011, Axel Börsch-Supan has been a Director at the Max Planck Institute for Social Law and Social Policy, where he heads the Munich Center for the Economics of Aging. Axel Börsch-Supan is also coordinating the Survey of Health, Ageing and Retirement in Europe, a pan-European interdisciplinary project to survey the issue of aging. He has also been a member of the Committee of Experts on Demographic Change, set up by the German Federal Government, since 2011.



Fascinating Hive Mind

Max Planck scientists cooperate with partners in around 120 countries worldwide. Here they relate their personal experiences and impressions. Materials scientist Jiali Zhang from the Max-Planck-Institut für Eisenforschung in Düsseldorf did a nine-month postdoctoral exchange at the Massachusetts Institute of Technology in the US. She was fascinated by the hive mind that prevails there.

I grew up in a small city in China, in a district with a large population and thus tough competition to be accepted to one of the really good universities. Unlike other Chinese families, my parents encouraged me to completely follow my own interests and not necessarily become a doctor or lawyer – so I finally found my true passion in metals and their sustainability.

Manufacturing new metal parts entails high carbon dioxide emissions. To prevent this and protect the environment, it makes sense to increase the lifespan of metal parts and thus avoid having to continually replace them. This can be done by enabling them to heal themselves. In fact, there are already a number of self-healing materials. At the Max-Planck-Institut für Eisenforschung (MPIE), we want to incorporate nano-sized particles into metals to heal cracks the moment they occur at the microstructure level. These particles are made up of a shape memory alloy – an alloy that reassumes its original shape when subjected to a specific temperature, even after it's been deformed.

Graphic: iStockphoto

Jiali Zhang, 28, studied metallurgy at the University of Science & Technology Beijing and at RWTH Aachen University before joining Prof. Dierk Raabe's Microstructure Physics and Alloy Design department at the MPI für Eisenforschung in Düsseldorf in 2011. There, she completed her master's thesis, then later wrote her PhD dissertation on self-healing materials on titanium-based alloys. Jiali Zhang has been conducting research as a postdoc at the Max Planck Institute in Düsseldorf since 2016, and spent nine months in the new MIT group headed by Cem Tasan, who was formerly a Group Leader at the Institute in Düsseldorf.

I've been at the Max-Planck-Institut für Eisenforschung for six years now, so I know exactly where to go and whom to speak to – I was trained to work in a very structured way and following a certain routine. The atmosphere at the Massachusetts Institute of Technology (MIT) stands in stark contrast to this. As MIT is a university, it brings together numerous people working on completely different projects. Everyone has their own individual working style. To get the information I needed, I had to tap into this hive mind. I like both working styles: the very focused one at the Max Planck Institute, where I work only on materials science and can follow a certain structure, and in contrast, the diversity inherent in the hive mind.

My conversations with the technical assistants, in particular, were very interesting because they use the same facilities for such a variety of projects and experiments. It can happen that samples are being analyzed for one group that is studying the influence of temperature on chocolate – how it melts and how its taste changes – just as I'm studying the influence of temperature in my self-healing alloys. I found this really intriguing and again, I spent a long time talking to the technician – just imagine the new flavors that could be created …

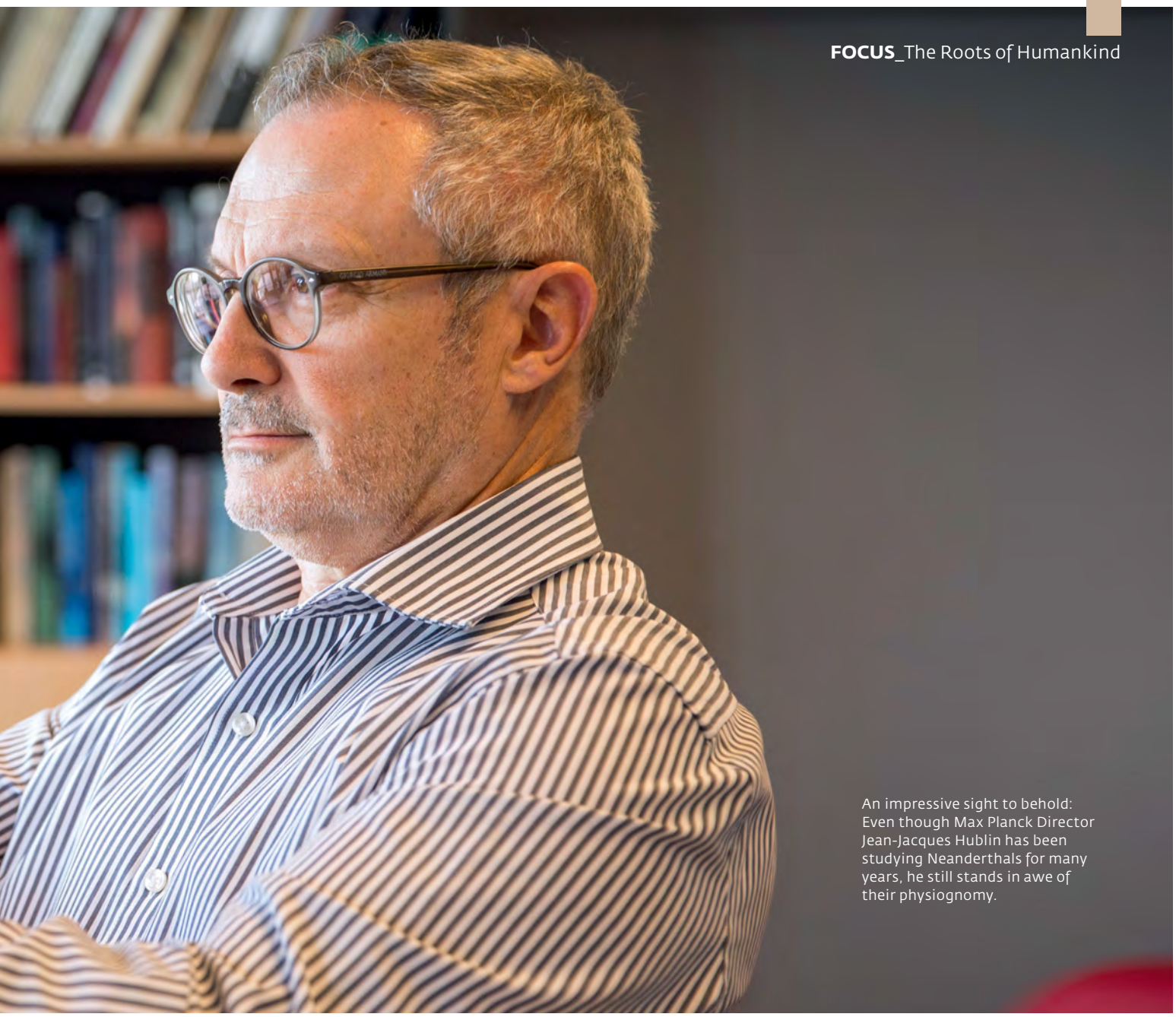
But there are also innovative things that I found only at MIT. The library online chatting system, for instance. During business hours, you can write to the library staff to find out if a certain publication is available and they would answer in real time. I found that very efficient and comfortable.

I also found it interesting to watch the outcome of the US election live on campus and to see how students reacted to it. The student body is very active and reaches out to the president of the university when they need help. MIT actually drafted a series of guidelines that protect international students and employees against the Muslim ban so they can focus on their research.

Photo: Private collection

Face to Face **with Neanderthals**

Neanderthals and modern humans must have coexisted in Europe for several thousand years. What happened when they encountered each other and how they influenced one another are riveting questions. **Jean-Jacques Hublin** and his team at the **Max Planck Institute for Evolutionary Anthropology** in Leipzig are searching for the answers. In the process, they have found clues as to what the Neanderthals learned from *Homo sapiens* – and what they didn't.



An impressive sight to behold: Even though Max Planck Director Jean-Jacques Hublin has been studying Neanderthals for many years, he still stands in awe of their physiognomy.

Photo: Anna Schroll

TEXT **KLAUS WILHELM**

Nobody knows what the baby died of. An infection? The attack of a wild animal? A congenital disease? Perhaps. In any case, the parents left the child behind in a cave in central France, which prehistorians today call the Grotte du Renne. It's even possible that the parents buried their baby in mourning.

Time travel: At the Max Planck Institute for Evolutionary Anthropology in Leipzig, the Human Evolution Department headed by Jean-Jacques Hublin conducts research into human prehistory, or paleoanthropology. Postdoc Frido Welker prepares bone fragments, some of them splinters, from the Grotte du Renne. All the experts had previously considered such fragments to be useless – or more accurately, paleoanthropologists such as Welker had no procedures for extracting insights from such damaged witnesses of prehistory.

Thanks to a method known as paleoproteomics, this has now changed. This method can detect even the minutest traces of proteins in ancient bone material and reveal information about the identity of the living being from which it stems – a "fairly revolutionary method," says Jean-Jacques Hublin. Proteins survive ten times longer than DNA in ancient bone material. Examination of the genome was previously regarded as the standard method of assigning a bone to a certain animal. Paleoproteomics could take over this mantle from DNA analysis. "The proteins of Stone Age bones contain valuable information on the evolutionary relationships and lifestyles of these people," Welker explains.

It was thus determined that the baby from the Grotte du Renne was a

Underestimated artists: Neanderthals were long thought to have lacked the ability to make jewelry. Scientists at the Max Planck Institute for Evolutionary Anthropology have been able to establish beyond doubt that these items of jewelry made from teeth, ivory and fossil shells were used by Neanderthals.

little Neanderthal, not even weaned, perhaps six months to two years old on the day it died 44,000 to 40,000 years ago. Its meager remains shed more light than ever before on a decades-long dispute among paleoanthropological experts. This genre of research is marked by sometimes heated debate. On the question, for example, of how Neanderthals and "modern man" – meaning you and me – encountered each other in Europe roughly 45,000 years ago. Following the latest high-tech analyses carried out by his team, Jean-Jacques Hublin is convinced that "there was a cultural transfer between the two hominins. It was only when *Homo sapiens* arrived that the Neanderthals suddenly began to do things they had never done before."

The Leipzig-based scientist assumes that this exchange "didn't require any particularly intensive contact." Let alone any love affair between *Homo sapiens* and *Homo neanderthalensis*, as was widely circulated in recent years. "Too many stories are being invented," says the Frenchman quite profanely. "It's highly likely that the truth was anything but romantic."

The witnesses to this past dating back tens of millennia – bones, teeth and cultural objects such as tools and jewelry – are limited and often lead to acrimonious discussions. "Of course that bothers me," says Hublin. "We would be well advised to distinguish between fact and fiction."

THERE WERE ALMOST NO HUMANS IN THE STONE AGE

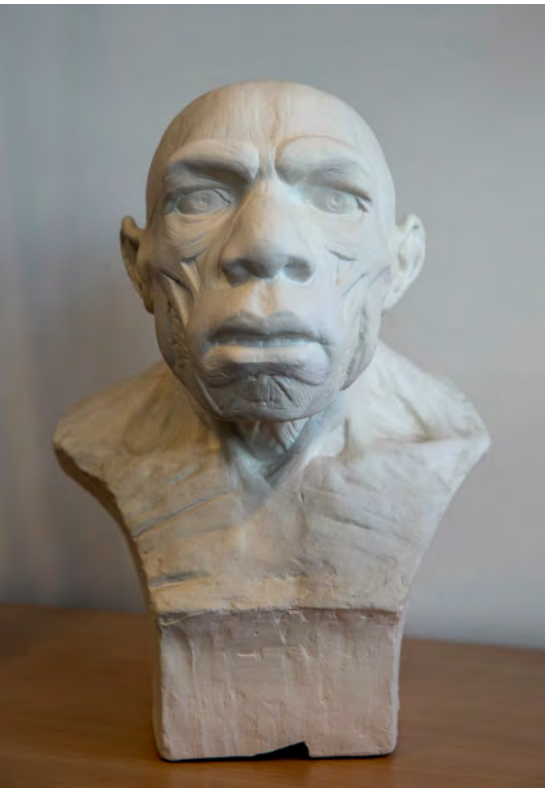
So let's take a look at the sapiens-Neanderthals case – one of the Max Planck scientist's specialist areas – in this light. Ever since the first bones of this hominin were discovered in the Neander Valley near Düsseldorf in 1856, legends have been woven around his existence – primarily because he looks so different from modern man.

With a height of no more than 1.70 meters, he wasn't particularly tall, but his physique was strong and powerful, with a very wide chest, the males weighing up to 90 kilos. "Very impressive," says Jean-Jacques Hublin as he gazes at the sculpture of a Neanderthal head in his office. It was fashioned at the beginning of the 20th century, but is still essentially in line with current knowledge. This means that the face is long and projected forward, with striking ridges over the eyebrows, while the nose is voluminous, the jaw massive and the chin area receding. "If you were to meet a Neanderthal in the train," the paleoanthropologist explains, "you'd change compartments."

Even 45,000 years ago, it must have been a highly unusual event when representatives of modern man, *Homo sapiens*, first came across members of *Homo neanderthalensis* in the forests and prairies of Europe. "For both sides," Hublin says with a laugh. According to the results of recent studies, the Neanderthals could already look back on at least 400,000 years on the continent – in an area ranging from Spain to the Russian Altai Mountains and up to the latitudes of northern Germany.

As hunters and gatherers, they most likely wandered across stretches of land measuring many thousands of square kilometers in groups number-

Photo: M. Hardy/MPI for Evolutionary Anthropology



Early settlers: Neanderthals – here an absolutely realistic bust from the 1910s – are estimated to have lived in Europe for 400,000 years before modern man arrived around 45,000 years ago. Both used the Grotte du Renne (right).

Photo: Anna Schroll (left), MPI for Evolutionary Anthropology (right)

ing no more than 50 to 60 men and women. They were able to kill even large animals such as bison and horses with great efficiency. They also consumed plants and vegetables to a much greater extent than previously believed. And Neanderthals probably lived at a faster pace. Hublin's team determined the age of a Neanderthal child from wafer-thin layers of enamel on its teeth. This showed that the children of this hominin matured one to two years earlier than the offspring of modern humans.

Their winters were brutal and long. It's likely that many of their small groups simply died out in long starvation phases and were replaced by new members. Even in times of their widest distribution, there were probably no more than an estimated 10,000 "Neanderthal Europeans." "The Stone Age was an empty world," Hublin says. According to the latest studies, Neanderthals faced this lonely existence with mental faculties that were almost as sophisticated as those of their cousins and (future) competitors. "They were more complex than we had long assumed," the researcher concedes. He then adds: "Both hominins were almost identical at this time in terms of their cognitive powers, definitely not apelike, but also not like us."

HOMO SAPIENS BROUGHT WITH THEM A SUPERIOR MIND

From a technical standpoint, Neanderthals were definitely skilled, as evidenced by the intricate spears they made in their earliest days. They even developed a tool culture roughly 120,000 years ago – or "industry" as paleoanthropologists say – which characterized a period: the Mousterian. During this time, they produced tools such as arrow points, scrapers, scratchers and blades that were hewn from stones in a characteristic fashion. Explorers have found artifacts from this culture in many archaeological sites – for instance in the aforementioned Grotte du Renne in Burgundy.

The Neanderthals thus coped with the adverse conditions in Europe quite well. They would doubtless have survived for further tens of thousands of years if another species hadn't suddenly created a stir in Europe 45,000 years ago: modern man. The new arrivals were much more delicately built than the established species. More importantly, they brought with them a mind that was ultimately superior. *Homo sapiens* not only worked stones, but also made fishhooks from fish bones, fashioned jewelry from bones, snails and eggshells, and formed points for arrows and harpoons. No sooner had they arrived in Europe than they created their own industry – this period is referred to as the Aurignacian. It is typified by projectile points, made from ivory and bones, that at the time were the finest in hunting technology.

The oldest bones bearing testimony to modern man are found in northern Italy, and soon they were scouring areas east of the Rhine in Baden-Württ-

Dental growth: Tooth enamel – here seen in a digital 3-D model – can be used to show how quickly Neanderthal children developed. According to this evidence, they matured one to two years earlier than children of modern humans.

temberg, not far from the Grotte du Renne. Around 20,000 years ago, the roof of this cave collapsed, burying everything beneath it – a stroke of luck for archaeologists, who have been uncovering rich finds from the various layers of the buried cave for decades. The cave was clearly a popular place of refuge during the Stone Age. People were continually stopping by. Besides the Mousterian artifacts in the deeper, older excavation layers, archaeologists also discovered remains of the Aurignacian industry in the upper, more recent layers.

However, in an intermediate layer in the Grotte du Renne – and at further sites with deposits – relics of the Châtelperronian (CP) culture were found. Many rings, pendants and clasps of ivory, antlers and other materials were found in the 1950s. Earrings; decorative pendants made from perforated, grooved teeth; fossils; and so on. Points or knives with a rounded, blunted back are also very typical. These elaborately worked utensils are occasionally strongly reminiscent of the subsequent Aurignacian industry of *Homo sapiens*. And not of the Neanderthals.

Drilling for samples: Proteins in bone fragments can be used to determine which creatures the remains stem from. To do this, small quantities of bone material are first extracted from the find.

At the same time, however, easily identifiable remains of bones and teeth were found in the CP layer of the Grotte du Renne – from Neanderthals, as a study from the 1990s suggested. But this sparked renewed debate. In 2010, British researchers believed they had proved that there were age differences between the various finds from the Châtelperronian layer. According to their interpretation, the jewelry had been made by modern man and only subsequently mixed up with the Neanderthal relics when the lower layers were dug up.

Jean-Jacques Hublin was disinclined to believe this, and together with international partners he embarked on a series of year-long tests. First, his team selected 40 well-preserved bone samples from the Grotte du Renne – mostly from areas containing CP jewelry or Neanderthal remains, and less frequently from Mousterian or Aurignacian layers. In addition, the researchers examined the shinbone of a Neanderthal from a different, well-known French excavation site in Saint-Césaire.

The scientists extracted collagen from the bone samples, an organic component of the connective tissue that consists of protein chains. Then came the hour of modern analytical equipment. “I’m obsessed with technology,” Hublin says, smiling. Half a dozen of the latest mass spectrometers can be found in his department – both high-tech scales that measure the mass of atoms and molecules, and accelerator mass spectrometers that can deter-

Photos: MPI for Evolutionary Anthropology (top), Anna Schroll (bottom)

mine the exact age of bones, for instance, by using the decay of radioactive carbon isotopes in molecules.

NEANDERTHALS ADOPTED MANY INNOVATIONS

The extensive analyses showed that the samples from the Châtelperronian layers are between 41,000 and 35,500 years old and therefore must indeed be assigned to this culture. In addition, the ages of the Châtelperronian finds didn't overlap with the finds from other layers, thus ruling out any mixing of the sediments. With an age of 41,500 years, the Neanderthal skeleton from Saint-Césaire also fits into the picture perfectly.

Neanderthals could thus also have created the CP industries in France. Could have! But there was still a lack of unambiguous evidence that the bones from the CP layer in the Grotte du Renne once belonged to Neanderthals – and not to modern humans.

The team working with Hublin therefore applied relatively new methods within paleoanthropology in its study: peptide mass fingerprinting and shotgun proteomics, methods borrowed from the field of proteomics. They demonstrated for the first time that their methods can be used to determine whether proteins in a bone

Photo: Anna Schroll

The bone material can be analyzed using mass spectrometry to determine its origins. Frido Welker prepares the samples in the laboratory for this purpose.

come from a Neanderthal or from a modern human. Tiny bone samples suffice for the test, and this is the aspect that is crucial and new. It is also the precise reason why the scientists were able, for the first time, to conduct a molecular analysis of 28 bone fragments from a layer of sediment attributed to the Châtelperronian period.

"They come from Neanderthals," says Frido Welker. By combining the paleoproteomic analysis with paleogenetics, it was ultimately clear that the bone fragments were those of an infant from the Châtelperronian period. "Our study shows that with paleoproteomics alone, it is possible to differentiate between different Early Stone Age groups within our Homo genus," says Welker.

The big question overshadowing the studies is: How did *Homo sapiens* get along with *Homo neanderthalensis*? The new finds can be interpreted in different ways. One could take them to mean that Neanderthals independently made an unexpected leap forward in their development just as *Homo sapiens* spread across Europe. "But that would border on a miracle," says Jean-Jacques Hublin. For him, it is far more likely "that the two hominins came into contact and the Neanderthals adopted some of the innovations of modern man."

The Neanderthals could have conceivably found tools and jewelry made by *Homo sapiens* – and then copied and, in time, introduced them to neighboring groups. They were likely intelligent enough to do so. Perhaps a well-meaning, modern human showed them how to make these wonderful articles. There were conceivably barter transactions between the groups. Who knows? Now we are back in the realm of ever-popular legends. And Jean-Jacques Hublin again urges caution.

TWO PERCENT OF OUR DNA COMES FROM THE NEANDERTHALS

The transfer of cultural innovations didn't require constant contact, much less close friendship. Modern man, too, had to master the harsh life of the hunters and gatherers, and competed with his contemporaries in the other species for territory and food. Even if there were only dozens or a few hundred groups that seldom encountered each other in the empty world of the Stone Age, most meetings of these contemporaries are more likely to have been unfriendly if not even hostile, aggressive and violent.

Admittedly, there is no concrete proof that this was the case. Nevertheless, we know that encounters between competing tribes seldom went smoothly in human history. It is therefore

Although the inner ear and middle ear ossicle of the Neanderthals are built differently than ours, both work in a similar way. This points to similarities in the sense of balance and the use of sound for communication.

Photo: Anna Schroll (top), MPI for Evolutionary Anthropology (bottom)

Left Focus on the facts in futuristic surroundings: Jean-Jacques Hublin takes a critical view when research and fiction are combined – for instance in the claim that there were love relationships between modern man and Neanderthals. Hublin suspects that encounters between the two were more likely to have been unfriendly.

highly likely that things would have been no different when *Homo sapiens* and Neanderthals met.

It's also possible that the females of the competing group were stolen in the process. So it may not have been fiery romances that led to sex between the parties, but acts of violence. They have left demonstrable traces to this day, as researchers have known for years. Around 2 percent of the DNA in our genome today stems from the Neanderthals – a limited but long-lasting legacy of this long-extinct hominin.

The earth has revealed evidence of the last Neanderthals in layers that are 40,000 or perhaps 38,000 years old. At some point during this period, the last of their species disappeared. "Because of us," says Jean-Jacques Hublin laconically. From a purely molecular standpoint, the differences between modern humans and Neanderthals are small: a mere 87 proteins separate the two species. Many of them, however, are important for brain function and development.

Something in modern man was different. It's possible he took a more aggressive approach than his related competitors; he probably cooperated more effectively in larger teams and in multiple groups, also showing more empathy and consideration for fellow members.

Experts have found some indications that this was the case. First, modern humans apparently bartered even in the early stages of their time in Europe. For example, shells from the Mediterranean have been found in Germany. "That suggests networks operating over large areas," says Hublin. "People knew that fellow humans were living on the other side of the mountains." And that they wear jewelry and decorate their bodies as a sign of their allegiance to a larger community consisting of hundreds or perhaps thousands. People who act in solidarity even if they don't see each other every day. There's nothing like this in the world of the Neanderthals.

HOMO SAPIENS PAINTED IMAGES FROM THEIR IMAGINATION

Second, Homo sapiens painted on cave walls in the early stages of their early European existence, also representing objects that didn't exist in reality, but only in their imagination. Men with lion heads, for instance. This means that, behind the objects, modern man recognized stories, mythical elements and faith. "This is a very strong factor that the Neanderthals apparently had no sense of," Hublin says.

Things of this nature are "difficult to investigate," even with the battery of equipment on hand at the Max Planck Institute in Leipzig. Just how much this frustrates the tech fan is noticeable. But who knows? Forty years ago, when he began his career as a young student, Hublin believed that all the essential elements of human history had already been researched, and that methodology wouldn't make any further significant progress: "I couldn't have been more mistaken." ◀

TO THE POINT

- **Neanderthals had similar cognitive abilities to *Homo sapiens* in the Stone Age.**
- **For example, they adopted the tool-making techniques of newly arrived modern man.**
- **The superiority of *Homo sapiens* probably consisted in their ability to form networks over large distances and to use artistic and mythical elements to reinforce the group.**

GLOSSARY

Paleoproteomics: Identification of prehistoric finds by means of protein analyses, for example in bone fragments.

(Tool) industries: Stone Age cultures characterized by certain tools – in some cases also jewelry and works of art – and the production techniques used.

Mousterian: The Neanderthal tool culture, marked by arrow points, scrapers and blades hewn from stone in a characteristic fashion.

Aurignacian: A culture that coincides with the appearance of modern man in Europe. Typified by projectile points of bone and ivory, long, narrow flint blades, and the first miniature works of art.

Châtelperronian: The last culture with which the Neanderthals are associated. It overlaps in time with the older Aurignacian and is characterized by bone, antler and ivory tools as well as jewelry.

It's all in the milk: The development of cattle breeding and arable farming ensured that there was a simple, reliable supply of meat and grain. The milk from cows, sheep and goats also proved especially valuable.

Change That Came **from the Plowed Field**

The transition to agriculture changed human society more drastically than almost any other innovation. Scientists at the **Max Planck Institute for the Science of Human History** in Jena are investigating this revolution from very different perspectives.

TEXT **CLAUDIA DOYLE**

Farming. That means getting up early and going to bed late, never going on vacation and always being there for the farm. Living on the edge and at the source. People have devoted themselves to agriculture for more than 10,000 years. Once upon a time, we were all farmers. But before our ancestors discovered agriculture, they roamed the land as hunters and gatherers. They lived together in small groups. There was no cause for warlike conflicts; the concept of social status was alien to them and possessions were shared. In the daily lives of our ancestors, there was no room for many things that we take for granted.

Anthropologist Robert Spengler, who will leave New York University to begin working at the Max Planck Institute for the Science of Human History in Jena in the fall of 2017, calls the change to an agricultural way of life "an unstoppable snowball." Arable farming brought the opportunity to store grain and thus to feed large families, resulting in rapid population growth. Not all members of the community were needed for agricultural work, which meant that some of them were able to indulge in intellectual, spiritual or artistic pursuits – but they also began to wage wars. Human communities became ever more complex with the development of professions, and changes increased exponentially. However, we still don't know exactly what got this snowball rolling. Researchers at the Institute in Jena are using a wide array of approaches to explore this question.

AGRICULTURE BROUGHT MORE PLANT-BASED FOODS

The transition from the nomadic way of life of hunters and gatherers to the sedentary farming lifestyle is fluid. There were, and still are, pure hunter-gatherer cultures that neither keep farm animals nor cultivate the fields. Coexisting with them were peoples who wandered the land with their herds and, to a limited extent, also indulged in arable farming. Added to the mix were the farmers, the most sedentary of the groups, who nevertheless still fished and hunted. It's clear that, over the course of the millennia, in many regions of the world, the sedentary farming way of life gradually and increasingly displaced that of the hunters, gatherers and nomads.

Those who study this transition and the cultural changes it brought about repeatedly encounter one anomaly. All over the globe, it was agriculture that set off wide-ranging social changes. The exception is the area that is today's Mongolia, Western China and Eastern Russia: the textbook opinion since the 1930s has been that people there ignored the innovations in agriculture, continued to live as nomadic shepherds and still developed a complex form of society.

For around ten years now, this worldview has been showing cracks. The man stirring up trouble – in a positive sense – is Robert Spengler. He joined archaeological digs in Central Asia and searched for evidence of early agricultural activity. While everyone around him was staring at skeletons, he scratched the ash

Photo: Thomas Stankiewicz/LOOK-foto

Above In excavations in Tasbas, Kazakhstan in northern Central Asia, Robert Spengler found the earliest evidence to date of grain cultivation. The early inhabitants of the region had long been regarded as exclusively nomadic.

Below Crops spread with merchants and migrants – for instance via the legendary Silk Road. This is evidenced by chickpeas from around 1100 CE found in excavations in Uzbekistan.

from 5,000-year-old hearths and found carbonized plant seeds.

Spengler can tell simply by their appearance under the microscope what plant they come from. The scientist found different types of wheat, millet, barley, peas, lentils and beans, all of them plants more often cultivated in fields than gathered in the wild. "The societies there are therefore no exception to the rule. Although they hunted, fished and gathered plants, they definitely also farmed the land," says Spengler. "It was simply that no one had ever investigated it."

One of the radical changes occasioned by the transition to agriculture was the supply of food. Nomadic peoples set off every day in search of something to eat and always follow their herds as far as they can walk. In addition to the meat from their herds, their menu also contains roots, fruit, bark and other edible parts of plants, but only to a small extent. Diet changed substantially when nomads discovered arable farming more than 10,000 years ago in the area known as the Fertile Crescent, which stretches from present-day Iraq to Syria. Vegetable nourishment slowly but surely acquired a much higher status.

Christina Warinner, a Research Group Leader at the Institute in Jena, has been interested in the diets of our Stone Age ancestors for many years. She wants to determine exactly what delicacies people in those days enjoyed and where they derived the majority of their calories.

ISOTOPES IN BONES REVEAL EATING HABITS

One good way to learn something about the diets of our ancestors is to analyze isotopes in bones or teeth. Nitrogen isotopes reveal whether a person consumed a lot of meat or tended to eat more plant-based foods. The ratios of the various carbon isotopes indicate whether their menu consisted mainly of C_3 plants, such as wheat, rice and potatoes, or C_4 plants, such as maize and millet. However, the analysis of isotopes doesn't supply precise information as to which C_3 or C_4 plants were important for the diet. Archaeologists must rely on other methods to obtain this information.

For a long time, the biggest problem for Warinner's research was that plants rot too quickly. Although animal bones can be found en masse at archaeologi-

Photos: Robert Spengler/MPI for the Science of Human History (2)

cal sites, the remains of vegetable meals are usually missing. The discovery of bones also tells us next to nothing about the purpose for which people once domesticated these animals. Did they harness their cow to the plow, milk it for its milk, or did they simply want to eat its meat?

In 2010, while still in Zurich, Christina Warinner began to apply a completely new method to tackle these questions. The object of her research was plaque. The tartar that dentists scrape from our teeth today as a matter of course consists of various calcium phosphate compounds. But does it contain more information? Are bacteria, pollen or proteins trapped inside it? That is precisely what Warinner believed. She began using scientific methods to examine the plaque on the teeth of our ancestors.

Initially, her colleagues didn't know what to make of this idea. What could be present in plaque? "I found it pretty discouraging," the researcher recounts. But she didn't give up. She procured skulls from archaeological digs as well as a few dental instruments that she used to carefully scrape the plaque from the teeth. With the aid of a fluorometer, she tested whether it contained DNA. Her measuring device initially showed an error message – not because there was no DNA to be found, but because the sample contained too much. "I never realized that that could be a problem," Warinner recalls, laughing.

The DNA in dental plaque stems largely from bacteria. No matter how thoroughly we brush our teeth, our oral cavity is teeming with billions of them. Warinner calls this community the "oral microbiome." Just like the microbiome in the gut, it has a unique composition in every person. There has simply been far too little research on it to date. Currently, Christina Warinner is analyzing bacteria populations from the plaque of Stone Age skeletons. She has already gained insights into diseases. Now she is hoping for clues about our ancestors' diets.

MILK IS A KIND OF CLEAN WATER

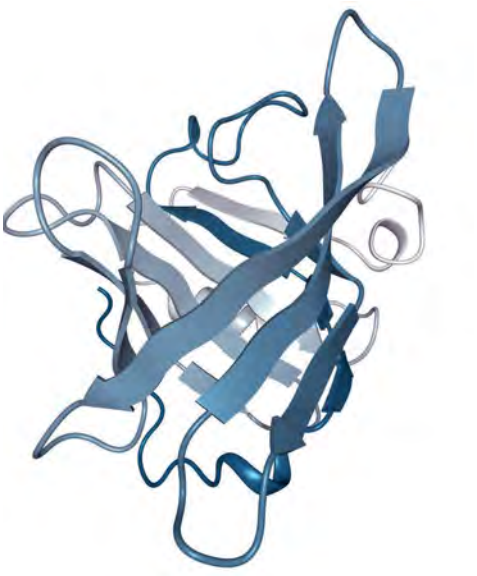
Warinner has already learned more about another mystery from the plaque. What she wanted to know was when and where people began dairy farming. People have been using the milk from animals as nourishment for at least 8,500 years. This is evidenced by proteins that have survived for millennia trapped in the plaque. One protein was found in a particularly large number of plaque samples: -lactoglobulin (BLG), which is present in the milk of cows, sheep and goats but not in human breastmilk. BLG is virtually indestructible. While other proteins collapse when exposed to heat or acid, BLG survives undamaged.

And even more important for Warinner's analyses was the fact that BLG has a different amino acid sequence for every animal. She can therefore tell exactly what kind of milk was consumed in a particular culture, and even when people first began to drink milk or eat dairy products far beyond childhood.

Humans are an exception when it comes to the consumption of milk. Although all other mammals tolerate milk in their early years, they lose this ability in adulthood. After the period of breastfeeding is over, the body stops producing the enzyme lactase. Without lactase, we are unable to digest lactose. A gene mutation is responsible for the fact that lactase continues to be produced in some people after infancy. Many adults are therefore able to

Useful deposits: Plaque contains valuable information on diseases and the diets of past eras, and it is preserved on teeth for centuries. Researchers use normal dental instruments to take samples (bottom).

Photos: Christina Warinner/MPI for the Science of Human History (2)



Historical research by means of microbiology: Christina Warinner examines fossil skeletons to determine whether people in the past consumed milk products. ß-lactoglobulin (right), a protein preserved in the plaque, even reveals which animal the milk came from.

drink milk without any problem, especially in Europe.

Milk supplies protein, fats, vitamins and minerals and is also a kind of "clean water." Camels, for example, can drink saltwater, which is undrinkable for humans, and pass on the liquid to humans in the form of milk. It is assumed that milk drinkers enjoyed an evolutionary advantage: people who could digest milk became stronger, lived longer and had more offspring. The mutation won out.

This so-called lactase persistence originated independently at least five times. It is most widespread today in Scandinavia. Around 80 percent of people there can drink milk without a problem, even as adults. Christina Warinner wants to find out more about how populations without lactase persistence used milk. Today's farmers in Mongolia, who should be genetically unable to digest lactose, in fact drink milk regularly and process the lactose differently than Europeans, for example. Their specialized dairy production processes, which include cultivation and consumption of large quantities of probiotic dairy bacteria, appear to allow them to digest lactose in the absence of a genetic mutation for lactase persistence.

EARLY CROP FARMERS WERE THE FIRST WHITE EUROPEANS

The advent of arable farming brought with it a further visible change in Europeans that has lasted to this day: their unusually fair skin. Our ancestors and their nearest relatives, from Neanderthals to Denisovans, were all dark-skinned. "Unfortunately, this insight has yet to reach museums," says Johannes Krause, Director of the Archaeogenetics Department at the Max Planck Institute for the Science of Human History. "The Neanderthals and Stone Age people there are always portrayed with pale skin and red hair." The hunters and gatherers as well as the first farmers in the Fertile Crescent also carried predominantly genes for dark skin.

Mutations in these genes that cause the color of the skin to become fairer were first found by researchers in the skeletons of early farmers in Europe. Initially, these mutations occurred only occasionally; then they prevailed. Today, they are fixed in 99 percent of the population of Central Europe. It is thought that Europeans would suffer from vitamin D deficiency without this adaptation. We humans, however, have two ways of acquiring this vitamin: we can absorb it through food, as meat and fish are a plentiful source of vitamin D, or our body can form it on its own with the aid of sunlight.

The dark-skinned farmers were unable to tap into either of these sources efficiently. They ate little meat, as we now know from analyzing isotopes in their bones, and they had ventured far

into northern latitudes where the sun shines much more weakly than at the equator. Fair skin saved them. It allows substantially more sunlight to penetrate, with the result that vitamin D can still be produced when the radiation from the sun is less intense.

ANIMAL HUSBANDRY LED TO NEW DISEASES

As people began to cultivate the fields, they became sedentary. As a result, they also began to live in much greater proximity to their animals: farm animals such as pigs, cattle, goats and sheep lived in fields and barns right beside their own homes. This proximity to their animals produced one major winner – but it wasn't either humans or animals, but pathogens. Pathogens love it when individuals live together in close communities. Viruses and bacteria need hosts – that is, people or animals – so they can multiply. The more hosts they can infect, the better for them.

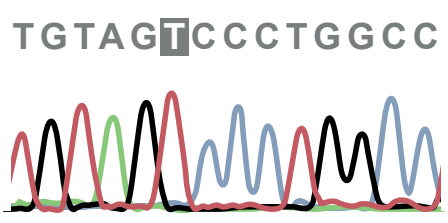
"It's a recognized theory, but so far we lack the evidence that early farmers were really exposed to more germs than hunters and gatherers," says Johannes Krause. "Unfortunately, the pathogens didn't leave any direct fossils behind." There are, however, clear indications that support the theory. For example, many of the pathogens related to measles, smallpox and whooping cough also infect farm animals, and were presumably transmitted from these to humans. Tuberculosis is an exception. It was humans that infected their cattle with this bacterium. It is still unknown who transmitted tuberculosis to humans.

Johannes Krause researches the evolution of pathogens. He wants to find out where they appeared for the first time, how they spread and how they adapted to new conditions. To do so, he needs first and foremost genetic material from ancient germs. One rich source for this is mass graves in which the victims of epidemics were buried. The DNA of the pathogens can be isolated from the bones and teeth of these old skeletons.

However, their genome is by no means intact, but has decayed into tiny fragments of only around 50 base pairs.

Right Mongolian shepherds process milk in such a way that lactose is largely broken down. Milk products are dried on yurt roofs to make them last longer.

Below Whether adults can digest milk is determined by the DNA component thymine at a particular location on the genome (highlighted T). If cytosine (C) is present there, the person will be lactose intolerant.



Graphic: designergold, based on original material provided by the MPI for the Science of Human History; photo: Eric Chretien/EXPLORER/GAMMA-RAPHO/laif

Dizzying search: Scientists found 6,000-year-old grains of barley in a cave near the Dead Sea. The entrance to the cave is located in an almost vertical cliff face around four meters above a path. Thanks to the aridity of the desert region, the grains are so well preserved that their genome can be reconstructed.

To find the pathogens' DNA at all among the human DNA, Krause has developed a method that is as simple as it is effective. He employs single-stranded DNA from modern pathogens as bait and uses it to fish the genome scraps of old pathogens from the samples. Then he washes off all of the DNA that isn't on the hook and that therefore stems, not from the pathogen, but from the human host itself or organisms in the soil. Using this method, the researcher has been able to reconstruct, for instance, the DNA of the plague virus *Yersinia pestis* with unprecedented accuracy. The bones came from a cemetery in London where only plague victims were buried in the 14th century.

The oldest plague germs examined, however, are much older. Scientists from the University of Copenhagen discovered them in 5,200-year-old skeletons from the Central Asian steppe. This may be where the disease originated. It's possible that it spread in all directions of the compass together with the very mobile inhabitants of the Central Asian steppe.

Johannes Krause and his colleagues also examined old skeletons and discovered that there was massive migration from the Central Asian steppe toward Central Europe at that time. More precisely, it was again their DNA that put the researchers on the right track. An analysis of the genome of more than 250 skeletons from various archaeological sites in Europe proves that there were two major population upheavals.

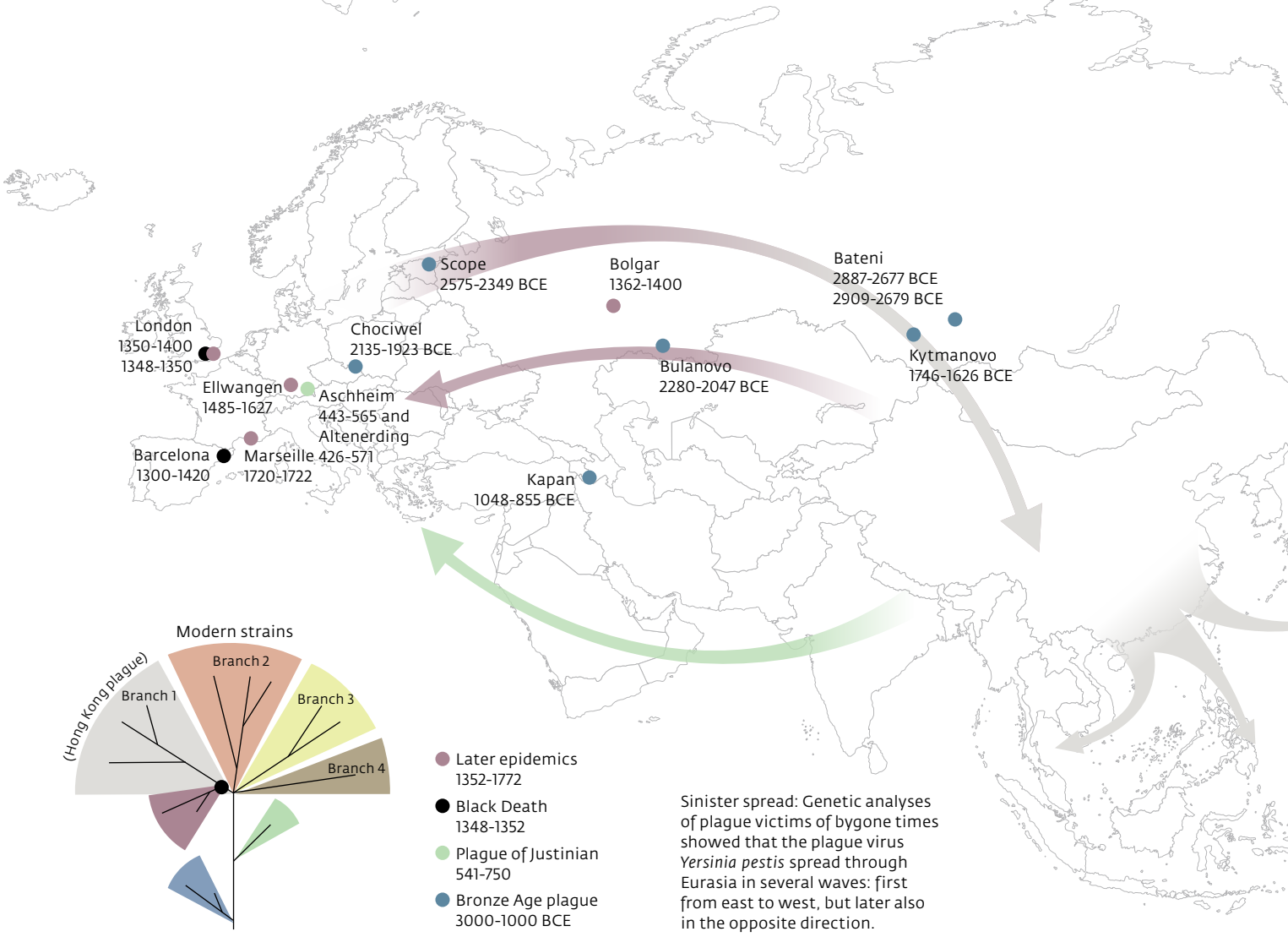
The earlier wave of migration began because the first farmers from the area of the Fertile Crescent were extremely successful. They enjoyed good harvests, always had food in abundance, their population grew and the first trade routes slowly developed. "Only when agriculture appeared did people have time for specialized crafts, standardized mass production and warlike disputes," says Krause.

In search of fertile land, some farmers migrated west and settled in Central and Western Europe, from Bulgaria to Spain, around 7,500 years ago. They didn't drive out the hunter-gatherer societies in these areas, but rather lived side-by-side with them until the hunters and gatherers gradually adopted a rural way of life and merged with the new migrants. Other early farmers left the Fertile Crescent for the East and settled the areas of the Asian steppe. They would later reach Europe in a second wave of migration.

WAVE OF MIGRATION FROM THE ASIAN STEPPE

This began around 4,800 years ago. In one fell swoop, an incredible number of people pushed toward Europe from the West Asian steppe. The migrants replaced the local population almost completely, as the scientists in Jena discovered in collaboration with an international team. This time, agriculture and the population growth that went with it can't have triggered this event,

Photos: Nature genetics, DOI: 10.1038/ng.3611 (2)



Sinister spread: Genetic analyses of plague victims of bygone times showed that the plague virus *Yersinia pestis* spread through Eurasia in several waves: first from east to west, but later also in the opposite direction.

as both populations engaged in farming. So what was the reason for it?

"That's precisely the question we're asking," says Johannes Krause. "How does it happen that one population is so successful?" One theory could be that the migrants brought the plague virus to Europe, against which they themselves had already developed resistance. By studying early outbreaks of disease and the evolution of germs more closely, the researchers are hoping to arrive at a better understanding of the dangers these germs pose and of ways of combating them.

Farming changed the world in many respects. It gave humankind food in great quantity and variety, but it also imparted new pathogens; it triggered waves of migration and allowed art and culture to flourish, yet it also encouraged war. By studying these comprehensive changes, scientists at the Max Planck Institute for the Science of Human History are gaining ever greater insights into how our present societies originated. ◂

TO THE POINT

- **Diet changed with the advent of agriculture: people began to eat more plant-based foods and less meat.**
- **As a consequence, there was less vitamin D in their diet, resulting in genes for fair skin prevailing among the originally dark-skinned Europeans. This way, the body can produce vitamin D itself with the aid of sunlight.**
- **Genes that allowed adults to digest milk also proved to be beneficial; farmers increasingly kept dairy cattle.**
- **Animal husbandry brought people into close contact with pathogens, and their immune systems had to adapt.**
- **More food and a better diet led to population growth and migration.**

GLOSSARY

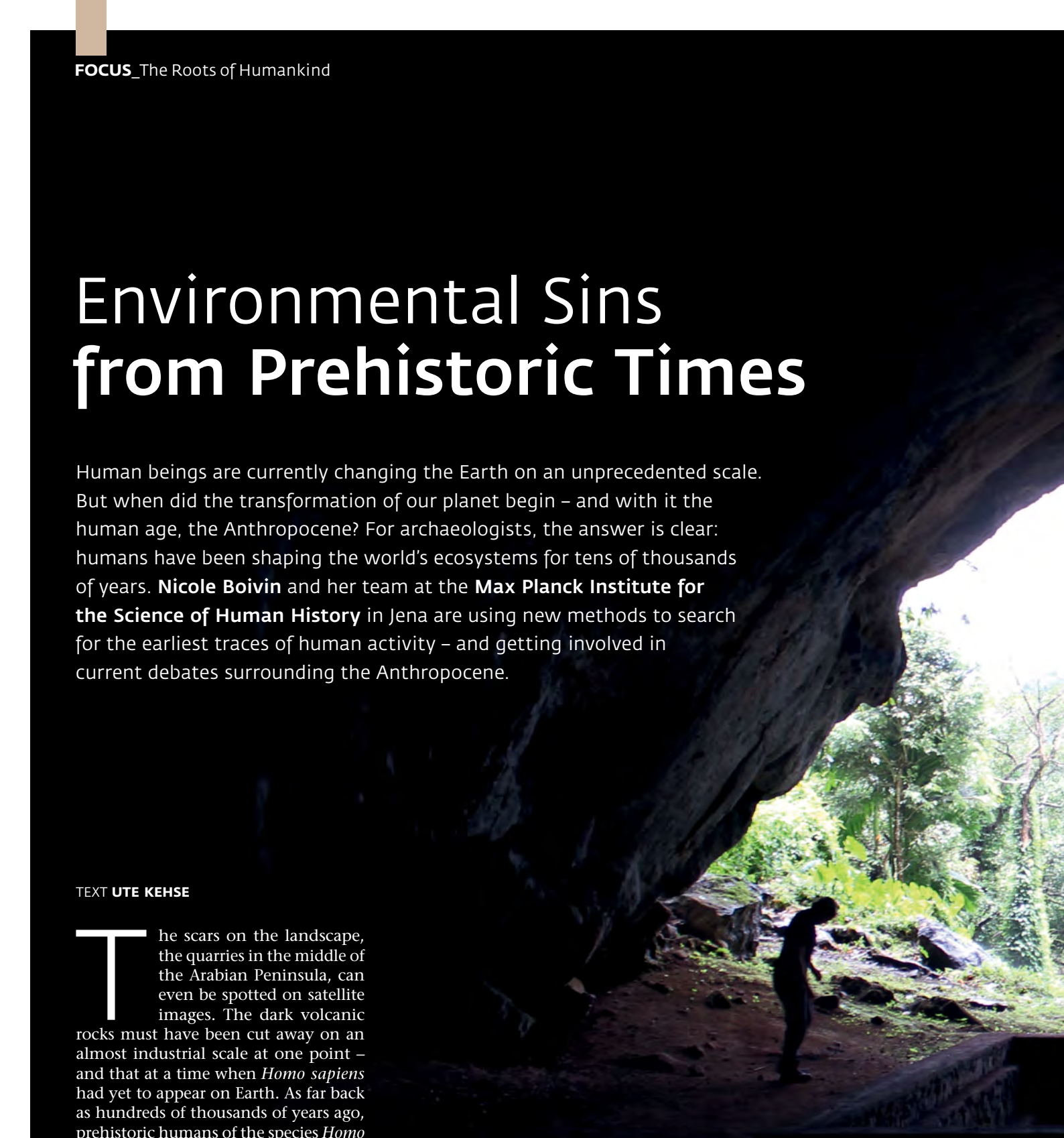
Isotopic analysis: Almost every element has different isotopes, meaning that their atomic nuclei contain differing numbers of neutrons. This can be measured using mass spectrometry. Information such as the age or origin of samples can be derived from the ratio of isotopes. In finds of historical skeletons, isotopes reveal information about their diet. Nitrogen isotopes point to a diet of predominantly meat, and the ratio of different carbon isotopes to the consumption of certain plants.

Lactase persistence: To enable it to digest the milk sugar lactose present in milk, the body needs the enzyme lactase, which isn't normally produced in adults. Genetic changes in farmers and settlers in Europe led to their bodies continuing to produce lactase after infancy. This lactase persistence is the opposite of lactose intolerance, the inability to tolerate milk.

Graphic: designergold, based on original material provided by the MPI for the Science of Human History

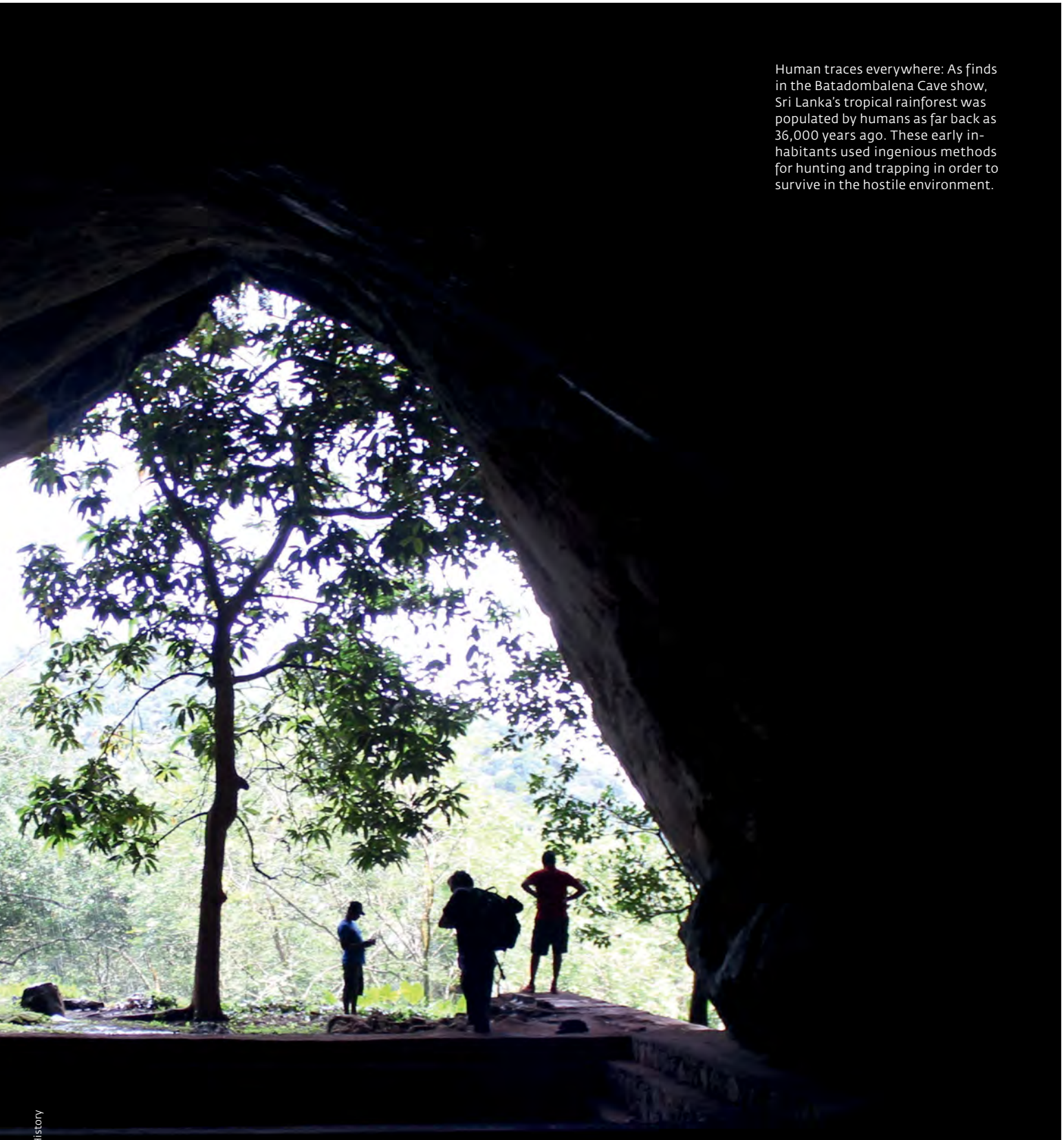
Environmental Sins **from Prehistoric Times**

Human beings are currently changing the Earth on an unprecedented scale. But when did the transformation of our planet begin – and with it the human age, the Anthropocene? For archaeologists, the answer is clear: humans have been shaping the world's ecosystems for tens of thousands of years. **Nicole Boivin** and her team at the **Max Planck Institute for the Science of Human History** in Jena are using new methods to search for the earliest traces of human activity – and getting involved in current debates surrounding the Anthropocene.



TEXT **UTE KEHSE**

The scars on the landscape, the quarries in the middle of the Arabian Peninsula, can even be spotted on satellite images. The dark volcanic rocks must have been cut away on an almost industrial scale at one point – and that at a time when *Homo sapiens* had yet to appear on Earth. As far back as hundreds of thousands of years ago, prehistoric humans of the species *Homo erectus* produced simple tools, hand axes, from the hard volcanic rock. "These people altered the geological outcrops across a vast strip of land measuring over 150 kilometers in length," reports Michael Petraglia, Professor of Human Evolution and Prehistory at the Max Planck Institute for the Science of Human History in Jena. "They took



Human traces everywhere: As finds in the Batadombalena Cave show, Sri Lanka's tropical rainforest was populated by humans as far back as 36,000 years ago. These early inhabitants used ingenious methods for hunting and trapping in order to survive in the hostile environment.

Photo: MPI for the Science of Human History

The desert was alive: The Arabian peninsula was wet and fertile for several periods over the past 500,000 years. Finds of hand axes bear witness to the presence of human life there. Michael Petraglia (right) and his team study how even early humans altered the environment there.

enormous boulders and broke them into pieces. You can find tens of thousands of splinters there," he adds.

Thus, according to Petraglia, humans started to change the Earth's geology with the arrival of the first stone tools more than three million years ago: "Even the predecessors of modern humans shaped their environment." However, the early traces of these changes are not always easy to identify, and the researchers in the Department of Archaeology at the Max Planck Institute in Jena have set themselves the task of tracking them down.

To be able to demonstrate the influence of humans on their environment in detail, they work closely with colleagues from the environmental sciences, including scientists from the Max Planck Institute for Biogeochemistry, which is also located in Jena. Through their collaboration, the archaeologists and environmental scientists aim to understand how the spread of human beings altered landscapes, such as the tropical rain forest, affected animal and plant species, and even created entirely new ecosystems.

DEFINING THE ANTHROPOCENE SPARKS CONTROVERSY

"Archaeologists are aware that even those landscapes that seem pristine to us today were often changed by humans," says Nicole Boivin, head of the new Department of Archaeology established at the Max Planck Institute for the Science of Human History last year. "Other disciplines are far less aware of this," she adds, referring to a debate that recently flared up in the geosciences.

In August 2016, a working group of the International Commission on Stratigraphy announced that it would define a new geological epoch, the Anthropocene, within the next three years. It argued that humanity has now become a "geological superpower" and has such a far-reaching influence on geological, biological and atmospheric processes on Earth that a new epoch needed to be defined.

But when did the Anthropocene start? The majority of the scientists in the working group are of the view that the beginning of this new age should be dated to 1950. New technologies that emerged in the mid-twentieth century left characteristic traces on the Earth from this point in time. For example, artificial radionuclides arose during nuclear bomb testing, and plastic and aluminum particles reached the environment for the first time and can be clearly detected in geological deposits. Other suggestions for the beginning of the Anthropocene include the year 1800 (the beginning of industrialization) and 1610 (argued to be

Photos: Michael Petraglia (2)

Pioneering work in the wilderness: While intensive research on the early history of Europe has been carried out for some time now, the Max Planck scientists in Saudi Arabia are truly breaking new ground with their work. With the help of satellite data, they focus their excavations on sites where rivers and lakes once existed.

Photo: Michael Petraglia

the point at which the global exchange of plants and animals began).

However, as Nicole Boivin and three colleagues pointed out in a comment published in the journal Nature in December 2016, the voice of the social sciences was missing from the debate. In particular, in the authors' opinion, the debate pays insufficient attention to archaeology, which, after all, has been exploring the influence of humans on the environment for a long time. According to their article, the formalization of the Anthropocene must be the product of a transparent, interdisciplinary discussion that should also involve the social sciences and humanities.

In the authors' view, in defining the new epoch, it makes no sense to refer to a single global event such as the beginning of above-ground nuclear tests. Instead, the significance of far-reaching social and ecological upheavals should also be examined. "It's obvious that the changes happening today are on a far greater scale than ever before," says Nicole Boivin. "But human beings caused species to become extinct and fundamentally shaped landscapes in the past, too," she observes.

HUMAN IMPACT ON THE PLANET UNFOLDED IN FOUR PHASES

The quarries of *Homo erectus* on the Arabian Peninsula indicate that even these prehistoric humans shaped their environment – which at the time consisted of a savannah studded with lakes. As part of the "Palaeodeserts" interdisciplinary EU project, which started in 2012 and is headed by Michael Petraglia, researchers from Jena, the University of Oxford and other institutes have been studying precisely how environmental conditions in the Arabian Desert changed – and how this shift between dry and wet conditions affected human settlement there. Conversely, humans are also likely to have left their mark on the environment – for example by hunting large animals such as elephants, hippopotamuses and antelopes. "They do not appear to have wiped them out completely," says Petraglia, "but an ecosystem changes even when a population isn't decimated by hunting."

Nonetheless, the changes initially remained more subtle, and are difficult to detect today. With the appearance of modern humans, *Homo sapiens*, the transformation of the planet picked up speed. Nicole Boivin points to four key phases of change: the spread of modern humans in the Late Pleistocene, which led to the extinction of many species; the development of arable and livestock farming, which led to the domestication of a range of species and resulted in the formation of entirely new

Prehistoric species extinction: Like the mammoth, many large animals all over the world became extinct after the last Ice Age. Their disappearance coincided with the spread of humans across the globe.

ecosystems; the settlement of remote islands where humans and their commensals often caused far-reaching changes; and finally, the growth of cities and development of trade networks, which resulted in the further intensification of agriculture, major land clearance, and the long-distance exchange of species.

MIGRANTS CREATED ECOLOGICAL NICHES

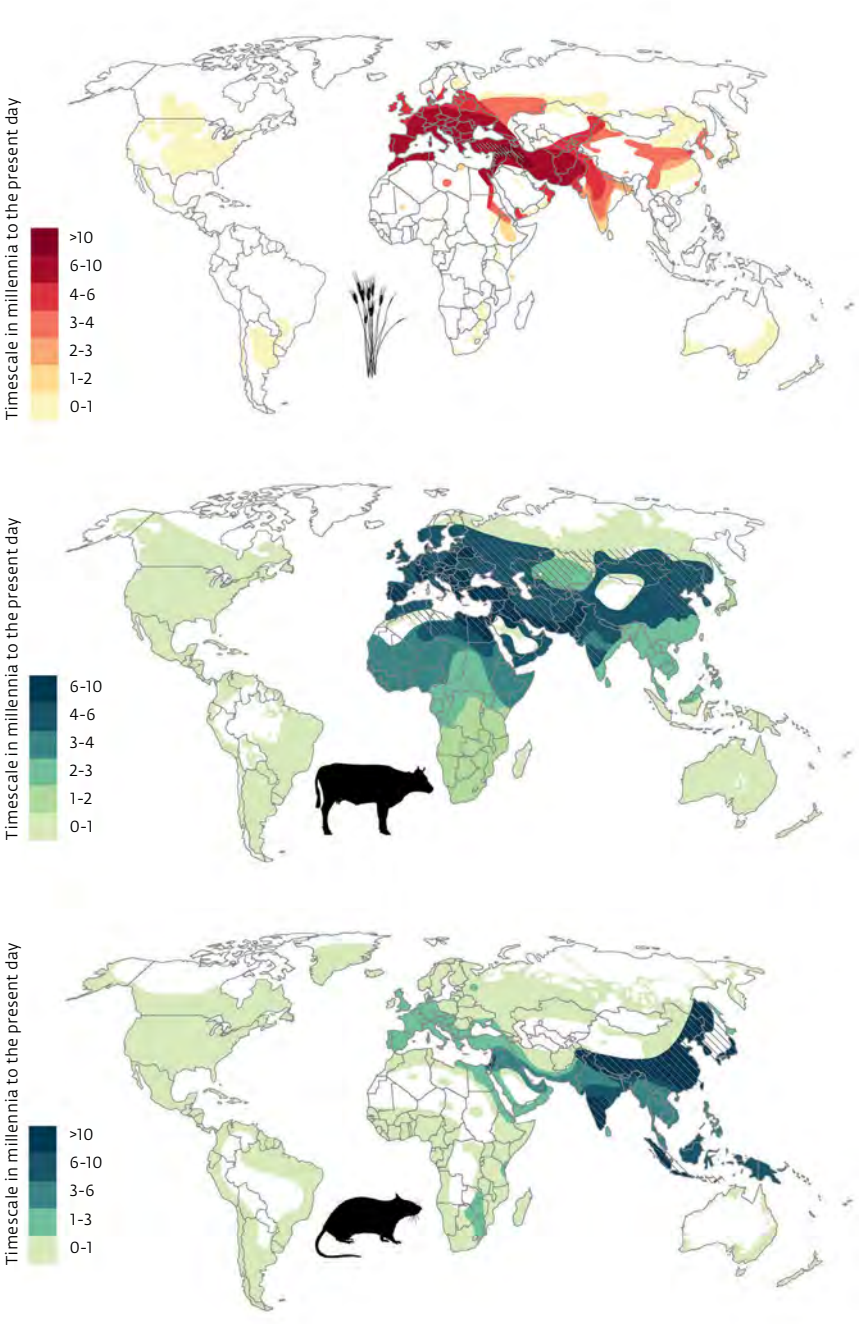
Homo sapiens arose some 195,000 years ago in East Africa and had settled in even the furthest reaches of Eurasia, Australia and America by around 12,000 years ago. This spread and the associated population growth changed the world: after the arrival of humans, some animal species disappeared, others were introduced to new areas and the settlers established new ecological niches for themselves that fulfilled their needs. For instance, humans started to burn gaps in the rain forest in New Guinea and Borneo to make way for the cultivation of starch-rich plants. In Australia and America, hunters set fire to the vegetation to attract wild animals to the young plants that replaced it. Or they introduced potential game to areas where there had been little or nothing worth hunting before. The grey cuscus, for instance, a small marsupial from New Guinea, reached Indonesia, the Salomon Islands and the Bismarck Archipelago with the first settlers around 23,000 years ago.

The extinction of giant animal species known as megafauna is an interesting topic in this context. In the Upper Paleolithic period, that is, from 50,000 to 10,000 years ago, more than 100 out of 150 species of large animals weighing over 44 kilograms, such as the cave bear, the mammoth and the giant ground sloth, disappeared from the Earth. "Whether humans had something to do with this or whether climate, diseases or even meteorite impacts played a more important role is something that has been debated for decades," says Nicole Boivin. In February 2017, a two-day workshop was held at the Max Planck Institute for the Science of Human History in Jena with the aim of launching a major research project on this topic. It is Boivin's intention to assemble an interdisciplinary group that can use new research methods to study complex questions that arise in several key areas. For example, it would be important to date individual events more accurately, to analyze old DNA and proteins, to create computer models, and to conduct paleoecological studies. A method known as ZooMS (Zooarchaeology by Mass Spectrometry) has lately proved particularly helpful in archaeological research, as it enables the identification of the species from which even gnawed, cooked and splintered bone remains originate based on collagen proteins.

"The megafauna are so important because their disappearance had dramatic consequences," explains Nicole Boivin. Giant herbivores such as mammoths are considered to be key species that can have a crucial impact on an ecosystem. They distribute nutrients and seeds over extensive areas and ensure that vegetation is kept in check. "When a species of this kind becomes extinct, the open landscape can become a forest. In extreme cases, if many large animal species disappear and forest regrows in extensive areas, this can even influence the global climate because carbon dioxide is removed from the atmosphere," says the Max Planck scientist.

It's difficult to pinpoint the extent of human influence on the environment at such an early stage, she notes.

Photo: dpa/Hendrik Schmidt



Plant and animal companions: Large numbers of individual species spread throughout the world in tandem with *Homo sapiens* – sometimes deliberately, sometimes accidentally. They include crops such as wheat (top) and domesticated animals such as cows (center), but also synanthropic species such as rats, which benefit from habitats created by humans (bottom).

Graphic: Alison Crowther/PNAS June 7, 2016, vol. 113, no. 23

Moreover, influencing factors probably differed depending on the continent and latitude involved. The Jena-based archaeologist finds it intriguing, however, that the later *Homo sapiens* reached an area, the larger the number of animals that became extinct in the Late Pleistocene. "In Africa and India, the animals had, in some cases, millions of years to develop in parallel with the evolving skills of the humans," she notes. When the first settlers reached Australia and South America, they already had advanced hunting techniques and better weapons at their disposal.

ANIMAL KINGDOM "NAIVE" IN NEWLY POPULATED AREAS

In regions more distant from Africa, the animal kingdom was probably still "naive" – with no fear of humans and unable to quickly adapt to the dangerous new enemy. The disappearance of the megafauna, which started around 50,000 years ago and is possibly the first human influence that can be detected in the ecological record, is one potential starting point for the Anthropocene.

According to the latest findings, humans also began to penetrate the rain forest around the same time, particularly in Southeast Asia. "Archaeologists had long assumed that the tropical rain forest represented an insurmountable barrier for early humans because it was too dark, too impenetrable and too dangerous, and moreover, it was not a good source of food," says Patrick Roberts, head of the Stable Isotopes Research Group at the Max Planck Institute for the Science of Human History. However, it has now been demonstrated that the first hunters and gatherers were present in these ecosystems a good 45,000 years ago, for example in Borneo, Sri Lanka and New Guinea. The Stone Age groups hunted a very wide range of animals and complemented their diet by collecting freshwater snails, nuts, fruits and roots. Roberts recently demonstrated that humans relied on the rain forest as a source of food in Sri Lanka many thousands of

Above Prehistoric plant remains are retrieved at an excavation site on the island of Unguja, which belongs to the Zanzibar archipelago off the coast of East Africa.

Below On the neighboring island of Pemba, Nicole Boivin's team found remains of an extinct or eradicated crocodile species.

years ago by testing the tooth enamel of human fossils. To do this, he determined the ratio of different carbon isotopes in human teeth originating from different sites in Sri Lanka, and was thus able to confirm the importance of the forest as a source of food.

Even these early inhabitants fundamentally altered the tropical forests, for example by setting fires and promoting the growth of certain plants. It would appear that tree species such as the Brazil nut, cocoa tree and cabbage palm dominate large swaths of the Amazon forest today because pre-Columbian groups deliberately cultivated them many thousands of years ago and spread their seeds. This was the finding of a study published in the journal Science in March 2017, in which Florian Wittmann from the Max Planck Institute for Chemistry in Mainz participated. The long-held view that rain forests such as the Amazon were pristine, ancient ecosystems is thus no longer valid. "In the Amazon, it's clear that humans interfered in the rainforest ecosystems prior to European colonization. There were even already cities there," says Patrick Roberts.

THE IMPACT ON ISLANDS IS PARTICULARLY EVIDENT

It's easier for archaeologists to detect the consequences of human settlement on islands than in impenetrable jungle areas. The first settlers didn't reach the remote archipelagos of the Indian and Pacific Oceans until a few thousand years ago – and their arrival often had devastating consequences. "We can see the impacts of this today wherever we take a more detailed look," says Nicole Boivin. "In New Zealand, for example, it took only a few decades after the arrival of humans for the forest cover to shrink considerably," says the Max Planck researcher. "Apparently-pristine tropical islands in the Pacific were altered dramatically well before Europeans arrived."

Photo: Mark Horton (top), Rainer Hutterer (bottom)

The Jena-based archaeologists are currently focusing on islands off the east coast of Africa: in the Zanzibar archipelago and the Comoros. Earlier excavations carried out by the team at the site of Kuumbi Cave in Zanzibar revealed that such animals as zebra, buffalo, waterbuck and gazelles disappeared when Zanzibar became an island. The promontory was connected to the mainland during the Ice Age and was separated from it only around 10,000 years ago when the sea level rose. It's still unclear whether these animals became extinct due to the reduction in habitat availability during island formation, or as a result of hunting or ecological alteration by humans.

"There are indications that the animals were hunted. We found projectile points, for example, and traces of cuts on some bones," reports Nicole Boivin. She and her colleagues are now in the process of providing a more accurate account of the ecological history of the islands in this region – an undertaking that arose out of the EU-funded "Sealinks" project, which was headed by Boivin and which examined the earliest trade relations between the cultures on the different coasts of the Indian Ocean.

The island of Pemba, the second-largest island of the Zanzibar archipelago, is also of interest to the Jena-based researchers in this context. It has been separated from the African mainland for millions of years. The first indications of human settlement there originate from the seventh century CE. In the past year, Boivin and her colleagues started excavating in a cave there and have accessed an environmental archive extending 5,000 years back into the past. Using molecular biological methods, her team helped demonstrate that crocodiles and giant rats existed on the island, but are extinct today. The team is currently examining the extent to which human beings altered other aspects of the island ecosystems.

The archaeologists are unanimous in their opinion that there is one conclusion that shouldn't be drawn from their research: that environmental, climate and species protection are unnecessary because humans have influenced the Earth since prehistoric times. "Even if completely pristine landscapes can no longer be found anywhere on Earth, protecting the environment is important," stresses Michael Petraglia. "We must learn to find a balance between the needs of humans and those of nature without causing too much damage to nature." ◂

Versatile researcher: Nicole Boivin is as well versed in biology as she is in archaeology. In her research, she traces the development and impacts of human life and activity from prehistoric times to the present day.

Photo: Sven Döring

TO THE POINT

- **Early humans left indelible traces on our planet even before the arrival of *Homo sapiens*.**
- **With the spread of modern humans, mammoths, cave bears and a large number of other species of megafauna went extinct.**
- **Through arable and livestock farming, humans created entirely new ecosystems and spread livestock and crops throughout the world.**
- ***Homo sapiens* left its traces for thousands of years, even in apparently untouched landscapes such as the Amazon rainforest.**

GLOSSARY

Anthropocene: Suggested designation for a new geological epoch that is characterized by human influence on the biological, geological and atmospheric processes on our planet.

Megafauna: Animal species weighing more than 44 kilograms.

Paleoecological studies: Scientific studies of ecosystems from the Earth's geological past.

Nuclear Magnetic Resonance Scanner for Individual Proteins

The nuclear magnetic resonance scanners we know from hospitals are set to become extremely sensitive. A quantum sensor developed by a team headed by Professor Jörg Wrachtrup at the University of Stuttgart and researchers at the Max Planck Institute for Solid State Research in Stuttgart makes it possible to use nuclear magnetic resonance scanning to investigate the structure of individual proteins atom by atom. The sensor, which the researchers presented back in 2013, consists of a nitrogen atom in a tiny diamond and detects magnetic signals from the atoms in a sample. The researchers have now improved its resolution to such an extent that it can distinguish the signals from different types of atoms. This method could one day help diagnose diseases in the early stages by detecting the first defective proteins. Defective protein molecules are what cause, for instance, Creutzfeldt-Jakob disease. (www.mpg.de/11383152)

Homo sapiens Older than Previously Thought

Modern man lived in Morocco as far back as 300,000 years ago

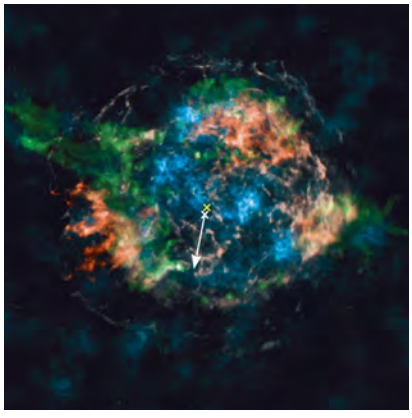
This find means we have to rewrite the early history of man: in Jebel Irhoud, some 100 kilometers northwest of Marrakesh, an international research team led by Jean-Jacques Hublin from the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, and Abdelouahed Ben-Ncer from the National Institute of Archaeology and Heritage in Rabat, Morocco, uncovered remains of *Homo sapiens* along with stone tools and animal bones. The finds are around 300,000 years old, making them the oldest securely dated fossil evidence of our own species.

The oldest *Homo sapiens* fossils previously known are from Ethiopia and are around 100,000 years younger. Most researchers therefore assumed that all humans living today descended from a population that lived in East Africa around 200,000 years ago. However, the fossils from Morocco show that *Homo sapiens* had already spread across the entire African continent around 300,000 years ago – long before the out-of-Africa dispersal of *Homo sapiens*.

The Jebel Irhoud site has been well known since the 1960s for its human fossils and stone tools. However, it was difficult to interpret these artifacts due to the uncertainty surrounding their geological age. New excavations since 2004 have uncovered further *Homo sapiens* fossils. There are a total of 22 fossilized remains of skulls, mandibles, teeth and long bones of at least five individu-

Neutrinos Drive Supernovae

The distribution of radioactive elements in the Cassiopeia A remnant provides insight into the explosion



Pronounced asymmetry: Titanium (blue) and iron (white, red) in supernova remnant Cassiopeia A. The yellow cross marks the geometric center of the explosion; a white cross and an arrow indicate the current position of the neutron star and its direction of movement. Computer simulations yield a similar scenario.

Supernovae are an important source of chemical elements in space. When these stars explode, radioactive atomic nuclei are created in the hot interior and can provide information about the invisible processes that cause the explosion. Using elaborate computer simulations, a team of scientists from the Max Planck Institute for Astrophysics and Japan's RIKEN research center were able to explain the recently measured spatial distribution of radioactive titanium and nickel in Cassiopeia A, a roughly 340-year-old supernova remnant. The theoretical scenario is that these elements are created in the hot ejecta near the core. Because of the wild boiling within the star, the neutrino-driven explosion begins aspherically, and the supernova expels the ejected stellar matter with a pronounced asymmetry. In the case of Cassiopeia A, the remaining compact neutron star should therefore be speeding toward the southern hemisphere, while the largest and brightest titanium structures containing most of the matter should be found in the northern half of the remnant. And that is precisely what observations of Cassiopeia A show, thus confirming the simulations. (www.mpg.de/11368641)

Photo: Macmillan Publishers Ltd: Nature; from Grefenstette et al., Nature 506, 339 (2014); iron distribution courtesy of U. Hwang

The first of our kind: Two views of a composite reconstruction of the earliest known *Homo sapiens* fossils. The shape of the facial skull falls within the variation of humans living today. The archaic-looking brain case (blue), in contrast, indicates that the brain shape, and possibly brain function, evolved within the H*omo sapiens* lineage.

als, documenting an early stage of human evolution. The team working with geochronology expert Daniel Richter from the Max Planck Institute in Leipzig used thermoluminescence dating methods on heated flints found in the deposits to determine the age of the various layers at the site. This method takes advantage of natural radioactivity and measures how much time has passed since the heating took place.

Anatomically, the early *Homo sapiens* were already very similar to modern humans: as the researchers discovered from computer tomography (micro-CT) scans of several original fossils, they had modern-looking facial skulls and teeth. Their brain cases, in contrast, were rather elongated and not round like those in humans living today. This suggests that the shape of the facial bones was already established when *Homo sapiens* emerged, while the brain shape and possibly also its function only developed later as our species evolved.

As a result of the most recent findings, earlier controversial finds are being reevaluated: scientists now likewise consider an approximately 260,000-year-old skull fragment from Florisbad, South Africa, to belong to *Homo sapiens*. (www.mpg.de/11322481)

Pointing a Finger at Electronics

Digital devices can be controlled with gestures above the back of the hand

Smartwatches have similar capabilities as smartphones, but they're not exactly easier to use. Anyone who has difficulties, say, selecting a point on a map on their cell phone screen probably won't have an easier time of it on a watch display. An international team working with researchers at the Max Planck Institute for Informatics is now remedying this. The team has presented WatchSense – an input method that converts finger movements on and above the back of the hand into control signals for a smartwatch, tablet or even a PC. To this end, a depth sensor attached to the forearm tracks the tips of the wearer's thumb and index finger moving across the back of the hand and transmits these finger positions to the electronic device. Users can monitor input directly on the device's display. As the researchers discovered, this method enables users to, for instance, select a new sound track or adjust the volume in a music player faster than is possible with conventional input methods.

A new type of remote control: WatchSense enables users to control electronic devices, such as smartwatches, with finger movements on and above the back of the hand by tracking the tips of the thumb and index finger.

The Amazing Flexibility of the Human Mind

A study among illiterate women provides clues about what causes dyslexia

Writing was such a recent invention in evolutionary terms that there hasn't been time for a dedicated "reading area" to develop in the brain. Instead, brain regions that originally evolved to recognize complex objects, such as faces, are "recycled" to learn to read. In a study conducted with illiterate adult women, researchers at the Max Planck Institutes for Human Cognitive and Brain Sciences and for Psycholinguistics have now shown that this process changes the brain more fundamentally than was previously assumed. As these women learned how to read and write, the scientists registered changes that extend into the thalamus and the brain stem, which are evolutionarily old brain regions. Previously, congenital dysfunctions of the thalamus were discussed as a possible cause of dyslexia. However, this seems doubtful, since it has now been shown that this brain region can be fundamentally modified through just a few months of reading training. (www.mpg.de/11312849)

Profound change: Illiterate women in India learned how to read Hindi, their native language. As they did so, brain regions that were previously assigned to different skills were modified.

With the Grip of a Gecko

A gripper that resembles a suction cup and is equipped with microscopic nubs grips a variety of objects

Robots will soon likely be able to hold on better when they want to grasp an object: a gripper developed by researchers at the Max Planck Institute for Intelligent Systems in Stuttgart flexibly adapts to objects of different shapes and also holds them securely because its surface is covered with tiny nubs. These kinds of contact surfaces, which are inspired by the fine, extremely adhesive hairs on the soles of gecko feet, did in fact already exist, but thus far only in the form of rigid materials. They don't adhere to arbitrarily shaped objects. The coin-sized gripper developed by the materials scientists in Stuttgart resembles a suction cup. It uses negative pressure to hug the contours of a variety of shapes and can hold, for instance, a 300-gram glass flask filled with liquid. (www.mpg.de/11315088)

Teacups and tomatoes – the gripper developed by the Stuttgart-based researchers grasps a variety of objects and also holds them securely.

Photos: Max Planck Institute for Psycholinguistics (top), PNAS (bottom)

Gut Bacteria Affect Aging

Microorganisms of young fish increase the lifespan of older conspecifics

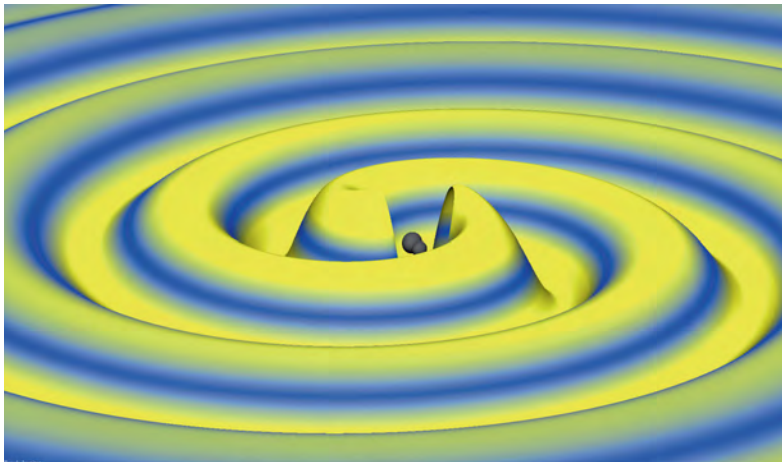
It loses its pigmentation, its motor skills and mental faculties decline, it gets cancer – the turquoise killifish struggles with similar signs of old age as many other living creatures. But this African fish is just a few months old when physical decline sets in. As with humans, the composition of the microbial community in the killifish gut changes with age: in young fish, many different species of bacteria ensure a healthy gut, but this diversity decreases as the fish age, while the proportion of pathogens increases. Scientists from the Max Planck Institute for Biology of Ageing in Cologne have now transferred the microorganisms of young killifish to middle-aged animals. With the young intestinal microbiota, the fish not only live around 40 percent longer, but at the ripe old age of four months, they are also still as agile as young fish. If young fish receive the gut microbes of older animals, their lifespan, in contrast, doesn't decrease. It's still not clear just how the microbes affect longevity. It's possible that the intestinal flora from a young organism supports the immune system and thus prevents the proliferation of pathogens over the course of the fish's life. (www.mpg.de/11236218)

After just a few months, the vibrant colors of the turquoise killifish begin to fade. The fish's rapid physical decline with age has piqued the interest of researchers on aging worldwide.

Gravitational Waves Detected for the Third Time

LIGO detectors observe a signal that is once again discovered at the Albert Einstein Institute in Hannover

For the third time, researchers have detected the gravitational waves that Albert Einstein predicted 100 years ago. The two LIGO detectors in the US signaled a hit on January 4, 2017 at 11:11:58.6 CET. The gravitational wave designated GW170104 reached the detector in Hanford three milliseconds before reaching the one in Livingston – an effect that owes to the source's position in the sky. Two black holes, with 31 and 19 solar masses, had merged into one black hole with 49 solar masses. The signal was first observed at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Hannover. There, Alexander Nitz investigated a few candidates that an analysis system he developed had identified in almost real time. In doing so, the researcher first came across a promising signal in the Livingston detector data, then subsequently also in the Hanford data. The newly observed black hole, with its 49 solar masses, fills the gap between the two merged black holes previously detected by LIGO and points to a new class of these objects. (www.mpg.de/11325825)



The source of the wave: This image comes from a numerical simulation of the gravitational wave event GW170104, which was generated by the merger of two black holes. The strength of the gravitational wave is indicated by both the height and the color: blue denotes weak fields, yellow, strong. The black holes were enlarged by a factor of two in order to improve their visibility.

Photo: Frank Vinken (top); numerical-relativistic simulation: S. Ossokine, A. Buonanno (Max Planck Institute for Gravitational Physics), Simulating eXtreme Spacetimes Project; scientific visualization: T. Dietrich (Max Planck Institute for Gravitational Physics), R. Haas (NCSA) (bottom)

DNA from Prehistoric Humans Discovered in Cave Soil

A new method enables researchers to detect millennia-old DNA in cave sediments

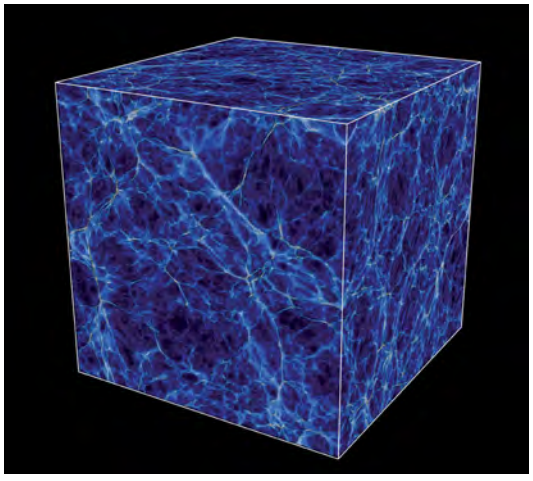
Tools and other artifacts produced by ancient humans have been unearthed at many prehistoric archaeological sites. It often remains unclear just who the creators were, as archaeologists rarely find human fossils such as bones or teeth in the sediment layers connected with these finds. But researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig "fished out" tiny DNA fragments from sediment samples ranging from 14,000 to more than 550,000 years old. The scientists were able to identify the DNA fragments as belonging to Neanderthals, Denisovans and modern humans, as well as various extinct mammals. Using these DNA traces in the soil, researchers will soon be able to detect the presence of ancient humans and other mammalian species even at archaeological sites where no more-conspicuous remains were found. (www.mpg.de/11247830)

Researchers found traces of DNA in the sediment layers of the El Sidrón cave in Spain.

Shedding Light on the Cosmic Web

Astronomers use the light from twin quasars to survey the structure of the universe

The matter in intergalactic space forms a vast network of interconnected filaments. Nearly all atoms in the universe – most of them direct remnants of the Big Bang – are part of this cosmic web. Now, a team led by researchers at the Max Planck Institute for Astronomy has surveyed the fine structure of this web some two billion years after the Big Bang – using a new method that takes advantage of pairs of distant, hyperluminous quasars located very close to one another to illuminate space. Quasars are the active cores of young galaxies. In their study of charted regions more than 11 billion light-years away from us, the scientists identified structural differences on scales of just a few hundred thousand light-years – comparable to the size of individual galaxies. The light from two sources (quasars) enabled them to describe these differences quantitatively. The astronomers then compared their findings with supercomputer models that simulate the development of cosmic structures from the Big Bang to the present. To the researchers' delight, these simulations yield a universe that matches the observation data quite well. (www.mpg.de/11259384)



Snapshot: An image from a supercomputer simulation of the cosmic web 11.5 billion years ago. The researchers created this and other models and subsequently compared them with the quasar observations to draw conclusions about the properties of the young universe. Each side of the cubic section shown here measures 24 million light-years.

Photo: MPI for Evolutionary Anthropology/J. Krause; simulation: J. Oñorbe/MPI for Astronomy

Being Overweight Increases Risk of Alzheimer's

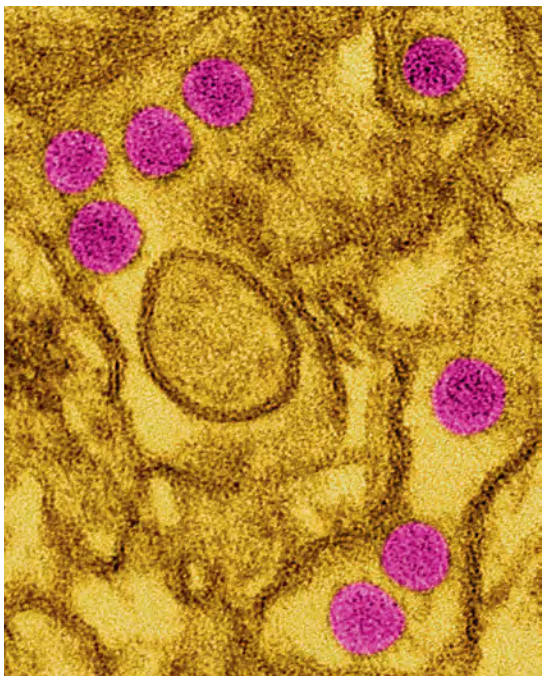
Obesity is associated with fewer connections between regions of the brain

Being severely overweight or obese not only increases the risk of diabetes, heart failure and arteriosclerosis, it evidently also compromises the brain. According to scientists at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, some areas of the brain are less strongly connected in severely overweight people aged 60 to 80. As a result, individual regions are less capable of interacting in the default mode network. This network becomes active when we let our mind wander, but also, for example, when we are planning future action or recalling the past. Weaker links within this network, on the other hand, are an early indicator of impending dementia. Older, severely overweight individuals could also be at greater risk for Alzheimer's. The researchers now plan to investigate how changes in diet affect the brain network and mental faculties in general.

Zika Viruses Produced in the Lab

Scientists fulfill a crucial prerequisite for vaccine production

In the last ten years, the Zika virus, which is transmitted by the yellow fever mosquito, spread from Africa and is now found in around 60 countries. The virus gained notoriety shortly before the 2016 Olympic Games in Brazil, when it became known that an infection during pregnancy can harm newborns. People who live outside of Africa have no natural immunity, so scientists are working to develop a vaccine against the pathogen. Researchers at the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg, in collaboration with a research team in Brazil, have now propagated large quantities of Zika viruses in the lab. To that end, they adapted hamster cells to be able to grow in a liquid nutrient medium and infected them with viruses from Brazil. After almost two weeks, the scientists harvested nearly 40 million infectious viruses per milliliter from high-density cell cultures. Thanks to these findings, researchers can now conduct further studies on the Zika virus. (www.mpg.de/11293337)



Colored electron microscopy image of Zika viruses (pink) in kidney cells: The viruses are transmitted to humans by mosquitoes, but they can also be transmitted sexually. If pregnant women contract Zika fever, their babies may exhibit brain growth disorders (microcephaly) after birth.

Photo: SPL/D. Kunkel Microscopy

Diagnosing Cancer with a Breath Test

Inhale deeply … and exhale. This is what a test for lung cancer could one day look like. Today, most lung cancer patients die within five years of being diagnosed. One of the main reasons for this is that the disease isn't noticed until it is too late. Scientists at the Max Planck Institute for Heart and Lung Research in Bad Nauheim therefore developed a method that can detect the disease at an early stage. To do this, they analyzed breath samples for traces of RNA variants of the GATA6 and NKX2 genes, which are produced in different amounts in cancerous and healthy cells. Using a newly developed method, they can isolate the RNA molecules that are present in the breath in trace amounts, and usually fragmented. In one study involving healthy subjects and cancer patients, the breath test correctly determined the health status of 98 percent of the participants. With such a high success rate, this method could be used for routine early detection in clinics, as a complement to conventional methods. Together with the technology transfer organization Max Planck Innovation, the researchers are now seeking licensing partners to develop the breath test to maturity and market it. (www.mpg.de/11237619)

Glass Fibre **Rainbows**

In their conventional form, hair-thin glass fibres ensure fast internet speeds – but conducting light with very low loss isn't the only thing they can do. **Philip Russell**, Director at the **Max Planck Institute for the Science of Light** in Erlangen, and his colleagues are using a novel type of optical fibre, known as photonic crystal fibre (PCF), to manipulate the properties of laser light and control its interactions with matter. Their work is leading to many applications, for example in advanced ultraviolet light sources and optical fibre sensors for medicine, industrial manufacturing, structural engineering and environmental monitoring.

TEXT **ROLAND WENGENMAYR**

"Can you see the fibre?" asks Johannes Köhler. And there it is: a gossamer thread bridging a gap about the width of my hand. The fibre is only 100 micrometres in diameter – roughly the thickness of a human hair. Despite being so small, it has some very special characteristics; they didn't yet exist 26 years ago, so the manner in which they might guide and modify laser light was unknown. For example, intense nonlinear optical effects within the fibre open up new vistas in basic research as well as promising new real-world applications. Conventional glass fibres have already fulfilled their promise – today's global fibre network forms the very backbone of our information society. Compared with the filigree fibres being developed in Erlangen, conventional glass fibres are as primitive as an early electronic calculator next to a modern tablet computer, in the sense that PCF offers a multitude of different "apps".

The research being pursued by Philip Russell's department at the Max Planck Institute for the Science of Light focuses on this new breed of glass fibre, which is produced by unique micro- and nano-fabrication techniques. Doctoral student Johannes Köhler and I are standing in his lab next to an optical table on which a race track for light has been set up, complete with a powerful laser, lenses, mirrors and other optical elements. The invisible infrared light of the laser is passing through the 12-centimetre-long glass fibre at which Köhler is pointing. The fibre is hollow, its interior spanned by two closely spaced parallel glass membranes that run along the entire length of the fibre. These membranes are so gossamer-thin that the laser light, whose photons exert a weak physical force, can set them vibrating. The optoacoustic oscillations, in turn, alter the properties of the light. Just what is going on is the focus of Köhler's work. Experiments with other fibres containing different nanostructures are being conducted in nearby labs. Each alters laser light in a different way. Theodor Hänsch, Director at the Max Planck Institute of Quantum Optics in Garching, and John Hall at NIST in the US, who shared the 2005 Nobel Prize in Physics with Roy Glauber, made use of one such glass fibre type in their prize-winning work.

Philip Russell, a British physicist born in Belfast, is the pioneer of PCF and mastermind of the Erlangen-based fibre world. He directs the 40-strong

Photo: Xin Jiang

White light source: Specially prepared crystal fibres produce a broad spectrum of light from monochromatic laser pulses. This "supercontinuum" can be spread out in space using a prism at the end of the fibre. At the right-hand edge, the ultraviolet light appears as a white glow.

Photonic Crystal Fibre Science Division. "We're concerned with the interaction between light and matter," he says, describing the thrust of his research. He patiently explains the fundamental difference to conventional glass fibres, without which the high-speed internet would be inconceivable. With wry British humour, he remarks that the glass fibre has also made the spread of fake news much more efficient. He is clearly glad that, so far, his own research isn't used in communications technology.

"Glass fibres for telecommunications work like elongated, almost perfect mirrors," he explains. Such fibres have a core and a cladding consisting of two grades of glass with different refractive indices. The interface between the core and cladding therefore acts as a mirror, which reflects laser beams back and forth inside the fibre. This is akin to throwing a Super Ball at an angle into a pipe, so that it bounces further and further into the conduit.

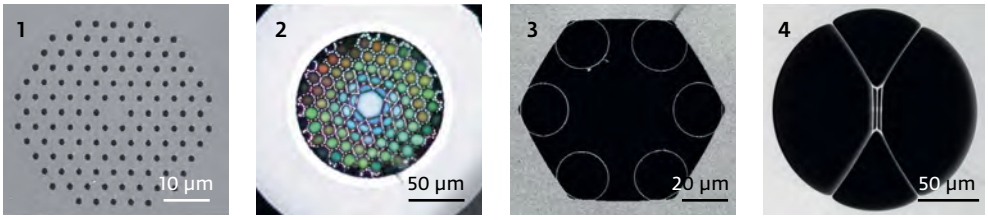
MARRYING GLASS FIBRES AND PHOTONIC CRYSTALS

Conventional glass fibres can be understood by viewing light as rays that propagate in straight lines, bouncing off the core surface. To understand Russell's fibres, in contrast, it is necessary to also take account of the fact that light also acts like a wave.

What this means is conveyed by taking a glance at one of Russell's shelves. A glass case contains a brilliant blue morpho butterfly, which the physicist bought many years ago in an entomology museum in France. The butterfly's iridescent colours aren't created by pigments but by tiny nanostructures that modify the light during reflection. The structures must have just the right spacing so that they match the wavelength of visible light: a few hundred nanometres (millionths of a millimetre).

The architectural dimensions of artificial photonic crystals are of the same order of magnitude. In one-dimensional form, such materials have important applications as antireflection coatings for mirrors, windows, spectacles and camera lenses.

In the early 1990s, Philip Russell asked himself what would happen if he combined a glass fibre with a two-dimensional photonic crystal. This should create a glass fibre with regularly spaced hollow channels running along its length, so that a cross-section of the fibre would reveal a regular pattern of holes – a photonic crystal. If their spac-



Above Researchers led by Philip Russell first produced PCFs with a solid glass core (1), which when appropriately designed could transmit light in a fundamental mode over long distances. Shortly afterwards they developed hollow-core PCFs, including a structure with a kagomé lattice (2), named after a woven bamboo pattern in Japanese Shinto shrines, which when filled with gas and driven by short laser pulses can produce ultraviolet light. Some simpler "single-ring" hollow-core fibres (3) can be used to produce a similar effect. Fibres with narrow glass membranes running over their entire length (4) are used in optoacoustic experiments. Light induces vibrations in the membranes.

Right page In a cleanroom, Michael Frosz, Xin Jiang and Philip Russell (left to right) watch the preform of a glass fibre being melted in a furnace and drawn to its final thickness.

ing is chosen appropriately – this is related to the wavelength of the laser light used – the jumps in refractive index between the air and the glass would cause strong reflection of the light in the core, preventing it from escaping through the walls of the fibre.

That was Russell's idea. But actually realizing the first photonic crystal fibre was no easy matter. "You've got this dream," Russell says, "but your courage falters in the face of difficulties." He had to find a way to provide the already ultrafine fibres with even smaller hollow channels. Moreover, all the channels must have a defined diameter, and they must maintain the same spacing over the entire length of the fibre. "Most of my colleagues thought I was crazy," he remarks.

Poor prospects for the young scientist who, at the time, was carrying out research at the University of Southampton. After many failures, his small team finally had a breakthrough with a technique similar to the method used for making candy floss. It exploits the fact that, at a temperature of around 1,850 degrees Celsius, quartz glass behaves very much like molten sugar. This makes it possible to draw it into ultra-thin filaments without breaking. Equally importantly, if the glass contains an internal pattern of holes, this too shrinks as the filament is drawn, without losing its structural integrity.

FIBRES WITH COMPLETELY NEW OPTICAL PROPERTIES

After trying in vain to drill millimetre-sized holes in a thick glass rod, ready for drawing it down in size in a fibre drawing tower, Russell's team finally came up with the idea that would prove successful. They assembled a stack of quartz glass tubes in a desired pattern and heated the stack in a furnace. They then drew the cluster of tubes down to a thin fibre. The result was the first functioning photonic crystal fibre.

Russell introduced the first photonic crystal fibre in 1996 and his team has subsequently perfected this "stack-and-draw" method. The new optical properties of the fibres soon attracted the attention of the laser world. Many research groups jumped on the idea, most notably a group at Bell Labs in Holmdel, New Jersey, who reported in 1999 that these new fibres could generate an octave-spanning frequency comb ("supercontinuum generation"), thus contributing to John Hall's and Theodor Hänsch's winning the Nobel Prize in Physics in 2005. A frequency comb makes it possible to measure the colours (frequencies) of light with unprecedented precision, and thus to construct optical clocks that are a thousand times more accurate than their conventional counterparts. This will make satellite-based global positioning systems even more accurate in the future. "We were just about 'there' in 1999," Russell sighs, "but we didn't have the necessary equipment at the University of Bath, so weren't the first to discover supercontinuum generation in PCF."

What exactly happens to light in such fibres depends on the internal microstructure. In simple terms, light waves are trapped inside the fibres rather like sound waves in a resonating musical instrument. Russell, himself an accomplished amateur pianist, takes the kettle drum as an example. When struck, the drum-skin begins to oscillate at its fundamental frequency, which carries

Photos: MPI for the Science of Light

Photo: Tilman Weishart

the deepest tone of the instrument. At the same time, it can emit many higher-frequency harmonics. Laser light in a photonic crystal fibre acts in a similar manner. In a PCF with a solid glass core, the surrounding triangular pattern of hollow channels acts as an excellent filter. It filters out all the harmonics so that the light in the core vibrates only at the fundamental frequency.

The light waves may be viewed as being "stretched" across the core, in analogy with sound waves on the skin of a drum. "For the fundamental mode of the "drum", the hollow channels act like the bars of a jail cell," Russell says, "trapping the light." In contrast, harmonics of the "drum skin" are able to escape between the bars. A pure fundamental mode can therefore be transmitted over very long distances, without any contamination from higher-order modes. "This endlessly single- mode behaviour was an unexpected discovery," says Russell, and the paper first reporting it is now the most highly cited in the field.

Hollow-core PCF introduced an exciting new feature: the ability to prevent, for the first time, the spreading out, or blooming, of laser beams as they travel through free space, diminishing the intensity of the light. As a result, laser light can be kept narrowly focused in a single-lobed fundamental mode over long distances. When the fibre is filled with gas, possible huge enhancements in nonlinear light-gas interactions become possible, as we shall see.

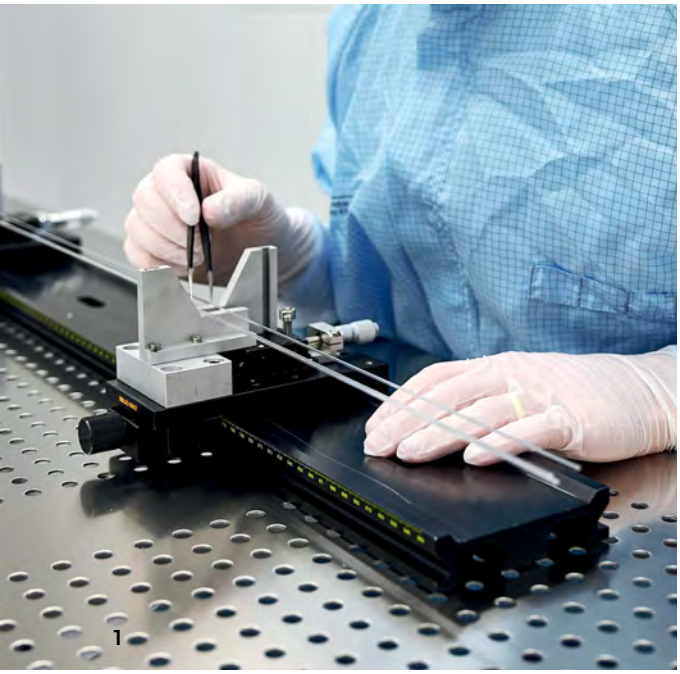
Over the past two and a half decades, Russell's team – since 2009 at the Max Planck Institute for the Science of Light – has developed a wide array of glass-fibre structures. At the Institute, Xin Jiang leads me to the sanctum sanctorum, a multi-storey cleanroom that houses the fibre-drawing towers. Because the fibre blanks are sensitive to dust, we can only peer at them through a window pane.

A METHOD THAT WORKS LIKE A PASTA MACHINE

The researchers in Erlangen fashion their glass fibres in two steps, explains Michael Frosz, head of the team responsible for producing them. First, they assemble a stack of prefabricated glass tubes into a desired pattern, heat it, fuse it together and stretch it to form a preform cane that is just a few millimetres thick. They then clamp the cane at the top of the fibre-drawing tower, which reaches a height of about eight metres. A compact, tubular graphite furnace melts the preform. Then the lower end of the preform is drawn into a hair-thin filament. A protective plastic sheath is added, and the finished fibre is rolled up onto a spool.

Beyond this standard procedure, Russell's team is developing a second method: extrusion. "In principle, it works like a pasta machine," says Xin Jiang, the manager of the "glass studio." A pasta machine presses dough through a disc pierced by holes. In a similar manner, a hot mass of glass is pressed through a perforated disc. By appropriate choice of hole pattern, almost any structure can be imparted to the fibre blank, which is subsequently drawn into a thin filament. "That gives us a lot of design scope," Russell says.

Three basic types of glass fibres can be distinguished. One type features such structures as thin glass membranes. Another has a glass-filled core through which light passes, surround-



ed by an array of narrow hollow channels: the photonic crystal. The third type has a hollow core within which the light is guided.

The Erlangen-based researchers use hollow-core fibres to manipulate microparticles with laser light inside the core. "We use photonic forces in the same way as they are used in a technique known as optical tweezers," explains team leader Shangran Xie. He and his team have developed a system that uses a light-trapped particle as a sensor for electric fields. Colleagues at the Jülich Research Centre have expressed interest in using this sensor to measure electrical fields in a high-voltage particle accelerator that people are not allowed to enter during operation.

Because the sensors, incorporated in photonic crystal fibres hundreds of metres long, can be used in locations that are too dangerous for human access, they have potential applications in nuclear power plants. These "flying particle" sensors could be used to measure radioactivity levels and can even be switched to respond to different types of radiation.

At the same time, the physicists in Erlangen have been pursuing a new idea. A liquid-filled hollow-core PCF is suitable for examining living cells, allowing light to be used, for example, to trap and propel a single cancer cell inside the core. A fluid containing a new drug could then be pumped through the fibre to test how the cell reacts. This represents an innovative approach to pharmaceutical research on individual cells.

However, the main area of research in Erlangen is nonlinear optics, specifically nonlinear wavelength conversion. This field exploits the ability of photonic crystal fibres to alter the colour of laser light. For example, a solid-core fibre produces the famous frequency comb mentioned above. Gas-filled, hollow-core fibres are currently a key area of research in Erlangen. The scientists fire powerful, ultra-short laser pulses into one end of such fibres, and light with transformed properties emerges from the other end.

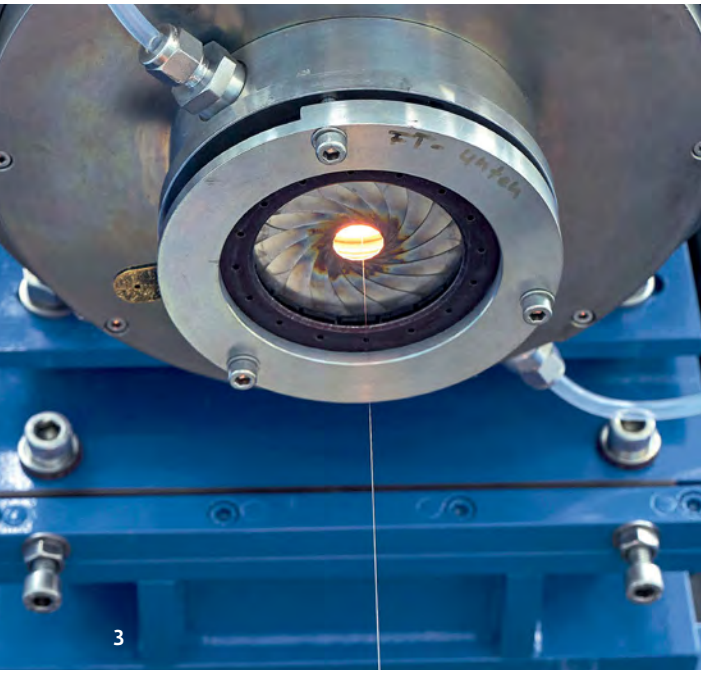
OF SPECIAL INTEREST: ULTRAVIOLET LASER LIGHT

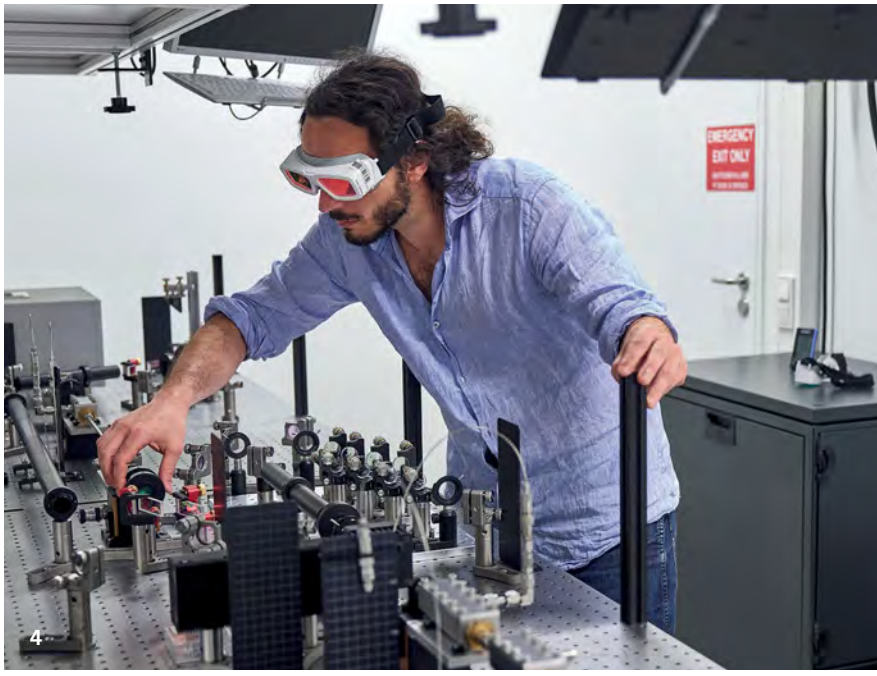
Russell compares the complex processes that take place inside the fibre with what an amplifier does to the signal from an electric guitar in rock music. As long as the amplifier is set to a moderate level, it amplifies the wave without distorting it. The gain is said to be linear. A rock guitarist, on the other hand, jacks up the amplification so high that the signal is distorted. This produces overtones that give the rock guitar its typical sound. In this case, the gain is said to be nonlinear, because it changes the waveform of the incoming signal.

That is more or less how photonic crystal fibres work. The team of Francesco Tani, a postdoc from Italy, is taking nonlinearity a step further. The fibres they are using are filled with a noble gas, such as argon or neon. The wavelengths of light from powerful infrared laser pulses fan out like a rainbow, with frequencies that can be tuned by varying the gas pressure in the fibre, enabling the colour of the light to be controlled. Ultraviolet laser light generated in this way has numerous applications in research and technology.

In fact, strong ultraviolet light can be produced so reliably with photonic crystal fibres that a start-up company at the institute intends to commercialize the process. The company, ultralumina, was founded in Erlangen in 2016. It has a staff of six and already has interested customers lining up. Companies in the semiconductor industry would like to use the ultraviolet light in their inspection systems. "To check the quality of structures on silicon wafers, electronic

Photos: Tilman Weishart (2)





chip manufacturers require very bright shortwave light," says technical manager Patrick Uebel. The new light source may also find applications in microscopy. "The first financial year was very good," his colleague Sebastian Bauerschmidt reports.

Photonic crystal fibres could even be used to construct compact sources of X-ray laser light. Current sources either involve free-electron lasers – huge, expensive electron accelerators – or high harmonic generation in noble gases using very short pulses with multi-milli-Joule energies. Gas-filled PCF could be the key to generating X-rays from ultrashort pulses with energies 1,000 times less, in a convenient tabletop system, for use in materials research, medicine and technology.

It would take a book to describe the broad range of activities being pursued in Erlangen – a "bible" of the photonic crystal fibre world, as it were. And the fibres also have a spiritual side, at least according to Google, which recognizes Russell's fibres as sacred. In his first presentations, the physicist used the term "holey fibre" to emphasize the perforation of the fibres. Visibly amused, Russell describes how a typo on the internet changed the term to "holy fibres". ◀

From production to experiment: A researcher in Erlangen stacks a preform of hollow capillaries and rods to form the starting structure – the preform – for a photonic crystal fibre (1). Philip Russell (2) proposed photonic crystal fibres in the early 1990s. The preforms are melted in a furnace, after which they are drawn into fibre about as thin as a human hair (3). Using gas-filled hollow-core PCF, Francesco Tani is able to produce a wide range of laser wavelengths, starting with invisible infrared laser pulses (4).

TO THE POINT

- **In photonic crystal fibre (PCF), Philip Russell has developed an optical fibre with a periodic lattice of microscopic hollow channels running along its entire length.**
- **Hollow-core PCFs can maintain laser light in a tight focus over very long distances, limited only by the loss of the fibre. Nonlinear optical effects in gases can thus be greatly enhanced by filling the fibre with gas.**
- **PCFs can be designed to generate new colours of light, including light in the ultraviolet range, from commonly available lasers. Other types of PCF can be used as versatile optical-fibre based sensors of multiple quantities, such as electric field, temperature, twist and radiation levels.**

GLOSSARY

The **fundamental mode** of light in a fibre core has a close analogy in the fundamental tone of a drum skin when the whole skin oscillates to and fro in the same direction. Higher-order modes ("harmonics") have sub-regions that move in opposite directions. Like a drum skin, most fibre cores support multiple harmonics.

Photonic crystal: A material whose optical properties are altered by a periodic structure, such as regularly arranged air-filled channels. Light can be selectively reflected at such structures according to its colour (wavelength). This phenomenon explains the iridescent colours of many butterfly wings.

Photonic crystal fibre: A glass fibre in which an array of microscopic hollow channels is arranged around a central hollow or solid core. This cladding structure can be used to control the light travelling through the fibre in diverse ways.

Photos: Tilman Weishart (2)

The **Protein Puzzle**

The human body consists of tens of thousands of proteins. What's more, these occur in several variants whose concentration in the organism can change over time. **Matthias Mann** from the **Max Planck Institute of Biochemistry** in Martinsried therefore needs clever algorithms and a lot of computing power for his research. His goal, after all, is to decode the entire human proteome – that is, the full set of proteins in the human body – for the benefit of medical science.

TEXT **TIM SCHRÖDER**

Matthias Mann's lab in Martinsried is as tidy as a hospital intensive care unit. The glass walls and doors provide a clear view, and several identical-looking workstations are set up around the room. At each station, a robotic arm hanging from the ceiling picks up small plates containing samples and places them in the instruments. Technically speaking, these systems represent the essence of what Matthias Mann has been developing over the years: machines capable of processing and analyzing proteins at breathtaking speed.

Mann is interested in these biomolecules because they are involved in almost all of an organism's biological processes. Proteins are made up of an amino acid molecule chain that folds into complex three-dimensional patterns. Some – like keratins in skin and hair cells – serve as structural substances. Other proteins, known as enzymes, speed up metabolic reactions: they convert fat into energy, for example, or make oxygen available to cells as a source of energy. If we subtract the body water content from body weight, most life forms consist of 50 percent protein. Without proteins, there would be no life on earth.

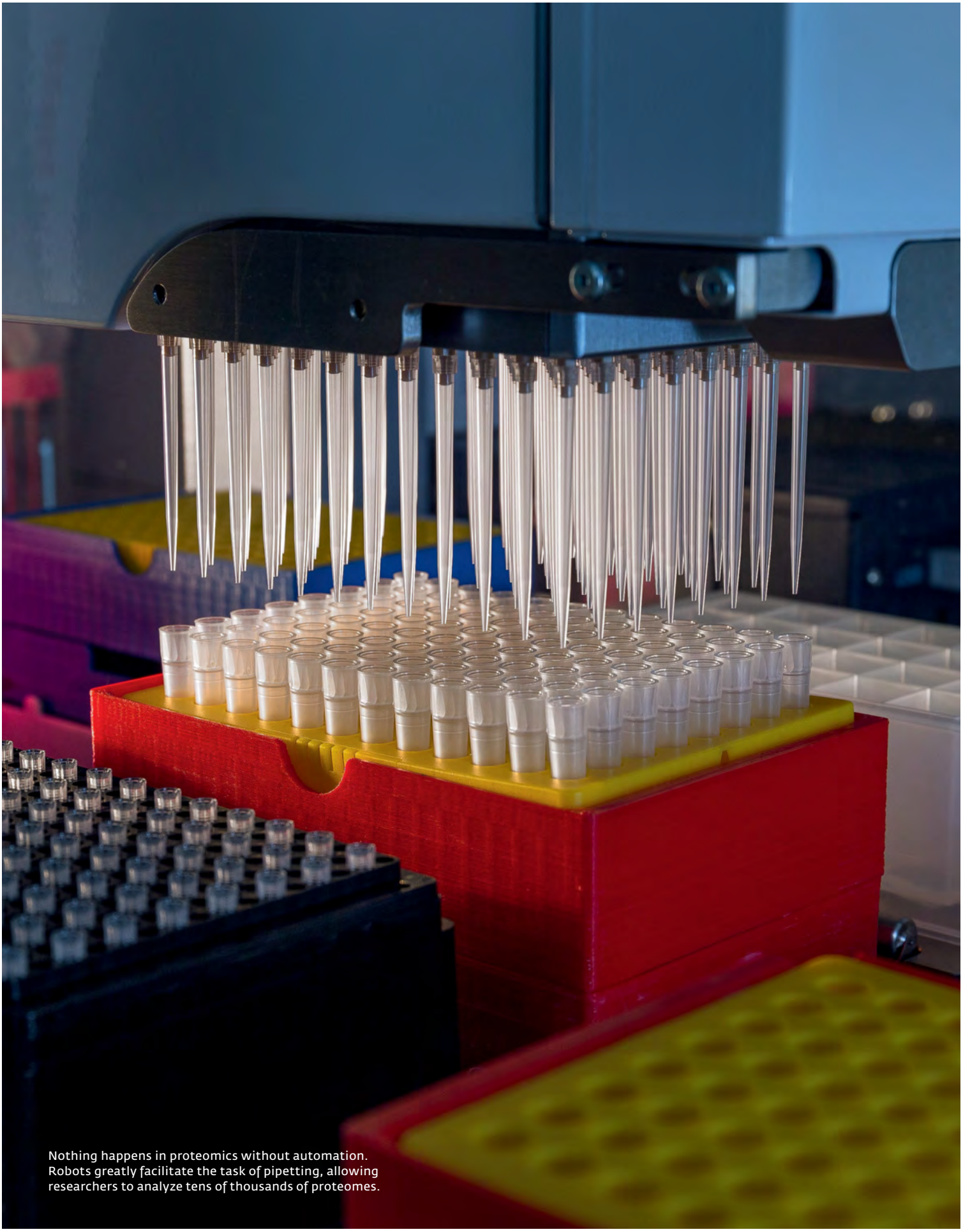
A MATURE TECHNOLOGY

Matthias Mann initially studied physics and mathematics, but he has been investigating the world of proteins since the 1980s. "It has taken two decades to develop the technology that allows us to analyze proteins in a reasonable manner," he says. "We've reached the point where we can actually apply the technology – and now things are getting really interesting!" The complex nature of protein analysis became evident when the human genome was sequenced in 2001. The scientists working on the Human Genome Project identified around 20,000 genes that encode the blueprints for around the same number of proteins.

Only gradually did it become clear that these proteins occur in many variants. Once a gene has been read, parts of the messenger RNA, which serves as a protein template, can be cut out. This gives rise to RNA molecules of various lengths, each of which is translated into a different protein. Numerous proteins, in turn, must be trimmed before they can be used as finished molecules, while chemical tags are appended to others. All in all, there are hundreds of thousands of protein variants that interact in a finely orchestrated choreography.

In addition, whereas an organism possesses the same genes throughout its lifetime, the protein composition varies according to cell type. Some proteins occur in large quantities and in every cell, while others occur only in trace amounts and only in certain tissues. >

Photo: Axel Griesch



Nothing happens in proteomics without automation. Robots greatly facilitate the task of pipetting, allowing researchers to analyze tens of thousands of proteomes.

Under the watchful eye of Heiner Koch, researchers Florian Meier and Scarlet Beck (left to right) analyze protein samples using the six mass spectrometers set up in Matthias Mann's (far right) laboratory alone.

Photo: Axel Griesch

Different proteins are active depending on the tasks the metabolic machinery is carrying out. "If we want to know how the metabolic machinery works or what its momentary state is, we must be able to analyze the protein profile in a tissue as well as how it changes," Mann says.

Scientists have always realized how important proteins are for body processes. Now, however, a growing number of researchers have become interested in studying the complete set of proteins in the body. This eventually resulted in the emergence of the research area we now call proteomics. But enormous quantities of data are required to analyze the protein composition of any life form. A huge volume of data must also be collected for evaluating and interpreting the results. Proteomics thus relies on sophisticated data processing.

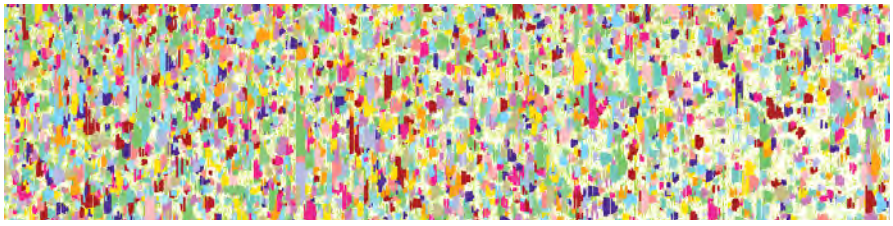
A major problem in analyzing proteins is that they are very sensitive. As anyone who has ever boiled or beaten an egg knows, the three-dimensional structures of proteins collapse when they are heated or mechanically stressed, and they clump together. It was therefore not possible to analyze proteins with the conventional method of mass spectrometry. Mass spectrometers are used to analyze samples containing unknown constituents, for instance to detect toxins in tissue samples.

DEFLECTION IN AN ELECTRIC FIELD

Before proteins can be investigated in a mass spectrometer, they must be converted into charged particles, for example by bombarding them with electrons or other charged particles, which converts them into electrically charged ions. Only electrically charged molecules are deflected from their path through the electric field of the mass spectrometer. The amount they are deflected depends on their charge magnitude and molecular weight, and this information allows scientists to infer a molecule's identity.

However, conventional mass spectrometry with ionization is too harsh a method for the sensitive proteins. In the lab of his doctoral supervisor, John B. Fenn, at Yale University, Matthias Mann, together with other colleagues, developed a gentler solution in the early 1980s. With the help of trypsin, a digestive enzyme, they snipped proteins into approximately ten-amino-acid-long fragments – so-called peptides. They then sprayed the peptides through a fine tube, imparting an electrical charge to them. Using this electrospray ionization method, they were able to analyze proteins for the first time in a mass spectrometer – a method for which Fenn was awarded the Nobel Prize in Chemistry in 2002.

The time had now come for computer scientists, as it is almost impossible for a human being to deduce the original proteins from a peptide mix. Together with his colleague Jürgen Cox, Mann developed an analytical program called MaxQuant, which can compare many thousands of peptide fragments with information contained in international databases. In addition to the



A section of the protein spectrum of a cancer cell: The proteins are first cut into peptides of varying molecular weight (shown in different colors), then separated from each other in chromatographic columns and subsequently analyzed in a mass spectrometer.

molecular weights of every conceivable peptide, the databases contain information about the protein to which each fragment belongs. MaxQuant compares the data from the mass spectrometer with the content of the databases and reconstructs the protein composition of a sample from the results.

CHROMATOGRAPHY IN MINIATURE FORMAT

Nevertheless, electrospray ionization and MaxQuant together were unable to overcome all the obstacles of protein analysis. For example, they could not detect proteins that are present in a sample only in trace amounts. This was because the researchers needed a relatively large liquid sample to separate the proteins from the other components by chromatography before the proteins are analyzed in a mass spectrometer. As a result, the trace proteins were excessively diluted and could no longer be detected.

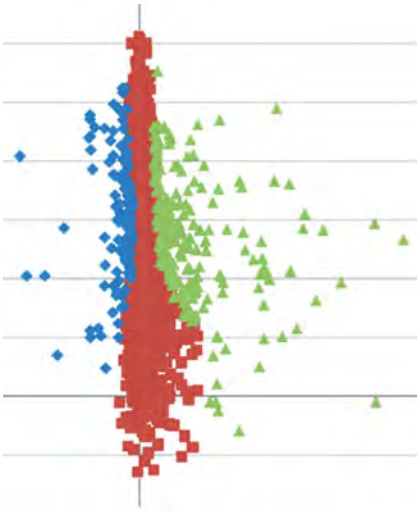
Mann miniaturized the tubes used in this type of chromatography down to a diameter of just a few nanometers. With these tubes, he needs only minute quantities of a sample: "Our nanochromatography enables us to obtain sufficiently high concentrations of proteins that are present in the sample in vanishingly small amounts."

By combining electrospray ionization, MaxQuant and nanochromatography, Mann succeeded in doing what had previously seemed impossible: decoding an organism's entire proteome. In 2008, the researcher analyzed the proteome of an entire organism, identifying the 4,399 proteins in a yeast fungus. He and his Max Planck colleague Frank Schnorrer achieved their latest breakthrough in 2016, when they decoded the fruit fly proteome. They discovered that the tiny insect has around 10,000 proteins. "By comparison, there are around 13,000 proteins in the mouse brain," Mann explains, and only 10 percent of them are limited to specific cell types.

Mann's method has since become the standard in proteomics laboratories around the world. Without the help of

The electrically neutral proteins are first cut into smaller peptide fragments. In order for the peptides to be deflected along different trajectories by the electrical field of the mass spectrometer, they must be electrically charged. This is accomplished by the electrospray ionization method, in which the peptides are given an electric charge in a metal capillary tube and then sprayed out at the tip of the tube.

Photos: MPI of Biochemistry (top), Axel Griesch (bottom)



Baker's yeast was the first organism whose complete proteome was analyzed. The unicellular organism can reproduce both sexually and asexually. The graph shows the ratios of proteins in both reproductive modes. Some proteins, such as protein attractants, are amplified during sexual reproduction (blue), while others are produced mainly during asexual reproduction (green). Still others are unaffected by the reproductive mode (red). Although all cells have identical complements of genes, they often use a completely different protein repertoire to carry out their specific functions.

computers, its use would still be unthinkable. Cox and Mann have refined the MaxQuant software so that they can now determine not just the identity, but also the quantity of proteins in a sample. Thus, multiple samples from a patient can be compared to determine how the concentration of a specific protein changes with time.

However, before proteomics can find application in hospitals, the methods have to be speeded up even more. "We're currently optimizing our system's workflow to allow us to analyze as many samples as possible. A year from now, we expect to be able to analyze 100 proteomes a day," Matthias Mann predicts. Researchers will then be able to study, for example, how a patient's protein concentration changes during the course of a day or as a disease progresses.

The scientists are already able to compare groups of people to determine differences in the metabolism of sick and healthy patients. To this end, Mann, together with doctors at Copenhagen University Hospital, studied how the proteins of obese people change during an eight-week diet.

NOT EVERYONE RESPONDS TO A DIET IN THE SAME WAY

The body reacts to obesity as if it were an inflammation, producing proteins that are typical of inflammatory reactions. The researchers wanted to know whether the quantity of inflammatory proteins decreases the same amount in all patients during a diet. Mann and his colleagues analyzed more than 1,000 proteomes and determined the quantity of inflammatory proteins using the MaxQuant software. They found that inflammatory proteins don't decrease at the same rate in everyone, even if they follow the same diet. In other words, not everyone responds the same.

Proteome analysis is complicated by the many variants that proteins can occur in. The protein ubiquitin, for example, binds to aging or defective proteins, initiating a breakdown process during which the protein is gradually dismantled. Moreover, many proteins are activated by tagging them with a phosphate molecule – a process known as phosphorylation.

Mann was able to show that an organism's day-night rhythm crucially depends on the phosphorylation state. "There are an enormous number of protein variants whose importance we still don't understand. Moreover, entire groups of proteins can take on different states. But it is precisely these changes in a patient's proteome that are decisive when it comes to treating diseases," says the scientist, who therefore thinks very little of some of today's diagnostic tests.

As an example, he mentions the PSA level, which can be an indication of prostate cancer, but which is controversial owing to its unreliability. "Such tests show the presence or amount of a single protein. Based on what we now know, though, that isn't enough. In the future, we will rely much more heavily on an individual's proteome to gain an overview of his or her health status," Mann says.

Another program developed by his colleague Jürgen Cox is expected to help: Perseus, as the program is dubbed, uses the statistical protein data from MaxQuant to conduct a big data analysis. The software accesses international databases containing the accumulated fund of knowledge about proteins – for example, where specific proteins occur and what it means when the metabolic system increases production of certain proteins. Perseus also takes existing knowledge about diseases into account.

The proteome-based diagnosis and treatment of diseases is still in its infancy. It would be extremely difficult to find early signs of malignant skin cancer in the proteome because the tumor is still very small in the early stage, meaning that very little of the telltale protein is released. Such minute amounts

Graphic: Max Planck Institute of Biochemistry/Matthias Mann

Analyzing data on the computer (clockwise from front left): Jan Rudolph, Jürgen Cox, Camila Duitama, Pavel Sinitcyn and Art Carlson – and playing a relaxing game of chess during a break.

can't be reliably detected even with the help of nanochromatography.

Nevertheless, proteomics has clearly advanced remarkably since the turn of the millennium. After the human genome was decoded in 2001, many start-up companies began offering proteome analysis as a service to clinical researchers. In light of such methods as nanochromatography and electrospray ionization, it's clear that the technology of the time was utterly inadequate.

Accordingly, the results proved useless for routine clinical practice. Complaints soon followed. Many startups disappeared from the scene, and the term proteomics became a mere buzzword. "Our new techniques have brought us a giant step forward, but things are only now really getting off the ground," says Matthias Mann. How fortunate it was that he didn't focus exclusively on computer science and physics, and instead took an early interest in the biological questions that his research raised. As a result, he can now help harness the potential of proteomics for the benefit of biology and medical science. ◀

TO THE POINT

- **For proteome analysis, the proteins must first be cut up into peptide fragments. Only sophisticated computer algorithms can reconstruct the original proteins from the huge volumes of data generated.**
- **The MaxQuant program accesses databases that serve as repositories of knowledge about peptides and proteins.**
- **Using the Perseus program, researchers analyze information from databases on the occurrence and function of proteins. This sheds light on the role of individual proteins in disease processes.**

GLOSSARY

Protein modifications: The number of proteins an organism produces can be several times greater than the number of its genes. This enormous diversity results from changes after a gene has been read (transcription) or after messenger RNA has been converted into a protein (translation). In a process known as alternative splicing, for instance, sections of a messenger RNA molecule are cut out or moved, resulting in a number of different gene products. Small molecular tags, such as phosphate and sugar residues, are subsequently added to alter the function of proteins. When a gene encodes several proteins, or when an amino acid chain is subsequently cleaved into several proteins, multiple proteins are produced from a single gene. In humans, up to ten different proteins can be traced to a single gene.

Proteome: It is now estimated that the human body contains between 80,000 and 400,000 proteins. However, they aren't all produced by all the body's cells at any given time. Cells have different proteomes depending on their cell type. There are thus at least 250 different proteomes corresponding to the 250 cell types in the human body. The proteome depends on many factors. For example, different proteins may be produced depending on an organism's age, diet and state of health. The protein composition is also affected by environmental influences such as medications and pollutants.

Photo: Axel Griesch

Aachen cathedral in miniature: 3D printing can be used to create very intricate structures.

Photo: Fraunhofer ILT, Aachen / Volker Lannert

Built **with Light**

3D printing is the future. But it's not yet possible to get the most out of the materials and the production processes used. Scientists at the **Max-Planck-Institut für Eisenforschung** in Düsseldorf, together with colleagues from the **Fraunhofer Institute for Laser Technology ILT** in Aachen, are therefore working to help the new method come of age.

TEXT **ALEXANDER STIRN**

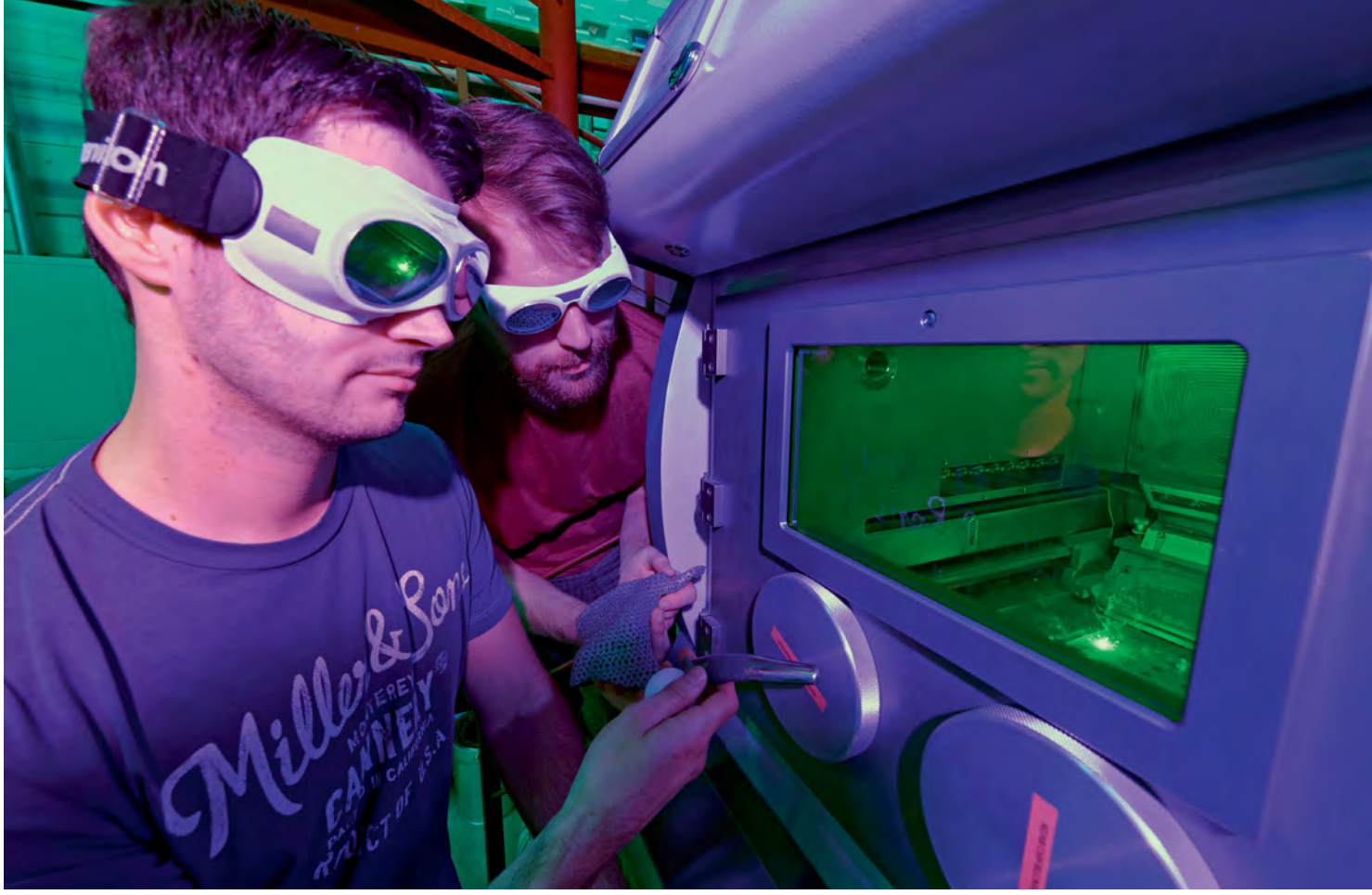
The blindingly bright spot of light dances to and fro, from right to left and left to right, spattering sparks as it does so. It pauses briefly, only to restart its motion anew. It never tires and is extremely productive.

This blindingly bright spot of light whirling along in a laboratory in Aachen is pursuing an ambitious objective: it is expected to radically change materials research. Its light is produced by a powerful laser; its sparks are part and parcel of the process. They bear witness to the fact that the laser continuously melts metal powder that then solidifies on a surface – spot for spot, layer for layer, like a Lego structure made with tiny metal building blocks.

The process for which manufacturing engineers have such high hopes is known as 3D printing. It promises to produce highly complex components at relatively low cost, with little waste and short lead times. Although a great deal of progress has been made, the method, which scientists call "additive manufacturing", still offers room for improvement. Particularly as regards the materials, 3D printing is still in its infancy.

"The materials that are used today in additive manufacturing are simply not optimized for this process," says Eric Jägle, head of a working group at the Max-Planck-Institut für Eisenforschung in Düsseldorf. The materials aren't made to be particularly robust during printing, nor are the printing processes optimized for getting the most out of the materials. And the materials don't yet fully exploit the novel manufacturing methods – although this is precisely what could bring about tremendous progress, as history has shown.

"As casting was being developed in its day, the materials were adapted as well, and alloys were developed that were perfect for the new process," says Andreas Weisheit, working group leader at the Fraunhofer Institute for Laser Technology ILT in Aachen. "Additive manufacturing will therefore achieve its full potential only when suitable materials are developed and, at the



same time, the processes are adapted to the new materials." The researchers are also experimenting with familiar materials that they are gradually improving.

This is precisely why the bright spot of light dances across the metal in ever wilder patterns. This is precisely why it spatters sparks from ever more complex materials: the laser is part of a research machine that Jägle and Weisheit developed to jointly analyze which materials are suitable for 3D printing. Their goal is to optimize production processes so that, for instance, the properties of known alloys can be improved and steels, for example, become particularly strong as a result of the laser treatment. The research project goes by the name of AProLAM (Advanced Alloys and Process Design for Laser Additive Manufacturing of Metals). The cooperation project between the two institutes was launched two years ago; now the intermediate report is available – with highly promising results.

But expectations are high, too. High hopes are pinned on 3D printing in the production process: currently, the first step in almost all manufacturing processes is to make special tools, such as casting molds or press molds. "This is incredibly expensive and is worthwhile only when large numbers of pieces must be produced," says Eric Jägle. Additive manufacturing, in contrast, requires no special tools – apart from the expensive 3D printer.

COMPLETELY NEW APPROACHES FOR OPTIMIZING STEELS

Small batches or individual parts such as prototypes, customized prosthetic joints and spare parts for planes can thus be manufactured without high one-time costs. In the future, printers could output them directly on site – without the need for expensive logistics or time-consuming shipping.

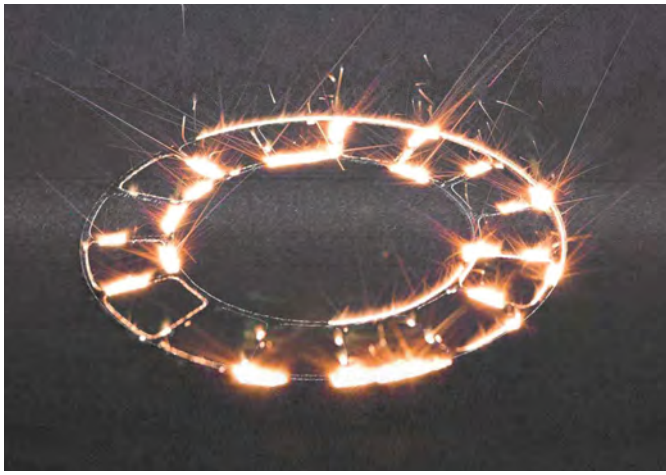
Moreover, additive manufacturing facilitates the production of highly complex components. "Production technology normally has its limitations: a metal is milled and turned, sheet metal is bent and welded, and if that doesn't do the job, the parts have to be assembled," says Jägle. With 3D printing, however, daring designs with cavities are also possible – similar to a Lego structure. Furthermore, the often intricate components are produced in one shot, with no bolted joints and no waste produced by milling machines or lathes.

"If desired, entire assemblies that were originally composed of 20 to 30 individual parts can be printed in a single part," explains Jägle. In addition, as far as materials science is concerned, 3D printing opens up completely new approaches for optimizing steels and other alloys.

The focus is currently on two printing processes. Both use lasers and both use metal powder. Eric Jägle grabs a small tube containing a gray substance from the windowsill and gives it a slight shake. The powder is so fine that it appears to slosh to and fro in the tube. The individual particles measure a mere 20 to 40 micrometers (thousandths of a millimeter), or around one-fifth the diameter of a human hair.

A fine powder of this sort is required particularly for the first of the two methods. In selective laser melting (SLM), a slider spreads a very thin layer of powder, just 50 to 100 micrometers thick, on a substrate. A laser beam that can be controlled via a mirror is

Photo: Fraunhofer ILT, Aachen / Peter Winandy



Left Researchers at the Fraunhofer Institute for Laser Technology ILT in Aachen watch the selective laser melting process: a laser beam, which can be seen here as a bright spot, forms structures out of a very fine metal powder that was previously spread on a substrate.

Right The AProLAM project is investigating two 3D printing methods: laser metal deposition (left), where metal powder is sprayed into the laser focus on a metal plate, and selective laser melting.

fired at it. This beam writes contours into the powdery layer, hatches areas and exposes individual points to the light. Where it strikes, the metal melts.

A short time later it solidifies again and bonds to the layer below. When one level is printed, the substrate is lowered 50 to 100 micrometers, the slider spreads the next layer of powder, and the laser sets to work again. Hundreds or thousands of layers are produced. They are so fine that they will later be unrecognizable in the finished product.

The other process that the AProLAM researchers started with is somewhat coarser. It is called laser metal deposition (LMD), produces thicker metal blocks than SLM and is hidden behind heavy, opaque sliding doors in Aachen. When it is in operation, a red warning light denies access to the room. Markus Benjamin Wilms, a member of the AProLAM project at the ILT, slides open the door. Behind it, a vertically mounted "laser gun" comes into view – not as slick and gleaming as those used by Goldfinger and other James Bond villains, but just as powerful.

Yellow cables with an optical fiber, almost as thick as a garden hose, lead to the actual laser source, a box the size of a cabinet. There, infrared laser light – which is invisible to the human eye – is produced with a power of up to two kilowatts. It is focused at the other end of the yellow cable in such a way that the beam impinges on a metal plate with maximum intensity. The material liquefies and starts to glow blindingly bright.

THE INTERPLAY OF METAL COMPOSITION AND PROCESS

"But we don't want to simply melt the metal, we also want to deposit something," says Wilms. Three nozzles are therefore located in the tip of the supposed "laser gun," grouped around the beam. They hurl metal powder that is transported by the noble gas argon into the focused laser beam – and thus into the tiny melt pool on the surface. The powder melts, emits a spark or two, and solidifies abruptly as soon as the prancing laser moves on, leaving behind a firmly welded tiny Lego block.

In the past, before the start of the AProLAM project, materials scientists primarily tried to optimize the conditions of the laser process so that serviceable products with no pores or cracks were produced from alloys that had been around for some time. Or they considered which new materials could be particularly suitable for 3D printing.

For Eric Jägle, the two approaches are inseparably intertwined. "It's the interplay of the composition of metals and a very specific process path that leads to microstructures with the properties we want," says the Max Planck researcher.

Regardless of whether it is strength, ductility or resistance to cracks or corrosion – it isn't only the physical properties of the individual constituents of an alloy that are crucial, but also their spatial arrangement after solidifying. "With additive manufacturing, we now have a new, interesting process – and therefore the opportunity to create completely new properties," says Jägle.

Take the maraging steels, for example – a portmanteau of "martensitic," the name of the microstructure, and "aging." These steels, which Eric Jägle and his colleagues optimize and refine for 3D printing, contain aluminum and titanium in addition to iron and other elements. Both metals can form tiny precipitates. >

Photos: Fraunhofer ILT, Aachen

These precipitates prevent dislocations from moving freely within the structure of the steel. The material doesn't deform as easily, and it becomes much stronger. The problem is that it normally takes a lot of effort to produce the precipitates. The material must initially be subjected to intense heat in order for the foreign substances to dissolve. It is then quenched and finally hardened at high temperatures for a long time so that the precipitates can form.

"Interestingly, all these steps are also found in additive manufacturing," says Eric Jägle. Here, a laser initially subjects the material to intense heat. The melt pool, however, is tiny – smaller than the tip of a pin. This is why it cools down immediately as soon as the laser moves on to the next point. When it returns and prints a neighboring row right next to it, the original tiny block is heated again. The effect is repeated in the row after the next, but is slightly weaker. The peak temperatures become lower and lower with increasing distance.

But if the next layer is applied directly on top of the tiny block, the lump of metal is again subjected to such intense heat that parts of the material melt. "What we have here is an enormously complex, completely wild temperature profile," says Philipp Kürnsteiner, AProLAM member at the Max Planck Institute in Düsseldorf. "This is precisely what could help us obtain precipitation-hardened materials directly from the machine in the future – without the need for any subsequent heat treatment whatsoever."

To test this, ILT researcher Markus Benjamin Wilms has in recent months

Photo: Frank Vinken

repeatedly donned his green-tinted protective goggles and a respirator to protect his lungs from metal dust. He set the spot of light dancing and printed cubes of an iron-nickel alloy – at the bottom, in the first layers, with no aluminum at all, then with an ever-increasing proportion until the aluminum content in the top layers finally reached 25 percent.

"As the material is what we are interested in, we usually print small blocks. This is the simplest conceivable geometry," says Wilms. Provided they have no cracks, the samples are then sliced through the middle and polished – with a finer and finer polish whose particles, in the final pass, have a diameter of just 0.04 micrometers (40 nanometers). The smooth samples are etched and inspected under an optical microscope. Then they are polished again and put under an electron microscope to obtain information about the material's microstructure.

A 3D DIAGRAM SHOWS THE PRECISE COMPOSITION

But the real acid test for the printed steel cube awaits on the ground floor of the Max-Planck-Institut für Eisenforschung. Here, side by side with historical forging hammers, stands one of the most advanced analytical instruments for metal structures: a 3D atom probe. Its maze of stainless steel tubes has a silver sheen; a blue decorative strip lights up along the top of the control unit, and the staccato tones of a helium pump, which cools the inside of the apparatus to minus 220 degrees Celsius, pounds away in the background.

In the high vacuum here, the materials researchers position a tiny pin with a radius of less than 50 nanometers. The pin was previously cut out of the printed material by a beam of gallium ions, which then sharpened the point as if it were a pencil, with increasingly tighter circular movements. The pin ends up under a detector system to which a high voltage is applied – around 5,000 volts – and a pulsing laser beam further tortures the sample.

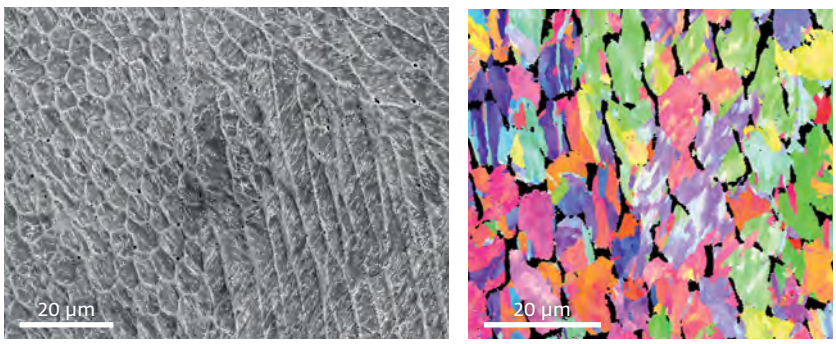
"The aim of this ordeal is to dislodge a single atom from the material with every pulse," says Eric Jägle. As it is positively charged, this ion moves along the electric field lines to the detector, which registers the exact position and the exact time of the impact. This data can be used to determine the point on the pin from which the particle was sent on its way, how heavy it was and how much charge it carried. At the end, the instrument produces a three-dimensional diagram that shows the composition of the tip of the pin in detail.

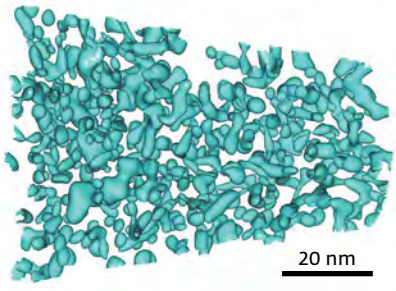
In his office within the brick walls of the Max Planck Institute in Düsseldorf, Jägle makes a couple of mouse clicks and brings one of his measurement results onto the screen. The iron atoms, shown in gray, are found to be

Photos: MPI für Eisenforschung

Left Philipp Kürnsteiner (in the background) and Eric Jägle check measurements made by an instrument that can act as a scanning ion microscope and also as a scanning electron microscope. They use the former to cut samples for atom probe analyses.

Below The image taken by the scanning electron microscope (left) shows the cellular structure of a steel sample that was first polished and then etched. In the electron backscatter diffraction image (right), the same cells are delineated by the black regions. The colors show the orientation of individual crystals.





This page Eric Jägle introduces a new sample into the 3D atom probe, which measures how different metals are distributed in a material atom by atom (above). The turquoise areas in the image to the left show the regions in the sample of a maraging steel that contain more than 20 percent aluminum. The structure with the high density of aluminum-rich precipitates formed during additive manufacturing – this is precisely what the Max Planck researchers wanted to achieve to make the steel stronger.

Right-hand page In the AProLAM project, Eric Jägle is attempting to optimize the properties of steels and alloys with the aid of 3D metal printing.

distributed homogenously throughout the pin. At many locations, however, finely distributed, aluminum-rich precipitates measuring only a few nanometers can be found; they show up in turquoise on the screen. These precipitates originate directly from the 3D printer – precisely what the AProLAM researchers were looking for.

The experiments also showed that the aluminum content must be at least 5 percent for them to appear – but it mustn't exceed 14 percent, otherwise the steel's desired microstructure will be lost. According to Jägle, an aluminum content of 9 percent has proven to be ideal. And compared with a pure iron-nickel alloy, the hardness values of a steel with aluminum precipitates are almost twice as high.

As their next step, the AProLAM researchers want to repeat the same experiments with titanium as the reinforcing additive, and then again with a combination of titanium and aluminum. They also plan to study other materials in the future, including aluminum alloys reinforced with the rare metal scandium, which are very popular in aircraft construction. Or steel in which embedded oxides promise enormous stability values even at high temperatures.

MATERIALS WITH IMPROVED PROPERTIES ARE THE GOAL

At the same time, the researchers are tinkering with the printing processes – in the hope of finding the optimum conditions for particularly effective precipitates. "The major challenge here is to not introduce either too much or too little heat into the material," says Philipp Kürnsteiner. The researchers have a lot of parameters at their disposal behind the heavy sliding doors of the lab in Aachen. Markus Benjamin Wilms can change the diameter of the focused laser beam – from 0.6 to 1.8 millimeters. A spot of light of this size leads to a large melt pool; it then takes much longer for the material to cool down.

The speed at which the laser dances across the metal and deposits new material also has an effect on the precipitates, but the pattern used to print the individual layers offers the greatest scope. The spot of light can always race across the metal from right to left. It can meander along a rectangle. It can pause after each layer so that the material has time to cool down. It can even change the printing direction by 90 degrees between two layers.

All this affects how each individual block in the big metal Lego construc-

tion heats up, cools down and is reheated again. The temperature profile, in turn, is responsible for how easily the aluminum islands form during the printing process, how large they become, and how they are distributed in the steel.

"It takes a great deal of experience to find the right parameters in each case," says Wilms. Nevertheless, the first attempt is usually unsuccessful. A quick look at the blindingly bright spot of light is all it takes to appreciate this: "Sometimes it lights up there as if in a thunderstorm; then you know that the process is running unevenly and the laser has to move more slowly."

Ultimately, despite all the experience gained, only an iterative process can help: Wilms has to tinker with one of the many parameters until the printed blocks don't get any better. The value is then fixed and the next parameter is dealt with – until finally a material is produced that outshines all of its predecessors.

And that is the ultimate goal of the AProLAM researchers, whether they work behind the brick walls in Düsseldorf or the sliding doors in Aachen. They want to facilitate the creation of new materials that not only can be manufactured more easily and without complex heat treatment, but that also surpass conventional materials with their improved properties. "The whole technology will only really take off when people recognize one thing," says ILT researcher Andreas Weisheit: "If you want to have such a novel material, the only way to achieve it is with additive manufacturing." ◂

TO THE POINT

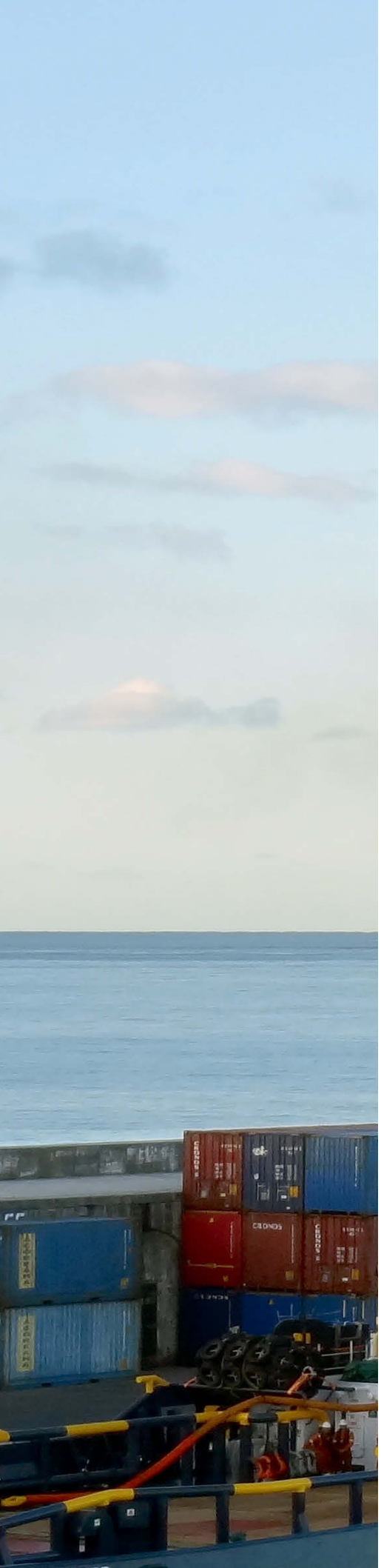
- **The pioneering 3D printing – known as additive manufacturing – offers many advantages, but its development still offers room for improvement, particularly as far as the materials are concerned.**
- **The research project AProLAM (Advanced Alloys and Process Design for Laser Additive Manufacturing of Metals) involves Max Planck and Fraunhofer researchers joining forces to pursue two objectives: first, they want to find out which materials are suitable for 3D printing; and second, they want to optimize the production processes to improve the properties of known alloys.**
- **There are primarily two printing processes in use: selective laser melting uses a layer of powder just 50 to 100 micrometers thick on a substrate; laser metal deposition produces thicker metal blocks.**
- **The materials that the researchers are optimizing and refining for 3D printing include, for instance, maraging steels. Besides iron, these contain, for example, aluminum and titanium, and don't deform easily.**

GLOSSARY

Laser: The word is an acronym for light amplification by stimulated emission of radiation and refers both to the physical effect and to the device. Laser beams are sharply focused, have a high intensity and usually a very narrow frequency range. They can also produce extremely short and intense pulses of radiation. In manufacturing, they are used as cutting and welding tools.

Alloy: A metallic material that is composed of two or more elements, at least one of which must be a metal.

Photo: Frank Vinken



Sailing
Close to the Wind

Ralf Schiebel has already undertaken more than 30 research cruises. The geologist has headed the micropaleontology working group at the **Max Planck Institute for Chemistry** in Mainz since autumn 2015. With each expedition, he has accumulated plankton and sediment samples, folders stuffed with logs and data – and memories of adventures that he will probably tell his grandchildren about.

TEXT **CATARINA PIETSCHMANN**

Haul in the net and let's get out of here pronto!" While Ralf Schiebel quickly stows his samples, the ship's crew members batten down the hatches. Rough seas are not uncommon in the North Atlantic, especially in mid-winter. The force eight gale is just a taster: a cyclonic storm 200 kilometers across is bearing down on their position in the middle of the ocean, at 47 degrees north, 20 degrees west. There's no way their research vessel, the *Meteor*, can escape now.

Battling winds of up to 230 kilometers per hour, the ship bravely breasts the waves towering 20 meters above it. "We were drinking water and eating chocolate bars," Schiebel recalls. Suddenly the howl of the wind subsides as the *Meteor* enters the eye of the storm, only to pick up again with undiminished force soon after.

Fortunately, perilous situations like this are rare, but Schiebel will never forget his trip in January 1994. He was 28 years old at the time. "When we finally came back on deck, we found utter chaos." Schiebel's plankton samples, which had been stowed below, were the only scientific yield of the entire expedition.

AT HOME IN THE MIDDLE OF THE NORTH ATLANTIC

Last autumn, the geologist returned to 47 degrees north, 20 degrees west – the spot in the Atlantic Ocean that was practically his living room in the 1990s. All in all, he spent almost two years there. Together with colleagues, he was studying carbon exchange between the ocean and the atmosphere on a moored plankton trap equipped with a flow meter, a temperature sensor and a salt probe. "It was very interesting to collect plankton again at the very same site after more than two decades. After all, the oceans have become more acidic due to increased levels of carbon dioxide in the atmosphere, and the pH of the water has dropped from 8.2 to 8.1," the researcher says. >

Photo: Ulrike Weis/MPI for Chemistry

Roaming about: Geologist Ralf Schiebel, here on board the research vessel *Maria S. Merian*, is continually drawn to the sea. There, he and his colleagues collect plankton and sediment samples containing calcareous single-celled organisms, which they use as climate indicators.

Above A seasoned mariner: Ralf Schiebel has undertaken more than 30 research cruises to many corners of the world.

Below The satellite photo shows the cyclonic storm the *Meteor* weathered in the North Atlantic in January 1994.

Ralf Schiebel studies climate change by examining foraminifera, tiny single-celled animals whose calcareous shells range in shape from spherical to elongated to spiral. Depending on the species and the latitude, masses of them live at various depth levels of the water column. Some species also thrive on or in the sediment.

Foraminifera (from Latin, meaning "hole bearers") are basically amoebas but with a shell. They can project finger-shaped pseudopods through minute openings. "Forms that live in the soil actually use this method to crawl across the ground," says Schiebel. The foraminifers use the sticky tips of their "feet" to capture prey. Many of them even grab morsels that are much larger than themselves, such as small crab-like plankton called copepods.

Because they evolved early in the history of the Earth and their calcareous shells are very durable, fossilized foraminifers and other calcareous unicellular organisms, such as coccoliths, serve geologists as index fossils. When the tiny organisms die, they sink to the ocean floor and become part of the sediment. When the researchers ram their sampling tubes into the seabed and lift samples from the depths, what they are essentially doing is bringing the Earth's climate archives to the surface.

A CLIMATE ARCHIVE COMPOSED OF FOSSIL SHELLS

The data is compared with that of foraminifers living in the oceans today. By studying the shell composition in the sediment layers, scientists can reconstruct a region's climate through glacial and warm periods.

Some of these organisms prefer conditions between the ocean surface and a depth of 30 meters. Others thrive at depths of 60 to 100 meters, while still others live in the twilight zone below 100 meters and as far down as 2,000 meters. There are even species that alternate between depths: they sink

Photo: Ulrike Weis/MPI for Chemistry

» Nature will adapt to climate change. The question is whether humans, given their habits, can do likewise

down to deeper layers to reproduce, and the new generation rises back up.

The researchers sample water from the desired strata using multi-nets, which automatically close at defined depths as they are pulled up. Under the microscope, the organisms are treated with formaldehyde, sorted by species and then further analyzed. "Otherwise, the bigger ones would then eat the little ones, and the snapshot would be distorted," Schiebel explains.

As small as foraminifers are, they are just big enough for the scientists to create tiny holes in their shells with a laser beam. The ionized debris flies through a mass spectrometer, which captures the chemical elements and isotope ratios in the shells. "The ratio of magnesium to calcium in the shells, for example, is a record of the temperature ratios of the past. The warmer the climate was, the more magnesium the foraminifers incorporated into their shell calcite. When the climate grew colder, calcium dominated more," Ralf Schiebel explains.

At the Max Planck Institute for Chemistry in Mainz, the researcher and his colleagues, as members of the new Department of Climate Geochemistry, are now able to analyze foraminifers and other climate archives and to refine and calibrate them for use as climate indicators. The new labs for organic and inorganic geochemistry and micropaleontology have state-of-the-art equipment and sufficient capacity to carry out large measurement series.

"Working with the other groups and departments at the institute is extremely motivating and productive, and support from the management is fantastic," Schiebel says. Together with German and international partners, the team will continue to collect samples from the ocean basins over the coming decades. There is also a constant exchange of technological information at all levels.

WILL CALCAREOUS PLANKTON DISAPPEAR?

Ralf Schiebel hopes that borders will remain open and that the researchers will be able to continue working with international teams to improve our understanding of the environment: "That's our best shot for maintaining our current quality of life."

So far, the oceans have absorbed a lot of carbon dioxide thanks to the calcium carbonate production of countless sea creatures. But if the carbon dioxide content of the atmosphere continues to rise, the oceans will become so acidic that this buffer could fail. Does this mean that calcareous plankton will vanish entirely one day?

"We haven't yet observed a definite decline, though we do expect the shells to become thinner. Laboratory experiments with coccolithophores – single-celled algae with calcareous skeletons – have shown that, of six clones, five stopped producing calcite in acidic water. The sixth group, in contrast, still produced copious amounts of calcite," Schiebel says. This means that the species composition of the oceans – and therefore of the entire ecosystem – is likely to change radically.

Geologists are known for thinking in terms of eons rather than years. There have been many warm periods in Earth's history. What makes the current period different from earlier ones? After all, 90 million years ago, the carbon dioxide content of the atmosphere was five times greater than it is today, yet coccolithophores were still producing calcite. The oceans and land ecosystems were able to absorb large quantities of carbon dioxide because the process was very, very slow. In addition, flowering plants began to emerge and accelerated the formation of soil, which also absorbed carbon dioxide from the atmosphere.

It is therefore extremely difficult to predict what will happen, not least because the current anthropogenic rate of climate change is unprecedented in the planet's history. Would Schiebel nevertheless venture to guess what the future holds? "Nature will adapt to climate change. The question is whether humans, given their habits, can do likewise." Their preference for living in coastal regions, for instance, which will be the areas hardest hit by rising sea levels.

As in previous warm periods, however, the carbon dioxide rise in the atmosphere can also have some positive effects. According to Schiebel, some

Above In a refrigerated storeroom, geologist Janne Repschläger takes a sediment core off the shelf. The cores are stored at 4 degrees Celsius, the temperature of the water near the seafloor. This prevents any volume change or chemical processes from taking place. The image on the right shows various species of calcareous microplankton, including foraminifers.

Right page Ralf Schiebel uses foraminifers as climate indicators. The new laboratories at the Max Planck Institute in Mainz feature state-of-the-art equipment and sufficient capacity to carry out large measurement series. The shelves hold thousands of slides of samples from research trips (right).

plants are sure to produce more biomass. Moreover, warmer air can hold more moisture, so the Sahel region, for example, will become greener.

Even as a boy, Ralf Schiebel knew that he wanted to become a geologist someday. His father's profession was certainly a factor. "He was a geodesist, and as a boy I used to accompany him in the field and hold the stadia rod." His favorite books were the World Atlas and the Bertelsmann encyclopedia. When he painted, he mostly depicted researchers driving through the desert in Jeeps. He loved to play handball – not surprising for a boy living in the German handball hub of Lemgo. A number of injuries meant that he spent a lot of time at the orthopedist, which stimulated his interest in medicine.

At the age of 19, he moved to Kiel, which was also handball-crazy. "I wanted to play more handball. While I was waiting to be accepted to study medicine, I enrolled in a geology course. However, my beanpole physique – 1.92 meters tall and weighing 70 kilos – was unsuitable for a sports career in handball, and my plan to study medicine was also soon abandoned."

"Studying geology was terrific! I immediately gave up competitive sports, sold my surfboard and hit the books." He met his wife in the department and became a father at the age of 22. "From that point on I had a single goal: to complete my studies as quickly as possible."

WATCHING THE JELLYFISH FEED

During his basic studies, Ralf Schiebel trained as a research scuba diver. For two summers he mapped the seaweed fields in the shallow waters of Eckernförde Bay for the University of Kiel. It was a relatively pleasant task; for another project, he dived off Sylt in the winter at water temperatures just two degrees above freezing. His task was to study the state of an artificial sandbag reef off Westerland, on the island of Sylt. "Afterwards, we had to be pulled out of the water because we were so numb with cold that we could barely move," he recalls. "When the mouthpiece was finally removed, your mouth stayed molded to its shape and gaped open. For a while we were unable to eat or drink."

But the pleasant moments far outnumbered the unpleasant ones. "As you drift in the Baltic Sea in the summer below the thermocline and look up to watch the jellyfish feeding, you come up with a lot of ideas about exchange processes in the ocean. And when the current in the Fehmarn Belt tugs at you, you can feel on your own body the very same forces that transport the sand there."

Ralf Schiebel supervises students doing internships, which introduced him to his current field of research: micropaleontology. His doctoral dissertation was on benthic – that is, bottom-dwelling – foraminifers.

Photos: Thomas Hartmann (left), MPI for Chemistry (right)

» I have a really cool job. And when things go wrong, you just have to pick yourself up again.

Research soon took Schiebel to many corners of the world. Each excursion was different and brought fresh surprises. He has collected samples off Mexico as well as in the radioactive waters off Fukushima. During a trip on the Aegean Sea, his ship sailed into a blizzard and had to take shelter on the leeward side of an island for three days.

Sometimes Schiebel and his colleagues hired on board large cargo vessels, for instance to study the ecological impact of oil platforms off the coast of the Republic of the Congo. "Due to a lack of space, I had to share a cabin with the Congolese sailors. During the day they were intrepid seafarers, but at night the light had to stay on, and the bosun told stories to drive away evil spirits," Schiebel recalls. "When you gazed around you from the deck in the evening, you could see hundreds of lights from the drilling and production platforms."

Things haven't always gone as planned in his life. The path for the geologist proved to be a rocky one on more than one occasion. At the age of 17, he almost lost his eyesight at a New Year's Eve party when a friend lit a firecracker close by. The lens of one of his eyes was destroyed. Replacing it with an artificial one restored full vision.

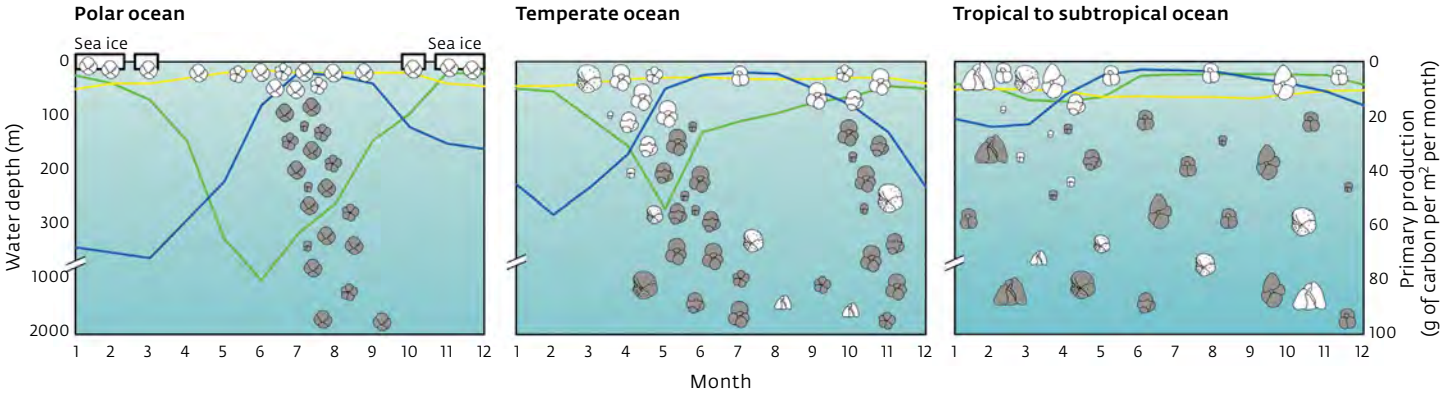
FROM CABIN TO DECK WITH HIS EYES CLOSED

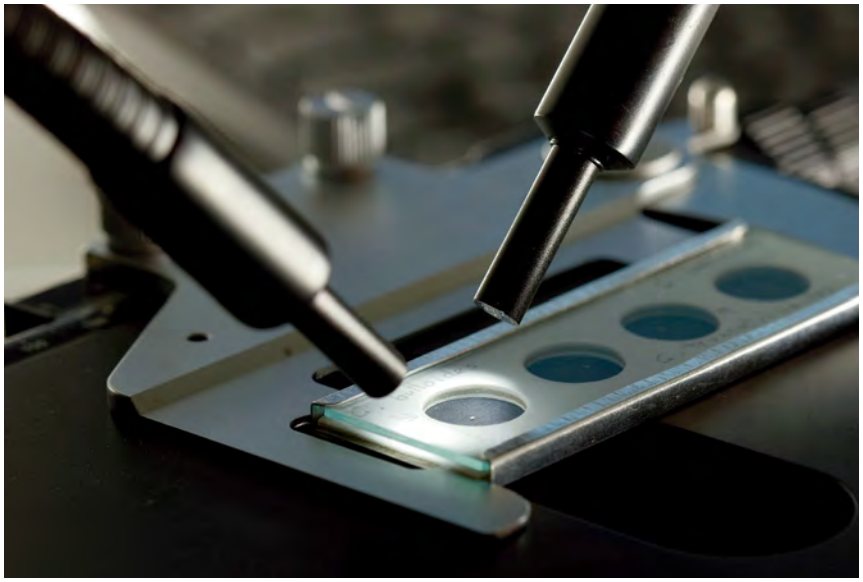
"I had gotten into the habit of counting my steps. Wherever I go, I still count the steps on every staircase." When Ralf Schiebel first sets foot on board a research vessel, he always paces from the cabin to the deck with his eyes closed. He wants to make sure he can find his way to the deck in an emergency even in the dark.

His private life hit a rocky patch. Weeks-long expeditions on board research vessels are good for science but hard for relationships. After eight years as a postdoc in Tübingen, sometimes with contracts for just three months, Schiebel took a position at ETH Zurich, where he remained for four years.

In 2008, long after his career had really taken off and he was conducting research at the National Oceanography Centre in Southampton, UK, a ladder slipped out from under him while he was working on the facade of his house. He landed hard on the ground, resulting in painful open fractures of both ankles. "'We'll probably have to amputate' – that was the last thing I heard before the anesthesia kicked in," he recalls. But the doctors managed to repair the crushed bones with titanium plates and screws.

These experiences have left their mark. Ralf Schiebel appears serious only at first glance. When you talk to him, you quickly realize that he is a very open and approachable person. Far from discouraging him, his experiences challenged him. Perhaps they also made him more laid back. "I have a re-





Above Oceanic productivity at middle and high latitudes varies seasonally. Foraminifers are more uniformly distributed in the plankton throughout the year in subtropical and tropical areas than at higher latitudes. Planktic foraminifers (white symbols) live only in the top layers of polar and subpolar seas, whereas they also thrive at depths of more than 1,000 meters in temperate and tropical seas. Once they reproduce, these single-celled organisms die off and their empty shells (gray) sink to the seafloor. Their fossil remains serve as a climate record of the past 100 million years. Green line: primary production; blue line: mixing depth; yellow line: one percent sunlight limit. The diagram applies to the northern hemisphere.

Left Single-celled organisms under the microscope: Measuring up to half a millimeter across, *Globigerina bulloides* can just be made out with the naked eye. The spherical shells of these foraminifers occur in oceanic sediments around the world. By analyzing the chemical composition of the shells, researchers can reconstruct the Earth's climate in past periods of time.

ally cool job. And when things go wrong, you just have to pick yourself up again. I don't panic in critical situations; I become calmer the more serious the situation becomes."

RED TAPE HOLDS BACK RESEARCH

Still unsteady on his feet after months of being bedridden, he began his professorship at the University of Angers in western France. He taught his first mapping course in the mountains of Haute-Provence while still on crutches. Research and teaching make him happy, but increasingly his work day is consumed by bureaucracy: "If it were up to me, I'd have remained a postdoc forever! But I suspect no one can do that."

Or maybe they can. As a Group Leader at the Max Planck Institute for Chemistry, he now seems to have found his niche. Largely freed from annoying paperwork, Schiebel can concentrate fully on his research. He once again has a young family, "despite the fact that I thought I would become a grandfather before becoming a daddy again," he says with a grin. "I'm very happy to come home in the evening, feed my baby and put him to bed – it's wonderful!"

If Ralf Schiebel goes to sea in the future, it will most likely be on the Max Planck Institute for Chemistry's research sailboat. The futuristic 22-meter yacht was designed by Milanese marine architect Lorenzo Argento. When it's completed in late 2017, it will open up new opportunities for the scientists at the Institute in Mainz. "On big research vessels, you're always under enormous time pressure. Now we can let ourselves drift for a week or so and drop the nets 20 times a day to help us gain an understanding of the daily rhythms of plankton," Schiebel says.

The spring plankton bloom in the Arctic could be another destination. Winter storms bring to the surface nutrients that microorganisms feed on.

As a result, the flora and fauna of the oceans are subject to seasonal changes. The researchers want to follow the currents from the Canary Islands to the subtropical gyre to analyze the change from nutrient-rich to nutrient-poor waters.

Ralf Schiebel and his colleagues have more than enough ideas to keep them busy. Once the new vessel has completed sea trials in the Baltic Sea, the first big trip will be in 2018: the Canary Islands, Cape Verde and then perhaps as far north as Iceland. The exact route hasn't been decided yet, but one thing is certain: The North Atlantic in winter? Never again! ◂

GLOSSARY

Foraminifera: Single-celled marine organisms that form a simple or multi-chamber calcareous shell, called a test. Most are microscopic, but some species have reached a diameter of up to five centimeters. When they die or reproduce, they sink to the seafloor to form thick layers of sediment. Depending on the environment in which they were formed, the layers contain different assemblages of species. Foraminifers therefore serve as index fossils for identifying and analyzing specific geological periods.

Ocean acidification: Carbon dioxide from the air can dissolve in seawater, where it then occurs in the form of various compounds, including a small percentage as carbonic acid. If the carbon dioxide concentration in the atmosphere were to double by 2100, the quantity of carbonic acid in the water would increase significantly, and the pH – a measure of the acidic or alkaline nature of an aqueous solution – would fall from 8.1 today to 7.8. That would have an impact on calcareous organisms, since calcium carbonate shells form more easily in an alkaline milieu. Calcareous plankton and corals are at particular risk.

The Old House and the Sea

With its verdant garden overlooking the Adriatic, it's hard to imagine a more idyllic research setting than the **Zoological Station in Rovigno**, on the Istrian peninsula. The marine institute, which was established more than 125 years ago, was originally a branch of the Berlin Aquarium. It was purchased by the newly established Kaiser Wilhelm Society in 1911 and became its first research institute.

TEXT **ELKE MAIER**

It was around the middle of the 19th century when the sea moved indoors: the aquarium was invented, and was met with great enthusiasm on the part of the general public. Large display aquariums enabled people to see the "strange sea creatures" they had previously only heard about. To maintain the underwater splendor behind the glass, supply stations were established in coastal locations to provide animals, plants and seawater for the aquariums. This is where the history of the Zoological Station in Rovigno begins.

The Berlin Aquarium *Unter den Linden* opened its doors on May 11, 1869. Visitors flocked to it to marvel at the filigree tube worms, ethereal jellyfish, comical hermit crabs and flamboyant sea anemones. The birth of a sea horse was witnessed there for the first time in 1876, and in 1892, visitors could gaze in wonder at a giant octopus with an arm span of two and a half meters. The Aquarium's regular "Marine Phosphorescence Evenings" were particularly popular.

In the early years, most of the exhibited marine animals originated from Trieste. When the water there became increasingly polluted due to the development of the harbor, an alternative source was sought. The harbor town of Rovigno (Rovinj in Croatian) on the Istrian peninsula – which was still part of Austria at the time – appeared to offer a perfect solution: the water there was clean and the rocky coast provided habitats for many marine species. Moreover, the town was on a railway line and the transportation of supplies to the German capital took just 29 hours.

Animated suspension: The predatory sea slug *Tethys leporina* while swimming. The photo was taken at the station's aquarium in 1912.

Photo: Archives of the Max Planck Society, Berlin-Dahlem

The Zoological Station of the Berlin Aquarium was opened on the coastal road in Rovigno's north harbor on May 10, 1891. The ground floor of the building contained 24 cement basins, which were fed with fresh sea water twice a day, and was also covered with glass vessels containing marine animals.

In 1897, the popular magazine *Die Gartenlaube* reported that "Some species of small sharks scuffle around looking for food, while at the far corner of the pool an enormous electric ray (torpedo) lies ready and waiting to dole out its electric shocks." Visitors were particularly fascinated by the pool with the seahorses and pipefish, "but after a while, they seem very uninteresting due to their low level of intelligence and their lethargy."

In addition to the aquarium room, the building also had an area for the production of wet and dry preparations, several work rooms, a library, a dark room and an apartment for Otto Hermes, the Director of the Berlin Aquarium. A west-facing patio provided a magnificent view of the garden, the town and the sea.

"Anyone who wants to work in peace and enjoys going out on the ocean, and, apart from their own research topics, gaining an impression of the entire animal kingdom in the rich waters of the Adriatic should go to Rovigno," wrote Hermes. "Overall, life [here …] is very pleasant."

The station was thus far more than a mere outpost of the Berlin Aquarium right from the outset. Researchers from different countries traveled to Rovigno to work there, and it soon became necessary to expand the station. The shipping operation also thrived. The station sent living and preserved marine material not only to Berlin but also to a number of universities. Some of the animals were provided by the local fishermen, but the station also had its own fishing fleet consisting of two rowboats, a sailboat, a motorboat and a small steamer.

The German Reich Department of Health even took up work in Rovigno in 1901. Against the backdrop of German activity in the colonies, the aim was to make advances in tropical medicine, so a laboratory was set up in the station to study unicellular parasites. Rovigno was still a malaria area at the time – an Eldorado for parasite researchers. Fritz Schaudinn, who made medical history as a co-discoverer of the syphilis bacterium a short time later, was head of the laboratory.

A prime location: The Rovigno Zoological Station was the first research institute of the newly established Kaiser Wilhelm Society – and perhaps also the most beautiful.

While the zoological station flourished, the Berlin Aquarium went into decline. People had seen enough, and maintenance costs were increasing. The operator eventually went bankrupt, the Aquarium closed, and Rovigno station was transferred into the private ownership of its Director, Otto Hermes. After his death, Hermes's heirs decided to sell the station, providing an ideal opportunity for the newly founded Kaiser Wilhelm Society. Given that it was already planning to establish two chemistry institutes, it was agreed that the field of biology and medicine shouldn't be neglected, and that Rovigno would provide the necessary research material. Everything fell into place when Paul Schottländer, a landowner from Breslau, agreed to provide the 100,000 marks required to buy the station. On October 1, 1911, the Zoological Station in Rovigno officially changed ownership. Thilo Krumbach, a biologist and jellyfish expert, had been the station's Director since 1908.

The plans for the development of the station included the expansion of its fleet. This project, however, was ill-fated. It started with the steamer, the *Albatros*, which was optimally equipped with three laboratories and was launched in Potsdam in 1913.

Frankfurter Zeitung from May 6, 1911

» Dr. Paul Schottländer, a landowner from Breslau, transferred a considerable sum to the Kaiser Wilhelm Society for the purchase and expansion of the zoological station in Rovigno. The Kaiser thanked the donor in a letter from the Achilleion Palace and approved the proposed use of the funds.

However, due to the outbreak of the war, it never reached its destination. Owing to its "unseaworthy construction," it was deemed to be of no use to the German Navy. To make matters worse, the ship, which by then had reached Hamburg, was damaged by a storm tide. It was eventually dismantled and sold off in separate parts.

The *Loligo*, the submarine boat sponsored by Schottländer, fared no better: it was requisitioned by the Italian Navy due to the war and eventually ended up with a scrap dealer. This outcome was all the more frustrating given that it would have been the world's first research submarine. The only boat in the fleet that took to the seas in the service of science was a glass-bottomed craft for the observation of marine animals. This vessel, however, later sank in a storm.

The situation on land was somewhat better: up until the outbreak of the war, the positions available for guest scientists were well occupied, and shipping operations flourished. Animals and plants were sent to German, Austrian, Dutch, and Danish aquariums, universities and museums. Thilo Krumbach had had a botanical garden planted at the back of the building. He also wanted to provide a display collection that would allow visitors to experience the native animals and plants and their ecology up close. To this end, he had aquariums built in which the marine organisms lived in the middle of original coastal rock formations.

Rovigno was captured by Italian troops on November 4, 1918. Krumbach succeeded in hiding parts of the station's inventory and library before fleeing. The station now belonged to Italy. However, the Kaiser Wilhelm Society didn't admit defeat and sought restitution or compensation.

Tough and lengthy negotiations followed. It took more than twelve years for the prospect of a solution to emerge: it was finally agreed that the institute would be placed under equal German and Italian management. The agreement for a German-Italian Institute of Marine Biology was ceremonially signed on February 25, 1930.

The post of German Director was assumed by Adolf Steuer, a plankton expert who was besotted with the Adriatic and spoke fluent Italian. He was considered the foremost expert in the flora and fauna of the Adriatic and worked to ensure that it was surveyed and recorded as comprehensively as possible.

The Italian Director was zoologist Massimo Sella. A very active scientist, he distinguished himself in the battle against malaria. He placed innumerable mosquitofish, which he had had specially sent from New York, in the ponds around Rovigno. These fish, which are related to the guppy, ate the larvae of the Anopheles mosquito, the carrier of the disease. Within just a few years, the region was malaria-free.

Another of Sella's specialties was fish migration, which he researched using some rather original methods. He demonstrated, for example, that Mediterranean tuna fish migrate from the Atlantic. In order to accomplish this, he collected the fishhooks that remained stuck in the mouths of the fish after unsuccessful attempts to catch them. The fishhooks had specific forms based on their origins. Last but not least, the creative Italian also had a passion for truffles and the culinary use of sea cucumbers.

At the end of the Second World War, Istria became part of Yugoslavia and the successful binational cooperation there came to an end. The Kaiser Wilhelm Society lost the station for a second time, this time for good. The Rovigno station had been part of its research institutes for around 21 years.

In 1946, the German department was nominally transferred to the Kaiser Wilhelm Institute for Biology, which had been moved from Berlin to Hechingen. A few years later, the Kaiser Wilhelm Institute for Marine Biology was established and continued to exist as a Max Planck Institute until 1968. Today, marine research within the Max Planck Society is located in Bremen, where the Max Planck Institute for Marine Microbiology was established in 1992.

The Rovigno Zoological Station still exists and now stands on Croatian soil. Since 1969, it has been a department of the Ruđer Bošković Institute in Zagreb. The building still looks almost the same on the outside as it does on the old postcards. While the shipping of marine animals ended a long time ago, scientists and students still frequent the location to study the fauna and flora of the Adriatic. A display aquarium is also open to visitors.

Photo: Archives of the Max Planck Society, Berlin-Dahlem

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From the Lab to the Stage

Olga Sin explains her research in three minutes and wins at FameLab Germany

Eight finalists presented their entries in front of an audience of 1,300 guests. The 30-year-old postdoc attributed her success to the Max Planck "Sign Up!" career-building program.

"What comes to mind when you think about worms? Some of you might think of bird food, some might think of gummy worm candy," says Olga Sin, researcher at the MPI for Molecular Biomedicine in Münster, at the start of her three-minute speech at the German FameLab finale in Bielefeld. She went on to demonstrate that worms – and especially the model organism *C. elegans* – are so much more. Specifically, that they might hold the key to treatments for such human illnesses as Alzheimer's or Parkinson's.

The reason behind this suggestion is that the cause – protein aggregation in the brain, which reduces mobility and memory abilities – also occurs in *C. elegans*. What's more, as this worm shares 80 percent of its proteins with humans, scientific studies could produce highly significant results. Pharmaceutical companies, for instance, are already using these worms to test substances that could slow or prevent these protein clots, Sin says. She made the intriguing point that, while *C. elegans* has no brain, it could nonetheless help shed light on the mechanisms and effects of Alzheimer's and Parkinson's.

Conveying the importance of research in such a concise manner is precisely the objective of FameLab, an international science communication competition. Sin had long harbored a desire to compete. The final push for her, says, was the MPG "Sign Up!" program aimed at outstanding female junior scientists. "The self-presentation training was really helpful here," she emphasizes – as was, of course, the associated task of presenting in front of other female participants in a self-organized "Science Slam."

Having won in her regional contest and then in the German national final, Olga Sin even qualified for the European final in England. Another important aspect for her was the success enjoyed by a fellow female Max Planck junior scientist in the German national final: the jury and the audience awarded Kerstin Göpfrich, postdoc at the MPI for Intelligent Systems, second place.

To watch videos of all presentations, visit:
https://www.britishcouncil.de/en/famelab

Olga Sin first won the regional contest before going on to secure first place in the German national final.

Photo: Bielefeld Marketing/Sarah Jonek

"We want to bring the best minds together"

A conversation with Vice President Ferdi Schüth about the Max Planck Schools

Every year, around 4,500 doctoral students conduct research in the Max Planck Society. They either dedicate themselves to a traditional individual doctorate or enroll in one of the 63 International Max Planck Research Schools (IMPRS), which provide a structured framework. The Society's development concept is to be expanded, with the Max Planck Schools becoming larger units. Vice President Ferdi Schüth is driving the plans forward.

Mr. Schüth, how do the new Graduate Schools differ from the IMPRS model?
Ferdi Schüth: The most significant difference is that the new schools are geographically dispersed, national alliances in which we want to bring together the best minds in Germany. The cooperating alliances, made up of various Max Planck Institutes, universities and other non-university organizations, should grow and become more visible. In addition, we plan to create a central applicant portal. The only criterion that matters is scientific excellence.

Who will organize the schools, and where?
That depends on the school in question. We want to experiment, and that's why we've designated an initial exploration phase. First of all, there are scientists and researchers that support such schools – but they are spread across Germany. Therefore, a school will need a coordination office. A centrally located Max Planck Institute could accommodate this office, but it could also be situated somewhere else, because this is an open system. This aspect is also expressed in the name: "Max Planck Schools – a joint initiative between German universities and the German research organizations."

Where are the students located?
I imagine that, depending on the school, students could initially progress through blocks of theme modules. In many sciences, the decision to obtain a doctorate is made right after completion of a Bachelor's degree. To give young people a sense of community and provide a common foundation to address their differing educational backgrounds, a three-month period studying together at a central location would be expedient. That location could be the Harnack House, or it could be a specific university where several scientists and researchers who are active in the school are located. It could also be the building for the Max Planck Institute for Physics in Munich, which our colleagues will vacate in a few years. Ultimately, we simply have to make sure that there are enough teaching and accommodation facilities available.

Ferdi Schüth, Vice President and Director at the Max-Planck-Institut für Kohlenforschung.

And what comes after that?
The doctoral students could progress through two or three stations in participating research groups and become better acquainted with their work. That would be equivalent to the research internship in a Master's program. After that, there could perhaps be another block module before the future doctoral students decide, based on their experiences with their various advisors, on a location for their doctorate. I must point out that this is only one possible model, and legal scholars might arrange things quite differently. We will have to adjust to various discipline cultures and the expectations of potential students.

If I were a prospective doctoral student, why would I opt for one of the new schools?
Ultimately, it depends on how deep your interest is in a particular area of research, and how ready you are to come into contact with people from other locations in external modular blocks. The IMPRS are much more specialized than we intend the new schools to be. And we make no bones about it: the new schools will be much more selective than the IMPRS. After all, the perceived quality of Harvard, Imperial, Berkeley and Oxford is also based in part on the rigor of the selection process.

How will the partners share the costs?
In the Max Planck Society, we have budgeted funding for the pilot phase that will help finance coordinators, travel costs and distance learning institutions, and perhaps also one or two dedicated teaching staff and bachelor's degree scholarships. Moreover, we believe that initiatives at the new Graduate Schools can be linked to an IMPRS and make use of their local funds. In any case, funding is provided for doctoral students in the Max Planck Institutes' budgets. Funding for fellows at universities has been requested from the German Federal Ministry for Education and Research. Each fellow and their faculty should re-

Photo: Amac Garbe /MPG

ceive funding to enable collaborations to take place on an equal footing. The other non-university institutions will have to account for the funding from their own budgets, as the Max Planck Society has done.

Has there been any response from the IMPRS, which might be worried about their future appeal?
In the initial phase, it was not clear to the IMPRS whether they were being left to wither away or whether there would be no new ones. That is by no means the plan. There are essentially three options for the IMPRS. First: they cease to exist because they become part of a new Graduate School and form the basis of a new local structure that must be retained for doctoral students. Second: they continue to operate under their current name but belong to a new School that comprises all the IMPRS, with a common application portal and a common teaching program. And third: the IMPRS and the new Schools coexist, which will typically be the case if there is only a slight thematic overlap between the two.

What do you think of the idea of the President of Hamburg University, who suggested Albert Einstein as a neutral figure to name the schools after?
We simply can't spend ten years trying to establish something new. Everyone – however grudgingly – has to admit that the most internationally recognized name in the German scientific community, the one that stands for high quality in basic research, is Max Planck. It would be negligent not to use such a well-known brand name.

And what is the schedule?
The selection meeting has already taken place, and a decision has been made. At the beginning of September, it will be announced which Schools will be supported in the pilot phase.

Interview: Susanne Beer

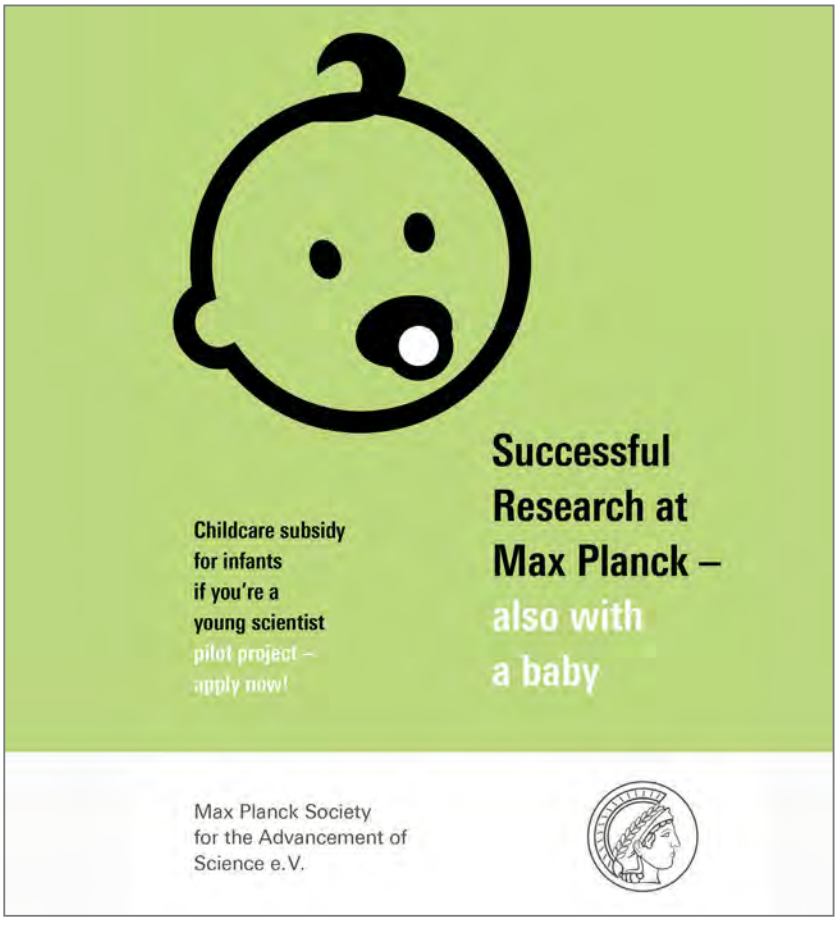
Childcare Subsidies

Applications can now be made to Max Planck Institutes

It looks like a baby version of a smiling emoji – but on a pastel green background: the cheeky face complete with pacifier adorns the cover of a new flyer explaining how scientists and researchers can obtain financial assistance for childcare for infants between the ages of three months and one year. It's not as straightforward as it sounds: for reasons relating to public funding law, the Max Planck Society is not permitted to bear childcare costs; it may only fund the provision of the corresponding infrastructure.

This is where the Max Planck Foundation comes in – to provide a jumpstart and help young researchers quickly reenter the world of science. The target group for childcare for the youngest children are doctoral students with funding contracts, and postdocs with a collective agreement for public employees (TVöD). Childcare costs pose a particular challenge for these income groups.

A precondition for funding is that both parents work or that the recipient is a single parent. If the mother and father both work in the Max Planck Society, only one parent may claim the subsidy. The funding will cover no more than half of monthly childcare costs, up to a maximum of 400 euros per month, for up to ten months. Applications should be submitted to the Institutes' administrations; the data will then be collected centrally to assess need for the coming year. The Max Planck Foundation will initially provide 500,000 euros for the pilot project.



Established in 2006 the Ernst Haage Prize honors young scientists for outstanding achievements in the field of chemical energy conversion and fosters young academics in particular.
The prize is awarded by the Ernst Haage-Foundation and is endowed with € 7,500.

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MAX-PLANCK-INSTITUT FÜR CHEMISCHE ENERGIEKONVERSION

Fascinated by Microbiology

Forty-six doctoral students meet in Marburg to shed light on their research passion from two sides

Lively interaction: In mid-May, PhD students from the Max Planck Institute for Terrestrial Microbiology in Marburg and the Bremen-based Max Planck Institute for Marine Microbiology met up at the two-day "It MaTter(s)" conference. In several sessions, young scientists presented their research in Marburg. Two poster sessions, with posters from all groups and departments, rounded out the event.

The Max Planck Society is made up of over 80 Institutes – but only two of these are dedicated to understanding the function of microorganisms and researching how they contribute to important processes in our world. To get to know each other's work, as well as to build networks and gain inspiration for further research, researchers from both of these Max Planck Institutes met up at the two-day "It MaTter(s)" conference held in mid-May. The meeting was held at the Max Planck Institute for Terrestrial Microbiology in Marburg, where the doctoral students from the Max Planck Institute for Marine Microbiology in Bremen had the opportunity to enjoy tours of all departments and laboratories.

Selected doctoral students presented their research in a series of sessions, ranging from marine ecosystems, surface structures and the marine nitrogen cycle to mitosis mechanisms, synthetic CO_2 fixation and plant-pathogen interactions. Two poster sessions, with posters from all groups and departments, rounded out the event.

"Lots of scientific discussions and potential collaborations have come about thanks to this lively interaction," say Max Mundt and Laura Zeugner, members of the ten-person organization team made up of doctoral students from the two Max Planck Institutes. Following the great success of this conference, a repeat event has already been planned for next year in Bremen.

Photo: Greta Giljan

Research Establishments

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

The Netherlands
- Nijmegen

Italy
- Rome
- Florence

USA
- Jupiter, Florida

Brazil
- Manaus

Luxembourg
- Luxembourg

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